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Radiopharmaceutical Dosimetry in Pediatrics

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The increasing use of radionuclides in diagnostic procedures and the importance of minimizing radiation exposure in infants and children necessitate accurate and detailed information concerning the radiation doses sustained from these procedures. This paper presents available information on the various parameters involved in radiopharmaceutical dosimetry in pediatrics. The age groups selected are the newborn and 1, 5, 10, and 15 yr. Measured and calculated parameters for these groups include: mass of whole body and target organs; effective half-lives and cumulative activities for the various radiopharmaceuticals; equilibrium dose constants; and absorbed fractions for spheres and ellipsoids for target masses down to 1. Radiation doses to whole body and to certain target organs for the various radiopharmaceuticals are included. Some consideration is given to adjustment of the activities administered to children relative to that normally administered to adults.

THE INCREASING USE of radionuclides in diagnostic procedures and the importance of minimizing radiation exposure to infants and children necessitate accurate and detailed information concerning the absorbed doses from these procedures. Although dosimetric information is frequently available for adults, only occasional reference is found to doses received by children, a group in whom there is increased concern about radiation exposure. In many instances, doses have been calculated for normal children based on metabolic values reported for adults. Because of the anatomical and physiological differences between adults and children, an increased effort is being directed toward obtaining and assessing metabolic information on various radiopharmaceuticals used in infants and children. Furthermore, much of the available data has been based on experience with the inorganic form of the radionuclide, whereas today many radionuclides are incorporated into compounds. These "tagged" substances are metabolized differently from the inorganic forms, resulting in altered radiation exposure.

It is the purpose of this paper to present available information on the various parameters involved in radionuclide dosimetry in pediatrics.

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MATERIALS AND METHODS

To date studies have been initiated on 238 infants and children with usable followup data accumulated on 35 children. Infants and children were followed for extended periods of time in a whole body counter following the administration of radiopharmaceuticals for diagnostic purposes. The whole body counter is approximately 8 × 8 ft with 8 in steel walls. An 8 × 4 in. NaI (Tl) detector is used for whole body counting in either standard-chair position or supine position. In addition, the detector assembly may be moved manually from outside the whole-body counter in a step-wise mode for whole-body profile scanning.

Regional body counts are obtained with ancillary detector systems. A flat-field collimated crystal, 4 × 4 in. NaI (Tl), is placed over specific organs or areas of interest. Dual 3 × 1 in. NaI (Tl) crystals with their central axes at right angles are used for thyroid radioiodine studies with photopeak to Compton scatter ratios to correct for effective thyroid depth.[1]

DOSIMETRIC CONSIDERATIONS

The average absorbed doses to the total body and to specific organs for administered radionuclides can be calculated according to the schema of Loevinger and Berman[2]

$$\bar{D}(v \leftarrow r) = (\tilde{A}_r/m_v)\Sigma_i\Delta_i\Phi_i(v \leftarrow r), \qquad (1)$$

where $D\ (v \leftarrow r)$ is the average dose in rads to volume v from radioactivity located in region r; $\tilde{A}_r$ is the cumulative activity in region r in μCi·hr; m is the mass of the target volume v in grams; Δ_i is the equilibrium dose constant in g·rad/μCi·hr; and $\Phi_i(v \leftarrow r)$ is the fraction of the energy emitted by activity in region r, which is absorbed in volume v. Φ_i depends on the gamma energy (MeV) and the source–target configuration.

When the target and the source are the same volume, then the above equation becomes

$$\bar{D}(v \leftarrow v) = \frac{\tilde{A}_v}{m_v}\Sigma_i\Delta_i\Phi_i(v \leftarrow v), \qquad (2)$$

where $\tilde{A}_v/m_v$ is the cumulative concentration in v.

m, Mass of Target Organ

Kereiakes et al.[3] urged the establishment of a series of standard children of various ages, derived by supplementing values of the 50 percentile for heights and weights of certain ages with pertinent information on organ weights and physiology. The age group selected and accepted by the various investigators include newborn and 1, 5, 10, and 15 yr old. Body weights of most organs of interest, largely obtained from Spector[4], are listed in Table 1. Thyroid weights given in parentheses are the recent data of Wellman et al.[5] and are somewhat lower than those previously reported by Spector.

