Radiation Safety

Fingertip and Whole Body Exposure to Nuclear Medicine Personnel

George A. Lis, Said M. Zu'bi, and Suresh M. Brahmavar

Baystate Medical Center—Springfield Hospital Unit, Springfield, Massachusetts

We calculate radiation exposure to the nuclear medicine technologist for all common sources of exposure. Special attention is given to exposure received by fingertips. We include typical exposure rates for patient injections, reagent preparations, generator handling and elution, patient positioning, and other phases of nuclear medicine. The cumulative exposure to fingertips and whole body is estimated. When every precaution is taken to minimize exposure in our laboratory, the unavoidable annual exposure to the fingertips is 11 R; to the whole body it is 1 R from all sources. When precautions are not taken, the annual exposure to the fingertips may exceed 170 R and the whole body dose may then approach 2 R. Our nuclear medicine laboratory averages about 1,000 injections per technologist per year.

Nuclear medicine's large dependence on technetium-labeled products has resulted in the ever increasing use of high activity doses. Many nuclear medicine departments are now imaging a greater volume of patients with the same number of personnel; a technologist may, therefore, be subjected to greater radiation exposure than in the past. Burr (*1*) has determined that the fingertip would receive approximately 6.7 times the exposure detected by a ring badge worn in the usual position. Neil (*2*) has reported that hand radiation may exceed regulatory levels by a modest amount and that film badges are not necessarily representative of peak hand radiation and may lead to a false sense of security.

Concern over radiation exposure prompted us to investigate the total yearly exposure to our technologists from all common sources of exposure found in nuclear medicine. We then tabulated and compared this total yearly exposure of each radiation handling technique to the yearly maximum permissible dose (MPD) to give perspective to the values derived. Each nuclear medicine department can appropriately adjust the charts to its individual patient volume and exposure times.

For reprints contact: G.A. Lis, Div. of Nuclear Medicine, Baystate Medical Center—Springfield Hospital Unit, 759 Chestnut St., Springfield, MA 01107.

Our investigation encompassed three different areas, namely:

1. Calculating the exposure rate from various points on a syringe.
2. Establishing a table of frequencies, exposure rates, and radioactive source geometry that reflect current radiation handling techniques.
3. Considering other contributing sources of exposure and determining the total whole body and fingertip cumulative yearly exposure from all common sources and techniques.

The volume of data generated by this report is presented in table format. Tables 1 and 2 contain data on syringe geometries and values for exposure rate computations. Tables 3, 4, 5, and 6 list exposures accumulated from routine nuclear medicine activities. The results are also presented in the text to emphasize their significance. Derivation of all values given in the tables can be found in the supporting data section of this article.

Results and Discussion

Exposures listed in the tables also include yearly cumulative estimates for the frequencies encountered in our laboratory. This was done to provide a perspective of how each dose handling technique compares to the yearly MPD limits for specified exposure times and frequencies.

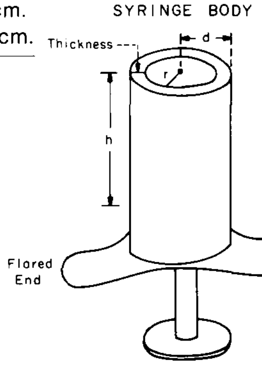
Exposure to fingertips during patient injections is found in Table 3. Whenever a syringe is held at mid-dose (Case A), the yearly exposure may substantially exceed the MPD limit of 75 R to the hands. Syringe shields are quite effective when a syringe is held at mid-dose. Holding a syringe at the flared end (Case B) will also result in reduced exposure to the fingertips. During patient injections and dose preparations, the fingertips are invariably located at the flared end of a syringe. Syringe shields do not effectively reduce the exposure to the fingertips at the flared end and may lead to a false sense of security. Exposure realized at the flared end will be smallest if the syringe is less than half full.

Whenever larger syringes are used, a greater distance is

TABLE 1. Syringe Geometry and Physical Constants

Syringe (cc)	Inner radius r (cm)	$\frac{5.94}{r^2}$ (per cm²)	p at surface of syringe = d/r = (0.1 cm + r)/r p	Volume in syringe (at k = h/r = 1) (ml)
1	0.235	107.6	1.43	0.04
3	0.44	30.7	1.23	0.27
5	0.60	16.5	1.17	0.68
10	0.72	11.5	1.14	1.17
Xe-133 vial	0.60	15.0	≈1.23	

Thickness of all syringes = 0.1 cm.
Thickness of Xe-133 vial = 0.15 cm.



introduced between dose and fingertips. The resultant exposure at the flared end is now less if a smaller syringe with a syringe shield is used. Syringe shields are still advisable on all size syringes to minimize exposure to the body. When precautions are taken to minimize exposure, the unavoidable yearly exposure to the fingertips from patient injections (Table 3) is about 3 R. Maximum yearly exposure—when precautions are not taken to minimize exposure—may exceed 100 R to fingertips (Table 3).

