A Mathematical Method for Determining Radiation Exposures Surrounding Technetium-99m-MDP Patients

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Radiation surveys of 16 technetium-99m- (^{99m}Tc) MDP bone scintigram prostate cancer patients were obtained at 5 min, 4 hr, and 24 hr postadministration at survey distances of 1 ft (30.5 cm) and 3 ft (~100 cm) from the patients. Patients with and without bone metastases were investigated. The data obtained were used to generate linear regression equations relating the radiation exposure between time periods as a function of body surface area (BSA). An example is provided where equation-generated radiation exposures for individuals are calculated around a hypothetical ^{99m}Tc-MDP bone scan patient at various times and distances. Such equations can be used prospectively or retrospectively for estimating radiation exposures surrounding ^{99m}Tc-MDP bone patients. The equations generated, which are applicable to the majority of all bone scan patients, approximate for the extremes of human morphology; a tall and slender or short and obese person. The relatively simple equations will be helpful for determining radiation exposures for a specific population of nuclear medicine patients.

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The radiation exposure of patients who have received radiodiagnostic agents is a function of several variables. These include the physical properties of the radionuclide, the administered dosage, the initial biodistribution and subsequent translocation of the radiopharmaceutical, excretion patterns, and time of exposure after administration at a specific distance. One additional variable involves the morphology of the patient. Different-sized individuals will attenuate variable quantities of photon radiation and this will be reflected in the radiation survey. Usually these differences are not included in the statistics associated with reported survey results (*1–3*). One report, however, did indicate radiation survey differences associated with body weight after the administration of technetium-99m-labeled red blood cells (*4*). In an effort to better understand this variable, body surface area (BSA) and radiation exposure were compared in a population of patients after the administration of ^{99m}Tc-labeled methylene diphosphonate (MDP). These patients are ideal for this purpose because they are given large activities that are readily measured with ionization chamber survey meters for up to 24 hr (*3*).

This study describes the radiation levels surrounding ^{99m}Tc-MDP bone scintigram, prostate cancer patients as a function of time, distance, and BSA. The survey results were mathematically related to BSA and equations were generated for determining radiation exposures. An example is provided utilizing these equations to calculate radiation exposure of a ^{99m}Tc-MDP patient over a 21-hr period (see Appendix).

MATERIALS AND METHODS

The survey population consisted of 16 adult males with histologically documented prostate cancer and normal renal function (ages: 45–81) who were referred for ^{99m}Tc-MDP bone scintigrams as a screen for skeletal metastases. Each patient received 20 mCi (740 MBq) of radioactivity and was scanned ~4 hr postadministration. These patients were also part of another investigation for which they would return at 24 hr for a whole-body retention study (*5*). The availability of these patients at the time of administration and at 4 hr and 24 hr postadministration presented an opportunity to perform time-dependent radiation surveys. We used a calibrated survey meter and all measurements were performed at the patient's waist (umbilicus) level, while the patient stood. At each time period, radiation surveys were obtained at the patient's surface, at 1 ft (30.5 cm) from the patient, and at 3 ft (rounded to 100 cm throughout this paper). The projections measured were the anterior, posterior, left lateral and right lateral views. The lateral measurements were obtained at 5 min only. Thereafter, these projection values were calculated by multiplying the mean anterior plus posterior values at 4 and 24 hr by a previously calculated correction factor for each patient. This correction factor was obtained by dividing the mean 5-min anterior plus posterior

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value into the right or left lateral value. All patients were asked to drink fluids and to void prior to each measurement. The 5-min surveys were expressed as the mean for N = 16 determinations for each projection and distance, in units of mrem/hr/20 mCi (mSv/hr/740 MBq). Twenty millicuries was chosen because it is the standard adult dosage for ^{99m}Tc-MDP. The two remaining survey times, 4 and 24 hr, allowed us to separate the patient population into those with, and those without, bone metastases as determined by the qualitative scintigram at 4 hr. Seven of the sixteen patients had positive bone scintigrams and nine had negative scintigrams.