$\tilde{A}$, *Cumulative Activity*

The cumulative activity $\tilde{A}$ is related to activity A by the expression

$$\tilde{A} = \int_{t_1}^{t_2} A(t)\,dt \qquad (3)$$

where $t_2 - t_1$ is the exposure time interval for which the absorbed dose is to be computed. $\tilde{A}$ has dimensions of μCi·hr. The activity $A(t)$ in an organ or tissue is in general governed by these factors: the amount of administered activity, the site and rate of the radionuclide intake, the rate of biological uptake and removal, and the physical decay of the nuclide. In practice, measurements are made over the area or organ of interest and the effective half-life (T_e) is determined. The cumulative activity (for 1 μCi administered) can then be calculated from $\tilde{A}$ (μCi·hr) = 1 μCi × 1.44 T_e (hours).

Table 1. Body Weights and Organ Weights (g) for Various Ages

Organ	Newborn	1 yr	5 yr	10 yr	15 yr	Standard Man
Whole body	3,540	12,100	20,300	33,500	55,000	70,000
Brain	350	945	1,241	1,313	1,350	1,400
Heart	20	47	86	140	209	298
Intestines	146	398	550	820	1,350	1,700
Kidneys	23	72	112	187	247	300
Liver	136	333	591	918	1,289	1,700
Lungs	52	172	291	523	701	1,000
Pancreas	2.8	14	23	30	68	80
Spleen	9.4	31	54	101	138	150
Stomach	6.5	27	57	90	120	160
Thyroid	1.9(1.5)*	2.5(2.2)	6.1(4.7)	8.7(8.0)	15.8(11.2)	20(16)
Testes	0.67	1.5	1.7	2.0	18	28
Ovaries	0.29	1.0	2.0	3.5	6.5	8.5

*Thyroid weights in parentheses are from the recent data of Wellman, et al.[5]

Table 2. Cumulative Activities for Iodine Radioisotopes in the Thyroid

Iodine Radioisotope	Effective Half-life [illegible]	Newborn	Cumulative Activity in μCi·h* (1 μCi administered) 1 yr	 5 yr	 10 yr	 15 yr	 Standard Man
[illegible]	[illegible]	13.3	5.1	5.1	5.1	5.1	5.1
[illegible]	[illegible]	772.0	298.0	297.0	297.0	297.0	297.0
[illegible]	[illegible]	174.0	67.3	67.2	67.2	67.2	67.2
[illegible]	[illegible]	2.4	0.9	0.9	0.9	0.9	0.9

*[illegible] [illegible]ke: 70% (newborn) and 27% (1, 5, 10 and 15 yr old and standard man).

Maximum thyroid uptake in the normal child is approached at about 24 hr. Mean uptakes of about 27% have been reported[6-9] and were used here for the 1, 5, 10, and 15 yr-old group (see Table 2). However, the thyroid uptakes of euthyroid infants during the first 2 wk of life are very high. Long-term data on the biologic half-life reported by a number of investigators reveal no significant variation with age.[7,15-17] A mean value of 68 days for thyroid biological half-life was used. Cumulative activities for iodine radiosotopes in the thyroid gland (for 1 μCi administered) are given in Table 2. Effective half lives measured in our laboratory, and corresponding cumulative activities, $\tilde{A}$ for other radiopharmaceuticals are given in Table 3.

Table 3. Measured Effective Half-Lives and Calculated Cumulative Activities and Doses for Various Radiopharmaceuticals in Children