Exposure received during withdrawal of Tc-99m doses is given in Table 4. Reduction in exposure is seen whenever a larger syringe is used. Preparation of Tc-99m reagents from kits often requires about 100-mCi Tc-99m in a 3- to 8-ml volume. A usual preparation procedure is to draw up the 100-mCi Tc-99m dose in a 3-cc syringe, dilute to 3 ml with saline, and inject into reagent vial for reconstitution. Table 4 (Case B) shows a 17-fold decrease in exposure to fingertips if a 10-cc syringe is substituted for the 3-cc syringe at dose withdrawal. Exposure to the hand from the open end of the shielded Tc-99m vial during dose withdrawal can be halved by two equally effective means. Holding a syringe at a 30° angle to the vertically held vial (Table 4, Case A) during dose withdrawal or using a syringe shield during dose withdrawal will halve the exposure received from the Tc-99m vial. The necessity for vial shields to securely hold the Tc-99m vial in the inverted position during dose withdrawal is made evident by Table 4, Case C. If a technologist must support the Tc-99m vial (in its shield) with his thumb during dose withdrawal, the annual exposure, based on 1,000 withdrawals per year, would be 56 R to that thumb. The unavoidable yearly exposure for our laboratory to the fingertips from all dose preparations (Table 4) is about 6 R when precautions are taken to minimize exposure. Maximum yearly exposure may exceed 60 R for the frequencies cited in Table 4.

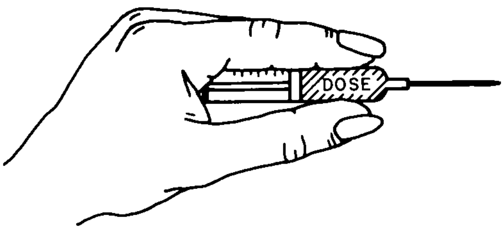
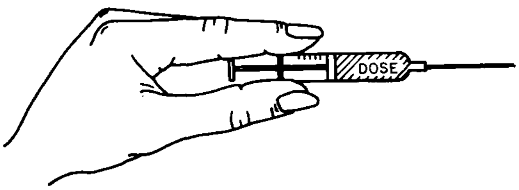
Unnecessary exposure should be viewed as unnecessary risk. Table 5 lists the common occurrences that may cause unnecessary exposure that could be prevented or reduced. Handling Xe-133 vials by hand is reckless; the exposure of 10.6 R per year can be nullified by use of tongs. Aseptic wiping of Tc-99m vials using 6-in. cotton swabs dipped in alcohol or using forceps with an alcohol wipe will reduce exposure. Exposure while changing a hypodermic needle is minimized by not expelling excess activity into the needle hub prior to the needle change. Returning this activity to its vial decreases the exposure four-fold compared to expelling this activity into the needle hub. The unavoidable yearly exposure (for our lab's frequency and exposure time) to the fingertips is about 0.9 R (Table 5) when precautions are taken to minimize exposure. The maximum yearly exposure—when precautions are not taken to minimize exposure—may exceed 15 R (Table 5).

Table 6 is a compilation of exposure sources to a technologist whose exposure rates were determined by survey meter or by calculation other than Table 2. The whole body

TABLE 2. Adjusted Values for G(k,p,0,0) for Use in Syringe Exposure Rate Computation

