

MIRD Dose Estimate Report No. 14: Radiation Absorbed Dose from Technetium- 99m-Labeled Red Blood Cells

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The estimated absorbed doses from an intravenous administration of technetium-99m-labeled red blood cells are given in Table 1. The data and assumptions used in these calculations are presented as follows.

RADIOPHARMACEUTICAL

Red blood cells (RBCs) may be labeled with technetium-99m (^{99m}Tc) by an *in vivo* technique, a modified *in vivo* technique, or an *in vitro* technique. To label the RBCs *in vivo*, an intravenous (i.v.) injection of 0.1 mg/kg of stannous pyrophosphate containing 10–20 μg Sn^{++} is administered to the patient, followed 20–30 min later by the i.v. administration of ^{99m}Tc as sodium pertechnetate (1). A modified technique that results in somewhat higher labeling yields is performed by administering the stannous pyrophosphate intravenously, waiting 20 min, withdrawing 30 ml of blood into a syringe containing heparin and pertechnetate, incubating at room temperature for ~10 min, and then reinjecting the labeled blood intravenously (2).

In vitro labeling is accomplished by the following method. Four ml of blood is withdrawn into a heparinized syringe and transferred to an evacuated vial containing lyophilized stannous citrate. After a 5-min incubation, either 6 ml physiologic saline or 1 ml of 4.4% EDTA solution is added, and the vial is inverted and centrifuged. One to 1.5 ml of red cells is removed and added to a [^{99m}Tc]pertechnetate solution. After another 5-min incubation, the labeled cells are administered intravenously (3).

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NUCLEAR DATA

Technetium-99m decays to ^{99}Tc by isomeric transition with a half-life of 6.02 hr. Technetium-99 undergoes beta-minus decay with a half-life of 2.13×10^5 yr. The very small contribution of ^{99}Tc to the radiation absorbed dose has been ignored in these estimates. The nuclear data for these isotopes are given in Table 2.

TABLE 1
Estimated Absorbed Doses from an Intravenous
Administration of ^{99m}Tc -Red Blood Cells

Target	2.4 hr voiding schedule		4.8 hr voiding schedule	
	In vitro labeling			
	rad/mCi	mGy/MBq	rad/mCi	mGy/MBq
Heart wall	0.054	0.015	0.054	0.015
Bladder wall	0.051	0.014	0.087	0.024
Spleen	0.041	0.011	0.041	0.011
Lungs	0.041	0.011	0.041	0.011
Blood	0.035	0.0095	0.036	0.0097
Liver	0.026	0.0070	0.026	0.0070
Kidneys	0.025	0.0068	0.025	0.0068
Red marrow	0.019	0.0051	0.019	0.0051
Thyroid	0.018	0.0049	0.018	0.0049
Ovaries	0.017	0.0046	0.018	0.0049
Testes	0.0071	0.0019	0.0081	0.0022
Total body	0.015	0.0041	0.015	0.0041
In vivo labeling				
Heart wall	0.057	0.015	0.057	0.015
Bladder wall	0.038	0.010	0.061	0.017
Spleen	0.043	0.012	0.043	0.012
Lungs	0.043	0.012	0.043	0.012
Blood	0.037	0.010	0.038	0.010
Liver	0.028	0.0076	0.028	0.0076
Kidneys	0.027	0.0073	0.027	0.0073
Red marrow	0.020	0.0054	0.020	0.0054
Thyroid	0.019	0.0051	0.019	0.0051
Ovaries	0.018	0.0049	0.019	0.0051
Testes	0.0076	0.0021	0.0082	0.0022
Total body	0.016	0.0043	0.016	0.0043

TABLE 2
Nuclear Data

Radionuclide		^{99m} Tc			⁹⁹ Tc	
Physical half-life		6.02 h			2.13 × 10 ⁵ y	
Decay constant		0.1151 h ⁻¹			3.25 × 10 ⁻⁶ y ⁻¹	
Mode of decay		I.T.			β ⁻	
Principal Radiations		E _i	n _i	Δ _i	Δ _i	(Gy kg/MBq s)
		(keV)		(rad g/μCi h)	(Gy kg/MBq s)	(rad g/μCi h)
Photon		18–21	0.079	0.0029	2.18 × 10 ⁻¹⁰	
		140.5	0.89	0.266	2.00 × 10 ⁻⁸	
Nonpenetrating				0.0332	2.49 × 10 ⁻⁹	0.216
						1.62 × 10 ⁻⁸

E_i is energy per photon.

n_i is mean number of particles or photons per nuclear transition.

Δ_i is mean energy emitted per nuclear transition.

Nonpenetrating radiation from ^{99m}Tc includes conversion and Auger electrons ranging in energy from 1.6 keV to 140 keV. Nonpenetrating radiation from ⁹⁹Tc includes beta-minus emissions with a maximum energy of 294 keV and an average energy of 101.3 keV. Only photons whose mean number per transition is 0.01 or greater are included. See references (6, 7) for sources of nuclear data.

Note: Complete decay of 1 unit of activity of ^{99m}Tc produces 3.2 × 10⁻⁹ units of ⁹⁹Tc.

BIOLOGIC DATA

These dose estimates are based on data obtained from nine normal subjects studied with the in vivo and in vitro labeling techniques at Brookhaven National Laboratory (4). Biologic parameters and residence times listed in Table 3 were calculated by curve fitting of the urine and blood data from these nine subjects. Corroborative data were obtained from subjects studied at the National Institutes of Health and at Albert Einstein College of Medicine, Bronx, NY.