Age	Weight (kg)	Effective Half-Lives T_e (days)		Cumulative Activity A (μCi•h) (1 μCi administered)		Dose (mrad/μCi Administered)	
		T_{e1} $(C_1)^*$	T_{e2} $(C_2)^*$	Whole Body	Organ	Whole Body	Organ
^{131}I-triolein							
3 mo	3.18	0.4(98)	6.4(0.02)	18.0		7.2	
2 yr	9.55	0.4(98)	6.0(0.02)	17.7		2.5	
^{131}I-serum albumin							
2 yr	7.50	4.7		163.0		12.3	
^{131}I-rose bengal							
5 yr	19.30	0.4(0.90)	3.0(0.10)	10.4	12.5	0.4	1.9 (liver)
13 yr	59.00	0.6(0.80)	4.3(0.20)	29.8	16.6	0.3	0.8 (liver)
^{51}Cr-sodium chromate							
4 mo	8.18	15.0		519		1.8	
14 mo	12.60	20.0		692		1.7	
5 yr	20.00	20.0		692		1.2	
6 yr	13.62	19.4		672		1.6	
6 yr	18.60	16.5		571		0.8	
^{59}Fe-ferrous citrate							
4 yr	19.00	26.0		900		49.3	
5 yr	20.00	38.0		1315		70.3	
6 yr	13.62	31.0		1072		78.0	
15 yr	55.00	39.0		1350		32.0	
^{197}Hg-chlormerodrin							
3 yr	14.55	0.8(0.82)	2.6(0.18)	38.9	38.9	0.16	68.1 (kidney)
12 yr	47.28	0.9(0.84)	2.6(0.16)	40.6	40.6	0.07	39.0 (kidney)
^{75}Se-selenomethionine							
7 yr	24.50	0.8(0.15)	23.3(0.85)	689	689 (liver) 689 (muscle)	10.3	34.0 (liver) 8.7 (muscle) 4.9 (pancreas)
^{47}Ca-calcium chloride							
7 yr	25.00	0.7(0.94)	4.6(0.06)	22.8	9.6 (bone)	2.8	4.5 (bone)
^{85}Sr-strontium nitrate							
4 yr	15.47	3.5(0.38)	58.0(0.62)	46.0	1224 (bone)	16.3	68.3 (bone)
10 yr	32.70	1.3(0.48)	44.0(0.53)	21.6	792 (bone)	6.0	40.8 (bone)
11 yr	54.50	3.2(0.20)	55.0(0.80)	22.1	1524 (bone)	9.2	62.5 (bone)
12 yr	40.00	1.4(0.30)	53.0(0.70)	14.5	1283 (bone)	8.6	32.8 (bone)
12 yr	60.00	1.5(0.65)	30.0(0.35)	33.8	364 (bone)	2.5	14.0 (bone)

* C_1 and C_2 are fractional components of administered activity.

$$4.7 = \frac{8.06\,T_b}{8.06 + T_b}$$

$$37.88 + 4.7\,T_b = 8.06\,T_b$$

$$3.36\,T_b = 37.88$$

$$T_b = 11.3\text{da}$$

Δ_i, Equilibrium Dose Constant

The nuclear parameters Δ_i for the radionuclides were taken from the work of Dillman.[18,19] These equilibrium dose costants can be divided into penetrating and nonpenetrating components as shown in Table 4. Particulate and electromagnetic radiation (less than 11 keV) are classed as nonpenetrating. For the nonpenetrating radiation, since the absorbed fraction is 1, the absorbed dose due to this component is readily calculated. In order to use the penetrating equilibrium dose constants for absorbed dose calculations, an effective absorbed fraction for the target organ must be determined. Effective absorbed fractions for several radionuclides in the various target organs are presently being calculated and will appear in subsequent MIRD Committee Reports.

Φ_i, Absorbed Fraction

The absorbed fraction as a function of photon energy is available from MIRD.[19-21] Table 5 lists the absorbed fractions for a uniform distribution of activity in elongated targets the ratios of the principal axes corresponding to width, thickness and height of these targets as ellipsoids are 1/1.9/9.27). Table 6 gives absorbed fractions for small target volumes which may be used as models of organs containing a uniform distribution of activity. Values applicable to either spheres or thick ellipsoids of masses ranging from 0.3 to 6 kg are given. Ellett and Humes[22] have recently presented tables of absorbed fractions for small unit–density-absorbing volumes of 1–500 g containing a

Table 4. Total Equilibrium Dose Constants for Various Radiopharmaceuticals

	Total Equilibrium Dose Constants ($\Sigma\Delta_i$) g·rad/µCi·h	
Radionuclide	Nonpenetrating	Penetrating
Fluorine-18	0.5157	2.1116
Chromium-51	0.0107	0.0612
Iron-52	0.4364	1.5640
Iron-55	0.0131	0.0000
Iron-59	0.2548	2.5083
Cobalt-57	0.0481	0.2590
Cobalt-58	0.0775	2.0935
Cobalt-60	0.2024	5.3321
Gallium-67	0.0776	0.3851
Selenium-75	0.0403	0.8185
Strontium-85	0.0195	1.1040
Strontium-87m	0.1421	0.6785
Technetium-99m	0.0362	0.2675
Indium-113m	0.2774	0.5601
Iodine-123	0.0602	0.3663
Iodine-125	0.0463	0.0861
Iodine-131	0.4135	0.8041
Cesium-129	0.0607	0.8362
Cesium-131	0.0168	0.0450
Xenon-133	0.2990	0.0896
Mercury-197	0.1579	0.1499
Mercury-203	0.2115	0.5066