At injection time, the height and weight of each individual were documented in order to calculate the BSA in units of square meters (*6*). Thereafter, each patient's BSA and associated normalized survey results were compared algebraically in a linear regression formulation ($y = mx + b$) to obtain the best straight-line equation for each set of patients or x, y pairs (*7*). From these data, the slope and y-intercept were obtained and expressed as follows: mrem/hr/mCi = [(slope)(BSA value)] + (y-intercept). The equations were generated for the 5-min, 4-hr, and 24-hr periods. The in-between periods, especially the 5-min to 4-hr time span, represent primarily tracer redistribution and urinary excretion (*8–10*). The linear regression equations that were determined for the three discrete times following administration cannot be utilized for other times unless a correction factor is introduced. This was accomplished by assuming a monoexponential decrease of exposure rate and then calculating the effective half-life ($T_{1/2}$eff) and decay constant (λ) between survey periods as follows:

$$T_{1/2}\text{eff} = [0.301(t_2 - t_1)]/(\log_{10}R_1 - \log_{10}R_2),$$

where $T_{1/2}$eff equals the effective half-life between time periods t_1 and t_2, R_1 equals the survey results at t_1, and R_2 equals the survey results at t_2.

In the present study t_1 = 5 min (0.083 hr) and t_2 = 4 hr, or t_1 = 4 hr and t_2 = 24 hr.

The linear regression equation was altered to account for the administered dosage (D) and a specific time period (tx) between the actual survey times as follows:

T = total mrem/hr at study time and distance

$$= (1/\lambda)(1 - e^{-\lambda tx})[(\text{slope})(\text{BSA}) + \text{y intercept}],$$

where: $\lambda = 0.693/T_{1/2}$eff.

The total radiation dose received by an individual exposed for a specific period of time (t) can be calculated by combining the above equations.

RESULTS

Table 1 lists the patient population indicating both BSA and status of bone metastases for each patient. The time-projection survey results are listed in Table 2 as the mean mrem/hr/20 mCi as a function of time, projection, and distance. Seven of the sixteen patients had bone metastases, which were demonstrated on the qualitative bone scintigram. As shown, the initial radiation levels at 5 min were reduced considerably at the 4-hr and 24-hr periods for the negative bone scan group. Those with positive bone scans, however, showed an increase in radiation levels. These patients had metastases in the lower lumbar region of the skeleton, an area close to the placement of the survey meter.

TABLE 1. Patient Population for Radiation Survey Study

Patient #	Body Surface Area (m^2)	Bone Metastases*
1	1.30	−
2	1.32	+
3	1.63	−
4	1.65	+
5	1.68	−
6	1.70	−
7	1.72	−
8	1.76	+
9	1.78	−
10	1.82	+
11	1.86	+
12	1.88	+
13	1.93	−
14	1.97	+
15	1.97	−
16	1.98	−

*As determined by bone scan: + = bone metastases, − = no bone metastases.

Linear Regression

Individual survey results were analyzed as a function of patient BSA for each patient group. In order to compare the individual survey readings, all results were normalized to a 1 mCi (37 MBq) administered dose. The constants associated with the linear regression equation are shown in Table 3, for 5 min, 4 hr and 24 hr, as a function of distance, projection, and metastatic bone status.

Determination of Effective Half-Life Between Survey Periods

The periods in between the survey times were corrected for decay, in the exposure calculations, by determining the effective half-life for the following pairs: 5 min to 4 hr, 5 min to 24 hr, and 4 hr to 24 hr. Effective half-lives were determined for each projection and distance. From these data, the decay constant was calculated and added to the corresponding linear regression equation, as follows: projection = anterior, distance = surface, and time period = 5 min (0.08 hr) to 4 hr. If, from Table 2, patient type = no bone metastases, 5-min exposure = 9.0 mrem/hr/20 mCi, and 4-hr Exposure = 2.6 mrem/hr/20 mCi, then, the $T_{1/2}$eff for 5 min (0.08 hr) to 4 hr is as follows.