k	p = 1.14	p = 1.17	p = 1.23	p = 1.43
0.25	0.50	0.45	0.36	0.27
0.50	0.87	0.79	0.64	0.50
0.75	1.18	1.07	0.88	0.70
1.0	1.45	1.32	1.09	0.87
1.5	1.756	1.610	1.340	1.080
2.0	1.958	1.800	1.507	1.225
2.5	2.094	1.927	1.621	1.325
3.0	2.189	2.016	1.701	1.396
3.5	2.2550	2.0790	1.7580	1.4470
4.0	2.3046	2.1264	1.8006	1.4850
4.5	2.3426	2.1637	1.8336	1.5150
5.0	2.3722	2.1925	1.8601	1.5394
5.5	2.3963	2.2162	1.8821	1.5600
6.0	2.4168	2.2365	1.9011	1.5778
7.0	2.4505	2.2700	1.9321	1.6071
8.0	2.4768	2.2961	1.9563	1.6299
9.0	2.4979	2.3169	1.9760	1.6486
10.0	2.5149	2.3335	1.9920	1.6640
11.0	2.5287	2.3471	2.0052	1.6768
12.0	2.5404	2.3587	2.0164	1.6876
13.0	2.5506	2.3688	2.0262	1.6971
15.0	2.5659	2.3840	2.0412	1.7119
17.0	2.5775	2.3955	2.0525	1.7230
19.0	2.58665	2.40460	2.06152	1.73192
20.0	2.59081	2.40870	2.06556	1.73591
21.0	2.59420	2.41211	2.06890	1.73920
23.0	2.60032	2.41820	2.07495	1.74520
25.0	2.60544	2.42330	2.08000	1.75021

TABLE 3. Exposure to the Fingertips during Patient Injections

Our lab's average: Exposure Time = 12 sec/injection Frequency = 1,000 injections/year	Dose volume (ml)	Syringe used (cc)	Syringe shield	Exposure rate* (mR/mCi-min)	Yearly exposure (R)
Case A: 20-mCi Tc-99m held at mid-dose	0.8	1	no	17.9	71.6
	0.8	3	no	27.4	109.6
	0.8	3	yes	0.04	0.2
	2.0	3	no	14.6	58.4
	3.0	3	no	10.6	41.6
	0.8	5	no	24.4	97.6
	2.0	5	no	17.7	70.8
	3.0	5	no	13.8	55.2
	0.8	10	no	23.2	92.2
	2.0	10	no	18.0	72.0
	3.0	10	no	14.7	58.8
	10.0	10	no	6.2	24.8
Case B: 20-mCi Tc-99m held at flared end	0.8	1	no	1.13	4.5
	0.8	3	no	0.50	2.0
	0.8	3	yes	0.20	0.8
	2.0	3	no	1.0	4.0
	2.0	3	yes	0.7	2.8
	3.0	3	no	5.5	22.0
	3.0	3	yes	4.8	17.2
	0.8	5	no	0.50	2.00
	2.0	5	no	0.68	2.72
	3.0	5	no	1.0	4.0
	0.8	10	no	0.26	1.04
	2.0	10	no	0.29	1.16
	3.0	10	no	0.34	1.35
	10.0	10	no	3.3	13.2

*as measured by survey meter through lead glass portion of syringe shield

as well as the fingertip exposure rate is included wherever possible. Exposure resulting from handling patients (Case A) is given. This probably cannot be reduced except by maximizing distance and minimizing exposure time. Technetium-99m contamination on the skin (*3*) (Case B) causes a significant one-time exposure and should be avoided by wearing gloves and changing gloves frequently.

Eluting Tc-99m generators (Case C) and handling Tc-99m generators (Case D) result in minimal exposure, which probably cannot be reduced further. Exposure associated with accidental Xe-133 gas escape into a room by a patient (Case E) is minimal. However, this type of accident seems to generate a good deal of concern. It is evident from the tables that other nuclear medicine procedures should cause more concern and replace the complacent attitudes of some technologists. Finally, countertop shields are recommended to eliminate exposure to the body during dose preparations (Case F). The unavoidable yearly exposure to fingertips is about 0.7 R and to the whole body about 0.2 R (Table 6). The maximum yearly exposure for our lab may exceed 1 R for fingertip and whole body (Table 6).

The total yearly unavoidable exposure from all sources in our laboratory is about 11 R to the fingertips and about 1 R to the body. Maximum yearly exposure may exceed 170 R to the fingertips and may approach 2 R to the body when minimal precautions are taken (i.e., no syringe shields but Tc-99m vials are shielded) to minimize exposure.

It is assumed that all technologists are being rotated through all radiation-handling procedures to spread the exposure over the greatest number. The frequency of exposure listed in the tables is our patient volume divided by the number of technologists in rotation.

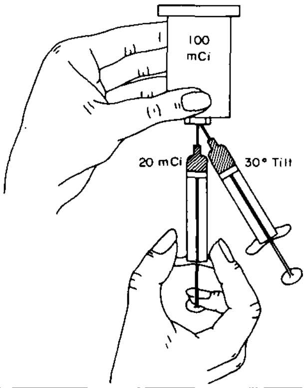
Most non-Tc-99m sources of exposure occur at roughly one-tenth the frequency of Tc-99m sources and involve about one-tenth the activity of Tc-99m sources. Thus, the expected exposure contribution of non-Tc-99m sources is roughly 1% the total Tc-99m contribution. Lombardi et al. (*4*) determined the non-Tc-99m contribution to be 2.4% of total hand exposure. Therefore, our tables of exposure include better than 95% of total exposure a technologist in nuclear medicine might receive. Exposure resulting from the contamination of one's person during administration of I-131 therapy doses are excluded from the scope of this article and should be determined on an individual basis.