Table 5. Absorbed Fractions for a Uniform Distribution of Activity in Ellipsoids*

Mass (kg)	φ										
	0.020 MeV	0.030 MeV	0.040 MeV	0.060 MeV	0.080 MeV	0.100 MeV	0.160 MeV	0.364 MeV	0.662 MeV	1.460 MeV	2.750 MeV
2	0.702	0.407	0.317	0.131	0.072	0.099	0.113	0.112	0.134	0.099	0.096
4	0.762	0.485	0.325	0.176	0.127	0.133	0.144	0.148	0.155	0.133	0.120
6	0.795	0.529	0.345	0.206	0.157	0.155	0.163	0.170	0.173	0.155	0.134
8	0.815	0.560	0.366	0.228	0.179	0.172	0.178	0.187	0.189	0.171	0.147
10	0.830	0.583	0.385	0.247	0.196	0.185	0.190	0.200	0.202	0.183	0.156
20	0.868	0.649	0.460	0.308	0.250	0.233	0.234	0.245	0.250	0.223	0.187
30	0.884	0.685	0.508	0.346	0.284	0.255	0.264	0.273	0.280	0.248	0.207
40	0.893	0.709	0.541	0.374	0.310	0.290	0.287	0.294	0.301	0.267	0.222
50	0.900	0.727	0.567	0.397	0.332	0.312	0.305	0.312	0.317	0.282	0.235
60	0.905	0.741	0.585	0.416	0.351	0.330	0.321	0.327	0.330	0.294	0.247
70	0.909	0.753	0.600	0.432	0.368	0.346	0.335	0.340	0.341	0.306	0.257
80	0.912	0.763	0.613	0.446	0.383	0.361	0.348	0.351	0.351	0.316	0.265
90	0.916	0.772	0.624	0.459	0.397	0.374	0.359	0.362	0.360	0.325	0.274
100	0.918	0.780	0.634	0.471	0.409	0.386	0.369	0.371	0.368	0.334	0.283
120	0.924	0.793	0.652	0.492	0.431	0.407	0.388	0.389	0.384	0.350	0.298
140	0.929	0.804	0.670	0.511	0.450	0.425	0.405	0.405	0.399	0.364	0.310
160	0.933	0.814	0.688	0.528	0.466	0.440	0.421	0.420	0.415	0.378	0.321
180	0.937	0.821	0.708	0.544	0.480	0.454	0.436	0.433	0.432	0.391	0.331
200	0.940	0.828	0.729	0.559	0.491	0.466	0.451	0.446	0.449	0.403	0.340

• The principal axes of the ellipsoids are in the ratio of 1/1.8/9.27.

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Table 6. Absorbed Fractions for Uniform Distribution of Activity in Small Spheres* and Thick Ellipsoids*†

Mass (kg)	φ 0.020 MeV	0.030 MeV	0.040 MeV	0.060 MeV	0.080 MeV	0.100 MeV	0.160 MeV	0.364 MeV	0.662 MeV	1.460 MeV	2.750 MeV
0.3	0.684	0.357	0.191	0.109	0.036	0.085	0.087	0.099	0.096	0.092	0.077
0.4	0.712	0.388	0.212	0.121	0.096	0.093	0.097	0.108	0.108	0.099	0.093
0.5	0.731	0.412	0.229	0.131	0.104	0.099	0.104	0.116	0.117	0.104	0.089
0.6	0.745	0.431	0.244	0.140	0.111	0.105	0.111	0.122	0.124	0.109	0.093
1.0	0.780	0.486	0.289	0.167	0.135	0.125	0.130	0.142	0.144	0.125	0.106
2.0	0.818	0.559	0.360	0.212	0.173	0.160	0.162	0.174	0.173	0.153	0.127
3.0	0.840	0.600	0.405	0.245	0.201	0.138	0.186	0.197	0.195	0.174	0.143
4.0	0.856	0.629	0.438	0.271	0.222	0.209	0.205	0.216	0.213	0.190	0.156
5.0	0.868	0.652	0.464	0.294	0.241	0.227	0.222	0.231	0.228	0.204	0.167
6.0	0.876	0.671	0.485	0.312	0.258	0.241	0.236	0.245	0.240	0.216	0.177

*The principal areas of the small spheres and thick ellipsoids are in the ratios of 1:1:1 and 1:0.667:1.333.