$$T_{1/2}\text{eff} = [0.301(4\text{hr} - 0.08\text{hr})]/(\log_{10} 9.0 - \log_{10} 2.6)$$

TABLE 2. Radiation Surveys of ^{99m}Tc-MDP Bone Scintigram Patients

Distance	Projection	N	5 min	N	Bone Metastases	4 hr	N	Bone Metastases	24 hr
Surface	anterior	16	9.0	9	no	2.6	9	no	0.4
	posterior	16	9.1	9	no	5.0	9	no	0.5
	rt. lateral	10	5.2	5	no	2.2	5	no	0.3
	lft. lateral	10	5.7	5	no	2.4	5	no	0.3
	anterior	—	—	7	yes	14.0	7	yes	1.5
	posterior	—	—	7	yes	48.6	7	yes	4.7
	rt. lateral	—	—	5	yes	15.4	5	yes	1.9
	lft. lateral	—	—	5	yes	16.7	5	yes	2.0
1 ft	anterior	16	3.1	9	no	1.0	9	no	0.07
(30.5 cm)	posterior	16	3.8	9	no	2.1	9	no	0.10
	rt. lateral	10	1.8	5	no	0.8	5	no	0.04
	lft. lateral	10	2.1	5	no	1.0	5	no	0.05
	anterior	—	—	7	yes	5.7	7	yes	0.30
	posterior	—	—	7	yes	17.3	7	yes	0.90
	rt. lateral	—	—	5	yes	6.0	5	yes	0.31
	lft. lateral	—	—	5	yes	7.0	5	yes	0.38
3 ft	anterior	16	0.9	9	no	0.27	9	no	BKG
(100 cm)	posterior	16	1.1	9	no	0.55	9	no	BKG
	rt. lateral	10	0.78	5	no	0.31	5	no	BKG
	lft. lateral	10	0.82	5	no	0.32	5	no	BKG
	anterior	—	—	7	yes	1.5	7	yes	0.08
	posterior	—	—	7	yes	4.3	7	yes	0.28
	rt. lateral	—	—	5	yes	2.3	5	yes	0.14
	lft. lateral	—	—	5	yes	2.4	5	yes	0.15

Radiation survey results expressed as mean mrem/hr/20 mCi as a function of time; mSv/hr/740 MBq = (mrem/hr/20 mCi)(0.01).

TABLE 3. Linear Regression Constants for ^{99m}Tc-MDP Patients

Population	N	Projection	Distance	Time	m*	b*
All patients	16	posterior	surface	5 min	−0.302	+1.06
			1 ft		−0.040	−0.260
			3 ft		−0.016	+0.084
All patients	16	anterior	surface	5 min	−0.303	+0.977
			1 ft		−0.016	+0.261
			3 ft		−0.020	+0.084
No metastases	9	posterior	surface	4 hr	−0.126	+0.468
			1 ft		−0.063	+0.210
			3 ft		+0.013	+0.094
No metastases	9	anterior	surface	4 hr	−0.074	+0.257
			1 ft		−0.023	+0.089
			3 ft		−0.029	+0.019
Metastases	7	posterior	surface	4 hr	−0.812	+2.120
			1 ft		−0.020	+0.247
			3 ft		−0.008	+0.087
Metastases	7	anterior	surface	4 hr	−7.598	+15.79
			1 ft		−0.888	+2.42
			3 ft		−0.207	+0.577
No metastases	9	anterior	surface	24 hr	−0.005	+0.026
	9	posterior	surface	24 hr	+0.002	+0.023
Metastases	7	anterior	surface	24 hr	−0.039	+0.143
	7	posterior	surface	24 hr	−0.370	+0.883

*y = mx + b or mrem/hr/mCi = slope (BSA) + y-intercept.