The film badge reports of our technologists average 1.8 R per year for ring badges and 1.3 R for whole body badges. We shall conservatively assume that fingertip exposures of our technologists range from equal to double the unavoidable yearly minimum of 11 R. This averages out to 16.5 R per technologist when every precaution is taken to minimize exposure. Thus, for our laboratory, the ring badge reports

TABLE 4. Exposure to Fingertips during Dose Preparation

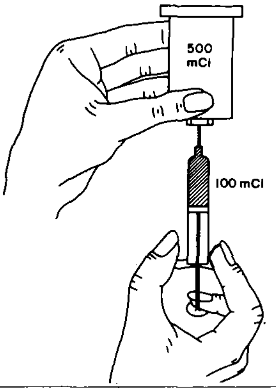
Yearly frequency and exposure time are based on our lab's average per technologist.

Case A: Exposure during patient dose preparation (20 mCi Tc-99m).
Calculations are based on:



	Dose volume (ml)	Syringe (cc)	Exposure rate mR/mCi-min	Yearly exposure (R)
1. *Withdrawal* of 20-mCi dose from shielded	0.8	3	0.5	2.0
100-mCi reagent vial, no syringe shield.	2.0	3	1.0	4.0
measurement of dose in dose calibrator,	0.8	5	0.50	2.0
change of hypodermic needle, and	2.0	5	0.68	2.7
transfer of dose to syringe shield.	0.8	10	0.26	1.0
2. Exposure time = 12 sec/preparation.	2.0	10	0.29	1.2
Frequency = 1,000 patient doses/year.				
Syringe held at flared end.				
3. Additional exposure to fingertips from			syringe held in vertical position	
shielded 100 mCi vial during dose withdrawal.			0.1	1.0
Exposure time = 6 sec/withdrawal.			syringe held at 30° from vertical	
Frequency = 1,000 withdrawals/year			0.05	0.5

Case B: Exposure during reagent dose preparation (100 mCi Tc-99m).
Calculations are based on:



	Dose volume (ml)	Syringe (cc)	Exposure rate mR/mCi-min	Yearly exposure (R)
1. *Withdrawal* of 100-mCi dose for reagent				
vial from shielded 500-mCi eluate vial.	3.0	3	5.5	55.0
Measurement of dose in dose calibrator.	3.0	5	1.0	10.0
Transfer of dose into appropriate shielded	3.0	10	0.34	3.4
reagent vial.	(if syringe shield used during withdrawal)			
2. Exposure time = 12 sec/preparation.	3.0	3	4.8	48.0
Frequency = 500 reagent doses/year.	3.0	5	0.7	7.0
Syringe held at flared end.	3.0	10	0.15	1.5
3. Additional exposure to fingertips from the shielded 500-mCi eluate during dose withdrawal	without syringe shield		0.1	2.5
Exposure time = 12 sec/preparation	with syringe shield		0.05	1.3
Frequency = 500 withdrawals/year				

Case C: Exposure to thumb of opposite hand when reagent vials are not held secure in their shields while inverted.

	Dose volume (ml)	Syringe (cc)	Exposure rate mR/mCi-min	Yearly exposure (R)
Thumb must then support 100-mCi reagent vial when inverted during dose withdrawal. Exposure time = 6 sec/withdrawal. Frequency = 1,000 withdrawals/year.			5.6	56.0*

*Exposure to opposite hand should not be added to other listed exposures, which occur to primary hand.

must be multiplied by about nine for an approximation of actual fingertip exposure. Our value of nine is in fair agreement with Burr et al. (*1*) who mathematically estimate the fingertip exposure to be 6.7 times the ring badge reports when the ring is worn on the palm side of the finger. Actual whole body badge readings of our technologists (average 1.3 R per year) agree well with our calculated unavoidable yearly exposure of 1 R.