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Table 7. Absorbed Fractions for Uniformly Distributed Sources in Small Unit-Density Spheres Surrounded by Scattering Medium*

Mass (g)	Photon energy (MeV) 0.030	0.040	0.050	0.080	0.100	0.140	0.364	0.662	1.460	2.750
1	0.050	0.023	0.011	0.009	0.009	0.010	0.011	0.011	0.010	0.008
2	0.064	0.030	0.014	0.012	0.012	0.012	0.014	0.014	0.012	0.010
4	0.081	0.038	0.019	0.016	0.015	0.016	0.018	0.018	0.016	0.013
6	0.092	0.043	0.022	0.018	0.017	0.018	0.020	0.020	0.018	0.014
8	0.103	0.049	0.024	0.020	0.020	0.020	0.023	0.023	0.020	0.016
10	0.111	0.054	0.027	0.022	0.021	0.022	0.025	0.024	0.021	0.017
20	0.139	0.070	0.035	0.029	0.027	0.028	0.031	0.031	0.027	0.022
40	0.174	0.090	0.046	0.037	0.036	0.036	0.039	0.038	0.033	0.027
60	0.230	0.121	0.064	0.050	0.048	0.048	0.053	0.052	0.045	0.035
80	0.286	0.152	0.079	0.064	0.061	0.061	0.066	0.065	0.056	0.046
100	0.306	0.165	0.087	0.070	0.067	0.066	0.072	0.070	0.061	0.050

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uniformly distributed photon source. The data for small volumes are especially helpful for absorbed dose calculations involving sizes of organs in children. The data for small volumes differ in one important aspect from absorbed fractions published earlier. In the results given in Table 7 and 8, it is assumed that the volume containing the activity is imbedded within a large scattering medium of the same composition. Backscattered radiation from these surroundings is included in the tabulated absorbed fractions.

Administered Activity vs. Age

It is evident that the radionuclide activities administered to children in nuclear medicine procedures by no means follow a uniform pattern, particularly for the imaging procedures, where the statistics of photon detection per unit organ area become the important technical consideration. Webster[23] proposes the possible use of $[(x + 1)/(x + 7)]A$, for adjusting the activities normally administered to adults, where x is the child's age and A is the activity used in adults. This is a modification of Young's rule $[x/(x + 12)]A$. However, the modification more closely approximates the criteria of equal activity per unit area of organ for most children's ages. Most internal organ weights maintain a reasonably constant fraction of whole-body weight. The important exception is the brain, which tends to reach maximum weight by age 5 yr. For this organ, Webster[23] indicates an administered activity schedule (^{99m}Tc pertechnetate) of

> 5 yr 0.1 mCi/lb (body weight)
< 5 yr 0.2 mCi/lb

where the adult administered activity is 15 mCi (approximately 0.1 mCi/lb).

Radiation Doses From Radiopharmaceuticals in Children

Table 9 gives the thyroid dose resulting from the various radioiodine compounds. The data also indicate the increased absorbed dose to be expected when radioiodine is administered to children down to the newborn. Whole body and organ doses for other radiopharmaceuticals in children of various ages are given in Table 3. These data are for children administered radiopharmaceuticals in our laboratory after being referred for various illnesses or because of diagnostic problems. Effective half-lives actually measured in these children were used for their dose estimates. Tables 10 and 11 were adapted from Ball and Wolf[25] and show data for comparable radiopharmaceuticals and for other radiopharmaceuticals used for blood volume measurements and as scanning agents.