TABLE 4. Effective Half-Lives and Corresponding Decay Constant for In-Between Time Periods

Projection	Bone Metastases	Time Interval	Effective Half-Life (hr)	Decay Constant (hr^{-1})
Surface				
anterior	no	5 min–4 hr	2.19	0.316
anterior	no	5 min–24 hr	5.33	0.130
anterior	no	4 hr–24 hr	1.23	0.563
anterior	yes	5 min–4 hr	−5.90	−0.117
anterior	yes	4 hr–24 hr	7.39	0.094
anterior	yes	5 min–24 hr	9.25	0.075
posterior	no	5 min–4 hr	4.54	0.153
posterior	no	5 min–24 hr	5.71	0.120
posterior	no	4 hr–24 hr	6.02	0.115
posterior	yes	5 min–4 hr	−1.62	−0.428
posterior	yes	5 min–24 hr	25.00	0.028
posterior	yes	4 hr–24 hr	5.93	0.117
1 ft (30.5 CM)				
anterior	no	5 min–4 hr	2.41	0.289
anterior	no	5 min–24 hr	4.39	0.158
anterior	no	4 hr–24 hr	5.23	0.133
anterior	yes	5 min–24 hr	7.07	0.098
anterior	yes	5 min–4 hr	−4.45	−0.156
anterior	yes	4 hr–24 hr	4.70	0.147
posterior	no	5 min–4 hr	4.54	0.153
posterior	no	5 min–24 hr	4.56	0.152
posterior	no	4 hr–24 hr	4.55	0.152
posterior	yes	5 min–24 hr	11.50	0.060
posterior	yes	5 min–4 hr	−1.79	−0.387
posterior	yes	4 hr–24 hr	4.67	0.148
3 ft (100 CM)				
anterior	no	5 min–4 hr	2.26	0.307
anterior	no	5 min–24 hr*	4.07	0.170
anterior	no	4 hr–24 hr	4.87	0.142
anterior	yes	5 min–4 hr	−5.36	−0.129
anterior	yes	5 min–24 hr	6.86	0.101
anterior	yes	4 hr–24 hr	4.74	0.146
posterior	no	5 min–4 hr	3.56	0.195
posterior	no	5 min–24 hr*	3.87	0.179
posterior	no	4 hr–24 hr	3.86	0.180
posterior	yes	5 min–24 hr	12.20	0.057
posterior	yes	5 min–4 hr	−1.99	−0.248
posterior	yes	4 hr–24 hr	5.06	0.137

*Assume background = 0.015 mrem/hr.

$T_{1/2}eff = 1.18/0.539 = 2.19$ hr

$$\text{Decay Constant} = \frac{0.693}{2.19} = 0.316\ hr^{-1}$$

This decay constant is then incorporated into the linear regression equation using the Table 3 surface values, as follows:

$$\text{mrem/hr/mCi} = \{[(\text{slope})(\text{BSA})] + (\text{y-intercept})\}$$

$$\cdot\ (\text{decay correction any time between 0.08 hr and 4 hr})$$

$$y = \{[(-0.303)(\text{BSA})] + (0.977)\}e^{-0.316(t)},$$

where t = any time between 0.08 hr and 4 hr.

Table 4 lists the effective half-lives and corresponding decay constants for the indicated time intervals.

Blood and Urine

The radiation exposure from handling blood or urine is of concern. The percentage of the administered dose in blood at any given time can be approximated by using the following triexponential release equation (*9*), where t = time after administration in minutes.

$$\%D = 78.7e^{-0.198t} + 14.1e^{-0.0257t} + 7.2e^{-0.00481t}$$

The urinary excretion can be extremely variable (*9–10*). For this reason a constant monoexponential pattern was assumed for the in-between time periods. This method is

TABLE 5. ^{99m}Tc-MDP Urinary Excretion: Mean Radiation Dose Equivalent Rate Around a Collection Urinal