With the in vivo technique, a variable percentage

(from 60%–90%) of the administered activity labels the circulating RBCs after the i.v. injection of [^{99m}Tc]pertechnetate. The dose estimates in this report use an observed in vivo labeling efficiency of 84% (4). The maximum level of radioactivity associated with the RBCs is attained 30–60 min after the ^{99m}Tc administration. The bulk of the activity not attached to the RBCs will be excreted, probably as a nonpertechnetate form of technetium after distribution throughout the extracellular space. This is considered to be in the “remainder of the body” prior to excretion. A small and variable fraction of the activity may remain as pertechnetate. In

TABLE 3
Biologic Parameters

Organ	α _{h1}	λ _{h1} h ⁻¹	α ₂	λ _{h2} h ⁻¹	α ₃	λ _{h3} h ⁻¹	τ _h h
In vitro labeling							
Blood	—	—	0.380	0.694	0.629	0.0339	5.97
Bladder contents							
2.4 hr void	—	—	—	—	—	—	0.23
4.8 hr void	—	—	—	—	—	—	0.45
Total body	—	—	0.273	0.186	0.727	0.00481	7.05
Remainder of the body	—	—	—	—	—	—	1.08
In vivo labeling							
Blood	-0.174	3.13	0.375	0.211	0.525	0	6.19
Bladder contents							
2.4 hr void	—	—	—	—	—	—	0.14
4.8 hr void	—	—	—	—	—	—	0.28
Total body	—	—	0.126	0.279	0.874	0.00450	7.69
Remainder of the body	—	—	—	—	—	—	1.50

The τ_h-value is given as the average of the individual patient values and can differ somewhat from the value which would be calculated from the average α and λ.

TABLE 4
S Values for Various Source Organs (rad/mCi hr)

Target	Source Organs		
	Blood ^(a)	Bladder contents ^(c)	Remainder of the body ^(f)
Heart wall	8.8×10^{-3}	$4.4 \times 10^{-5(d)}$	1.7×10^{-3}
Bladder wall	$2.1 \times 10^{-3(b)}$	1.6×10^{-1}	1.8×10^{-3}
Spleen	6.5×10^{-3}	6.6×10^{-4}	1.9×10^{-3}
Lungs	6.6×10^{-3}	2.4×10^{-5}	1.6×10^{-3}
Blood	5.5×10^{-3}	$2.1 \times 10^{-3(e)}$	$2.0 \times 10^{-3(g)}$
Liver	4.0×10^{-3}	1.7×10^{-4}	2.1×10^{-3}
Kidneys	3.8×10^{-3}	2.6×10^{-4}	2.1×10^{-3}
Red marrow	2.5×10^{-3}	2.2×10^{-3}	2.9×10^{-3}
Thyroid	2.7×10^{-3}	2.1×10^{-6}	1.4×10^{-3}
Ovaries	2.1×10^{-3}	7.3×10^{-3}	2.4×10^{-3}
Testes	6.9×10^{-4}	4.7×10^{-3}	1.8×10^{-3}
Total body	2.0×10^{-3}	1.9×10^{-3}	2.0×10^{-3}

Note: The values in the above table are in units of rad/mCi hr. To change to rad/ μ Ci hr, multiply by 10^{-3} (e.g., S (heart wall—blood) = 8.8×10^{-6} rad/ μ Ci hr)

^a S-values for the blood as a source organ were taken from Ref. 5.

^b Taken to be the same as the S-value for blood as the source organ to the uterus as the target.

^c Except as indicated, S-values were taken from MIRD Pamphlet 11 (Ref. 8).

^d Derived from MIRD Pamphlet 13 (Ref. 9).

^e Taken to be the same as the S-value for blood as the source organ and the uterus as the target organ using the reciprocity relationship.

^f Remainder of the body refers to the total body minus the blood and bladder contents. The remainder of the body S-value for each target organ, except the blood, is obtained by multiplying the total body to organ S-value by the mass ratio of total body to remainder of the body and then subtracting the blood to organ and bladder contents to organ S-values, each multiplied by their respective source organ to remainder of the body mass ratios (Ref. 10).

^g Taken to be the same as the S-value for blood as the source organ and the total body as the target organ using the reciprocity relationship.

addition, technetium is gradually eluted from the labeled RBCs and excreted in the urine. A total of ~21% of the injected activity (unbound as well as eluted from red cells) is excreted over a 24-hr period.

Labeling efficiency with the in vitro method is generally ~97%–98% (3). Immediately after administration of the labeled blood, there is some elution (~5%) of ^{99m}Tc. Peak blood levels are obtained immediately after administration, whereas peak levels following ad-

ministration of activity with the in vivo method are significantly delayed. Peak blood levels with the in vitro labeling technique are higher ($24 \pm 16\%$) than those with the in vivo technique. For the in vitro labeling method, blood levels remain higher for up to 8 hr, after which they are lower in comparison to the in vivo method because of a higher excretion rate (4).

ABSORBED DOSE ESTIMATES

Absorbed dose calculations are based on the biologic parameters in Table 3. Source organs are blood, bladder contents, and “remainder of the body.” “Remainder of the body” distribution is assumed for that fraction which is not in the blood pool and which has not been excreted. The S values for source organs are given in Table 4.

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