With few exceptions, radiation doses from radiopharmaceuticals used in children are within the acceptable range. Certainly ^{131}I administration is one of the greatest potential sources of tissue dose, especially in very young children. This dosage problem is best resolved through the use of ^{123}I since the physical characteristics of ^{125}I are suboptimal.[24] Mercurial compounds also result in high doses but are not now used widely because other more suitable radiopharmaceuticals are available for brain and kidney studies. It is evident that for many procedures, dose reduction can be achieved by using ^{99m}Tc

Table 8. Absorbed Fractions for Uniformly Distributed Sources in Small Unit-Density Ellipsoids Surrounded by Scattering Medium (Axes 1:2:4)*

Mass (g)	Photon energy (MeV)									
	0.030	0.040	0.060	0.080	0.100	0.140	0.364	0.662	1.460	2.750
1	0.045	0.021	0.010	0.008	0.008	0.009	0.010	0.010	0.009	0.007
2	0.058	0.027	0.013	0.011	0.011	0.011	0.013	0.013	0.011	0.009
4	0.073	0.035	0.017	0.014	0.014	0.014	0.016	0.016	0.014	0.012
6	0.082	0.040	0.020	0.016	0.016	0.016	0.018	0.018	0.016	0.014
8	0.092	0.045	0.022	0.018	0.018	0.018	0.021	0.020	0.018	0.015
10	0.100	0.049	0.024	0.020	0.019	0.020	0.022	0.022	0.019	0.016
20	0.125	0.063	0.032	0.026	0.025	0.025	0.028	0.028	0.024	0.020
40	0.155	0.081	0.042	0.034	0.032	0.032	0.035	0.035	0.030	0.025
60	0.192	0.101	0.052	0.043	0.040	0.041	0.044	0.044	0.037	0.031
80	0.229	0.121	0.063	0.051	0.049	0.049	0.053	0.052	0.045	0.037
100	0.244	0.131	0.069	0.056	0.053	0.053	0.057	0.056	0.049	0.040

*Reprinted from the MIRD Supplement.

compounds where possible. Strontium-85 results in relatively high doses to bone in children. Of all the radiopharmaceuticals reviewed, ^{59}Fe results in the highest whole body doses by far because of its prolonged retention.

Table 9. Thyroid Doses in Children (rad/μCi)[24]

Radioiodine Mass Number	Newborn (1.5)*	1 yr (2.2)	5 yr (4.7)	10 yr (8.0)	15 yr (11.2)	Standard Man (16.0)
123	0.160	0.109	0.051	0.03	0.021	0.015
125	11.1	7.6	3.54	2.1	1.5	1.04
131	16.0	10.9	5.1	3.0	2.1	1.5
132	0.160	0.109	0.051	0.03	0.021	0.015

* Thyroid weight (grams).

Table 10. Radiation Doses (mrad/μCi) From Radiopharmaceutical Scanning Agents*

Agent	Newborn	1 yr	5 yr	10 yr	15 yr	Standard Man
Kidney scanning						
^{203}Hg-neohydrin	2480	800	500	317	242	200
^{197}Hg-neohydrin	187	54	33	21	16	13
^{99m}Tc–Fe complex	9.3	3.3	2.3	1.3	1.1	1.0
Spleen scanning						
^{51}Cr-red blood cells	600	160	100	55	43	40
^{99m}Tc-red blood cells	20	6	3.5	2.2	1.3	1.3
Liver scanning						
^{131}I-rose bengal	10	4	2	1.3	1	1
^{131}I-MAA	5	2	1.3	0.8	0.6	0.5
^{198}Au-colloid	380	160	93	67	44	33
^{99m}Tc-sulphur colloid	2.3	1.1	0.6	0.4	0.3	0.3
Brain scanning (dose to critical organs)						
^{131}I-albumin (whole body)	30	10	6	4	3	2
^{203}Hg-neohydrin (kidney)	2480	800	500	317	242	200
^{197}Hg-neohydrin (kidney)	187	54	33	21	16	13
^{99m}Tc-O$_4$ (gut)	1.6	0.4	0.3	0.2	0.1	0.1

*adapted from Ball and Wolf.[25]
MAA, macroaggregated serum albumin.

Table 11. Whole-Body Doses (mrads/μCi) from Blood-Volume Measurements*

Agent	Newborn	1 yr	5 yr	10 yr	15 yr	Standard Man
^{131}I-albumin	32.0	10.0	6.0	4.0	2.4	2.0
^{99m}Tc-albumin	0.20	0.07	0.04	0.03	0.02	0.02
^{51}Cr-red blood cells	7.0	2.5	1.5	1.0	0.6	0.5
^{99m}Tc-red blood cells	0.2	0.07	0.04	0.03	0.02	0.02

*adapted from Ball and Wolf.[25]

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