Time after administration	mCi	MBq	Dose equivalent rate at urinal surface (mrem/hr)	(mSv/hr)	Dose equivalent rate at urinal handle (mrem/hr)	(mSv/hr)	Dose equivalent rate at 15 cm distance (mrem/hr)	(mSv/hr)	Dose equivalent rate at 100 cm distance (mrem/hr)	(mSv/hr)
0–1 hr	6	222	115.6	(1.16)	45.8	(0.46)	17.1	(0.17)	0.476	(0.0048)
1–4 hr	3	111	68	(0.68)	26.9	(0.27)	10.1	(0.10)	0.280	(0.0028)
4–7 hr	1.2	44.5	26.4	(0.26)	10.4	(0.10)	3.9	(0.04)	0.108	(0.0011)

Results based on 300 cc in urinal/time period, using a Victoreen panoramic ionization chamber (470A). ^{99m}Tc-MDP administered to 11 patients. Mean dose = 20 mCi (740 MBq).

indicated when urinary excretion times are unknown. However, the collection and subsequent handling tasks for patient excreta have the potential for radiation exposure. The exposure to the handler would be a function of the time it takes for this task to be completed and the number of such tasks performed over a given time. Table 5 illustrates the radiation exposure surrounding a collection urinal containing variable quantities of ^{99m}Tc.

The above formulae can be used to estimate the radiation dose equivalent received by individuals who may come in contact with the bone scan patients. General equations for these estimations combine the survey results with the patient's BSA and the total time (t) spent by the exposed individual at a particular distance from the patient.

The Appendix consists of several typical patient situations where the linear regression equations are used to estimate radiation exposure to contact individuals up to 21 hr postadministration. The calculated exposures serve as an approximation when such information is desired either prospectively or retrospectively. The latter methodology was employed when estimating close contact doses to young children (*11*).

APPENDIX

A prostate cancer patient is accompanied to the nuclear medicine clinic by his daughter. His previous bone scan showed several skeletal metastases in the lower lumbar region. His height and weight are 6 ft (189.2 cm) and 200 lb (90.7 kg), respectively. He is given 22.5 mCi (832.5 MBq) of ^{99m}Tc and is told to return for the bone scintigram 4 hr later.

1. Estimate the radiation levels around this patient 5 min after radionuclide administration.
   A. The patient's BSA is 2.12 m^2 (*6*).
   B. Calculation of anterior radiation levels at 5 min postadministration (Table 3).
      (1) Surface
         y = m(BSA) + b
         y = (−0.303)(2.12) + 0.977
         y = 0.335 mrem/hr/mCi
         exposure/dosage = (0.335)(22.5 mCi) = 7.53 mrem/hr
      (2) 1 ft (30.5 cm)
         y = (−0.061)(2.12) + 0.261
         y = 0.131 mrem/hr/mCi
         y = (0.131)(22.5) = 2.95 mrem/hr
      (3) 3 ft (100 cm)
         y = (−0.02)(2.12) + 0.0842
         y = 0.0418 mrem/hr/mCi
         y = (0.0418)(22.5) = 0.914 mrem/hr
   C. Calculation of posterior radiation levels at 5 min postadministration (Table 3).
      (1) Surface
         y = (−0.302)(2.12) + 1.06
         y = 0.420 mrem/hr/mCi
         y = (0.420)(22.5) = 9.44 mrem/hr
      (2) 1 ft (30.5 cm)
         y = (−0.04)(2.12) + 0.26
         y = 0.175 mrem/hr/mCi
         y = (0.175)(22.5) = 3.94 mrem/hr
      (3) 3 ft (100 cm)
         y = (−0.016)(2.12) + 0.0838
         y = 0.05 mrem/hr/mCi
         y = (0.05)(22.5) = 1.13 mrem/hr
   D. Right lateral radiation levels (Table 2).
      (1) Surface
         y = (7.53 + 9.44)/2 = 8.49 mrem/hr
         y = (8.49)(5.2/9.05) = 4.88 mrem/hr
      (2) 1 ft (30.5 cm)
         y = (2.95 + 3.94)/2 = 4.92 mrem/hr
         y = (4.92)(1.8/3.45) = 2.57 mrem/hr
      (3) 3 ft (100 cm)
         y = (0.941 + 1.13)/2 = 1.04 mrem/hr
         y = (1.04)(0.78/1.0) = 0.811 mrem/hr
   E. Left lateral radiation levels (Table 2).
      (1) Surface
         y = (8.49)(5.7/9.05) = 5.35 mrem/hr
      (2) 1 ft (30.5 cm)
         y = (4.92)(2.1/3.45) = 2.99 mrem/hr
      (3) 3 ft (100 cm)
         y = (1.04)(0.82/1.0) = 0.853 mrem/hr
2. Calculate the radiation exposure to the patient's daughter who meets him for breakfast in the hospital cafeteria immediately after tracer administration. Assume the daughter sits directly across from her father for 2 hr at a distance of 3 ft.
   A. The exposure to the daughter would be a function of the distance from her father, the initial 5-min to 4-hr

radiation level changes, and the time spent in this situation.

(1) The effective half-life and decay constant associated with a patient with bone metastases, for the anterior 3-ft (100-cm) projection and the 5-min to 4-hr time period, are obtained from Table 4 as follows; $T_{1/2}$eff = −5.36 hr and the decay constant = −0.129/hr.

(2) The 2-hr radiation dose rate = (5-min value) $(e^{-\lambda t})$ = (0.914 mrem/hr)$[e^{-(-0.129)(2\ hr)}]$ = 0.914(1.29) = 1.18 mrem/hr.

(3) The daughter's exposure (D) for a 2-hr period immediately after tracer administration is as follows.

D = (mrem/hr at 2 hr)(time of exposure)$[e^{-\lambda t})]$.

D = (1.18)(2)$[e^{-(-0.129)(2\ hr)}]$

D = (2.36)$(e^{-(-0.258)}$ = (2.36)(1.29)

D = 3.05 mrem

3. One hour later a pregnant individual joins their table and sits 1 ft (30.5 cm) away from the patient, on his left. What are the radiation exposures at the woman's right side and at the surface of the fetus, who is at 1 ft (30.5 cm)? She stays for 0.5 hr.

A. The woman joins the cafeteria table 3 hr after tracer administration and leaves 0.5 hr later. The decay constant from 5 min to 4 hr is an average of the anterior and posterior values: [(−0.156) + (−0.387)]/2 = −0.272/hr.

(1) The patient's 1-hr right lateral radiation exposure = (2.99 mrem/hr)$[e^{-(-0.272)(1\ hr)}]$ = 2.99(1.31) = 3.92 mrem/hr.

(2) The pregnant woman's radiation dose (PD) for her 0.5-hr stay is calculated as follows.

PD = 3.92(0.5)$[e^{-(-0.272)(0.5)}]$

PD = 1.96(1.15) = 2.25 mrem

B. Fetal dose

Now calculate the radiation dose to the fetus (FD) at 1 ft (30.5 cm) from the right lateral side of the mother. The radiation dose received by the mother's right side equals 2.25 mrem. The 140-keV photons of ^{99m}Tc are attenuated by the soft tissue thru 1 ft (30.5 cm) and the linear attenuation coefficient for this photon energy in this medium is 0.151/cm.

FD = 2.25 mrem (e^{-ux}) = 2.25$[e^{-(0.151)(30.5\ cm)}]$

FD = 2.25$(e^{-4.6})$ = 2.25(0.01)

FD = 0.0225 mrem

4. After the cafeteria break, the daughter goes shopping and the patient arrives at the urology clinic. The urologic nurse sees the patient at 2.5 to 3.5 hr postadministration to fill out a questionnaire and to take a 5-cc blood sample. The nurse sits 3 ft from the patient's anterior and takes the blood sample at the end of the session. The venipuncture procedure takes 5 min at a distance of 1 ft (30.5 cm).

A. The radiation dose rate at the beginning of the visit with the nurse is 0.914 mrem/hr$[e^{-(-0.117)(2.5\ hr)}]$ = 1.22 mrem/hr.

B. The radiation dose to the nurse (ND) is:

ND = 1.22$[e^{-(-0.117)(1\ hr)}]$ = 1.22(1.12)

ND = 1.37 mrem

Note: The exposure during the 5-min venipuncture procedure is; 2.95$[e^{-(-0.156)(3.5\ hr)}]$ = 2.95(1.73) = 5.10 mrem/hr. Thus, ND − venipuncture procedure = 5.10(5/60)$[e^{-(-0.156)(5/60)}]$.

ND − blood letting = 0.425 mrem(1.01) = 0.431 mrem

Total ND = 1.37 + 0.431 = 1.80 mrem

C. The tracer concentration in the blood at the time of the venipuncture procedure (3.5 hr or 210 min postinjection) (*9*) is:

(1) %D calculation

%D = 78.7 $e^{-(0.198)(210)}$ + 14.1 $e^{-(0.0257)(210)}$ + 7.20 $e^{-(0.00481)(210)}$

%D = 78.8(8.8E − 19) + 14.1(4.5E − 03 + 7.20(0.364)

%D = 2.62

(2) Blood concentration

The patient weighs 200 lb (90.7 kg) and his blood volume is 90,700 cc (0.07) = 6349 cc.

The total radioactivity in the blood is:

22,500 μCi (.0262) = 589.5 μCi

The concentration = 589.5/6349 = 0.0928 μCi/cc (5 cc) = 0.464 μCi/5 cc

D. The tracer concentration in the urine is a function of pathology. Table 5 lists the radiation levels surrounding a urinal containing variable quantities of ^{99m}Tc. The decay of this activity would follow that of ^{99m}Tc (0.114/hr) after collection.

5. The patient then leaves the urology clinic and returns to the nuclear medicine department for his bone scintigram. He arrives 3.75 hr postadministration and waits an extra 0.5 hr in a patient waiting area. At 4 hr, he begins his bone scintigram, which takes 1 hr. During this time the technologist is an average of 3 ft (100 cm) from the patient for one-half of the time and 1 ft (30.5 cm) for the remaining half of the scan time. What is the whole-body exposure to the technologist? Assume the anterior projection is performed first, and then the posterior projection.

A. For the anterior projection, the technologist is to the patient's right, and for the posterior projection, the technologist is to the patient's left. The exposures at 4 hr for the right lateral at 1 ft (30.5 cm) and 3 ft (100 cm) are as follows.

(1) The exposure at 4 hr for the right lateral (RL) at 1 ft (30.5 cm) and 3 ft (100 cm):

RL-1 ft = (2.57 mrem/hr)$[e^{-(-0.272)(4\ hr)}]$ = (2.57)(2.96)

RL-1 ft = 7.63 mrem/hr

RL-3 ft = (0.881 mrem/hr)$[e^{-(-0.189)(4)}]$ = (0.881)(2.13)

RL-3 ft = 1.88 mrem/hr

(2) The technologist's radiation dose during the anterior projection (TD-A) equals:

$$TD\text{-}A = (7.63)(0.25\ hr)[e^{-0.1475(0.25)}] + (2.13)(0.25)[e^{-0.142(0.25)}]$$

$$TD\text{-}A = 1.84 + 0.514 = 2.35\ mrem$$

(3) The exposure at 4 hr for the left lateral (LL) at 1 ft (30.5 cm) and 3 ft (100 cm):

RL-1 ft = (2.99)(2.96) = 8.85 mrem/hr

RL-3 ft = (0.853)(1.88) = 1.62 mrem/hr

B. The radiation exposures at the start of the posterior scintigram at 4.5 hr are corrected by using the 4-hr to 24-hr decay constants in Table 3 as follows:

RL-4.5 hr-1 ft = $(8.85)[e^{-(0.098\ +\ 0.06)/2)(0.5\ hr)}]$

RL-4.5 hr-1 ft = 8.51 mrem/hr

RL-4.5 hr-3 ft = $(1.60)[e^{-(0.101\ +\ 0.057)/2)(0.5\ hr)}]$

RL-4.5 hr-3 ft = 1.53 mrem/hr

C. The technologist's radiation dose for the posterior scintigram (TD-P) equals:

$$TD\text{-}P = (8.51)(0.25\ hr)[e^{-(0.079)(0.25\ hr)}] + (1.53)(0.25)[e^{-(0.079)(0.25)}]$$

$$TD\text{-}P = 2.09 + 0.375 = 2.47\ mrem$$

D. The total technologist's dose (TD) from the anterior and posterior study equals:

TD = TD-A + TD-P = 1.53 + 2.47 = 4.00 mrem

6. The patient leaves the clinic and meets his daughter for a ride home in her automobile, 5.5 hr postadministration. The daughter sits 3 ft from the left side of the patient and the trip takes 3 hr. What is the daughter's radiation dose (DD) during the trip home?
   A. The 5.5-hr left lateral radiation level = the 4-hr level corrected for the 4-hr to 24-hr decay constant:
   5.5-hr RD = $(1.82)[e^{-(0.079)(1.5\ hr)}]$ = 1.62 mrem/hr
   B. DD for the 3-hr trip equals:
   DD = $1.67(3\ hr)[e^{-(0.079)(3)}]$
   DD = 3.83 mrem
7. After arriving home, the patient takes a rest and does not have contact with anyone for 2 hr. At this time, 10.5 hr into the study, his 5-yr-old grandson sits on his lap and is read a story for 0.25 hr. Calculate the radiation dose the grandson receives (DSD).
   A. The patient's anterior surface radiation level at 10.5 hr = $(7.53\ mrem/hr)[e^{-(0.075)(10.5\ hr)}] = 7.53(0.45) =$ 3.43 mrem/hr.
   B. The grandson's radiation dose is:
   DSD = $3.43(0.25\ hr)[e^{-(0.075)(0.25)}]$
   DSD = 0.842 mrem
8. The daughter and grandson leave the patient's home and 11 hr postadministration he and his wife share dinner. She sits 3 ft (100 cm) away from him (anterior exposure) and dinner lasts 0.5 hr. Calculate the wife's radiation dose (WD).
   A. Anterior − 3-ft (100 cm) radiation level at 11 hr = $(0.914)[e^{-(0.101)(11\ hr)}]$ = 0.310 mrem/hr
   B. WD = $0.301(0.5)[e^{-0.101(0.5\ hr)}]$ = 0.143 mrem
9. After dinner, the patient watches TV alone and retires to bed with his wife 13 hr postadministration. Assume the wife averages 1 ft (30.5 cm) distance from her husband's right side. Calculate her radiation dose (WD-S) for 8 hr of sleep, until 21 hr into the study.
   A. The right lateral radiation level at the start of sleep equals $(2.57\ mrem/hr)[e^{-(0.098\ +\ 0.06)/2)(13\ hr)}]$ = 0.920 mrem/hr.
   B. WD-S = $(0.920)(8\ hr)[e^{-(0.079)(8)}]$
   WD-S = 3.91 mrem
10. The patient awakes at 21 hr postadministration. Calculate the anterior and posterior radiation levels at 3 ft (use data from Table 4).
    A. Anterior (A)
    A = $(0.914)[e^{-(0.101)(21\ hr)}]$
    A = 0.110 mrem/hr
    B. Posterior (P)
    P = $(1.13)[e^{-(0.057)(21\ hr)}]$
    P = 0.341 mrem/hr

The above examples provide simple calculations for determining the radiation dose received by various individuals whom the patient encounters. The data contained in this report can be used in most circumstances.

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