Supporting Data

A technologist receives the bulk of his exposure from syringes of high activity Tc-99m. Knowledge of exposure found at the surface of a syringe is helpful in determining the exposure received by the fingertips during handling of radioactive syringes. The exposure E to external point A from a cylindrical source (Fig. 1) can be calculated from this expression (*5*):

$$E = 4\pi\Gamma\theta = 4\pi\Gamma\frac{Svr}{2\pi} G(k, p, \mu_s r, b_1) =$$

$$2\Gamma r\,[\underbrace{SvG(k, p, \mu_s r, b_1)}_{\text{upper cylinder } h} + \underbrace{S'vG'(k', p', \mu_s r, b_1)}_{\text{lower cylinder } h'}].$$

$$E = 2\Gamma r\,(SvG + S'vG') = 2\Gamma r \left[\frac{\frac{hN}{H}}{\pi r^2 h} G + \frac{\frac{h'N}{H}}{\pi r^2 h'} G' \right] R/hr$$

$$= \frac{2\Gamma N}{\pi r H} [G + G']\ R/hr.$$

$$E/N = \text{exposure/mCi} = \frac{2\Gamma}{\pi r H} [G + G']\ R/mCi\text{-}hr.$$

upper cylinder h, lower cylinder h′

$$E/N = \frac{5.94}{r^2} \left[\frac{G + G'}{k + k'}\right] mR/mCi\text{-}hr \text{ for Tc-99m.} \quad (1)$$

Where $G(k, p, \mu_s r, b_1)$ is tabulated by Goussev et al. (*5*) and defined as the attenuation function encompassing source geometry k, distance p, self absorption $\mu_s r$, and shield attenuation b_1.

Γ is the specific gamma ray constant $= 0.56 \frac{R}{mCi\text{-}hr}$ at 1 cm for Tc-99m (*6*)
r is the inner radius of the syringe and the radius of the source.
θ is the uncollided flux of gamma rays through point A from both cylinders $= \frac{r}{2\pi}(S_vG + S'_vG')$.

S_v is the activity per unit volume $= \frac{N}{\pi r^2 h} =$ mCi/cc.

N is the total activity in mCi in both cylinders $= \frac{hN}{H} + \frac{h'N}{H}$.

H is the height of the activity = h + h′ of both cylinders in cm.

For upper cylinder (h) $k = \frac{h}{r}$ for calculation of G from Table 2.

For lower cylinder (h′) $k' = \frac{h'}{r}$ for calculation of G′ from Table 2.

Example: 20-mCi Tc-99m in 2 ml in a 3-cc syringe held at mid-dose. From Table 1, we have r = 0.44 cm and p = 1.23. At mid-dose there is contribution from two cylinders (Fig. 1).
Upper cylinder = 1 ml; thus $k \approx 3.75$ (3.75×0.27 ml ≈ 1 ml). (0.27 ml is associated with $k = 1$ in Table 1.)
Then G from Table 2 ≈ 1.78.
Lower cylinder = 1 ml; thus $k' \approx 3.75$.
Then G′ from Table 2 ≈ 1.78.

$$\text{Exposure/mCi} = \frac{5.94}{r^2}\left[\frac{G + G'}{k + k'}\right] mR/mCi\text{-}min =$$

$$\frac{5.94}{0.4^2}\left[\frac{1.78 + 1.78}{3.75 + 3.75}\right] = 14.6 mR/mCi\text{-}min.$$

Hereafter for this article, "dose" refers to the radioactive cylindrical syringe volume source of Tc-99m as used in the following: 20-mCi dose, dose withdrawal, mid-dose, dose volume, etc.

When syringes are held at the flared end of the syringe creating a distance between source and fingertips (Fig. 2), we then use the expression:

$$E = 4\pi\Gamma\theta - 4\pi\Gamma \frac{Svr}{2\pi} G(k, p, \mu_s r, b_1) =$$

Both Cylinders H, Lower Cylinder h′

$$2\Gamma r\,[SvG(k, p, \mu_s r, b_1) - S'_vG'(k', p', \mu_s r, b_1)].$$

$$E = 2\Gamma r(S_vG - S'_vG')$$

$$= 2\Gamma r \left[\frac{\frac{HN}{h}}{\pi r^2 H} G - \frac{\frac{h'N}{h}}{\pi r^2 h'} G' \right] R/hr = \frac{2\Gamma N}{\pi r h}[G - G']\text{-}R/hr.$$

Both Cylinders (H), Lower Cylinder (h′)

$$E/N = \text{exposure/mCi} = \frac{2\Gamma}{\pi r h} [G - G']\ R/mCi\text{-}hr = \frac{5.94}{r^2}\left[\frac{G - G'}{K - k'}\right] mR/mCi\text{-}min \quad (2)$$

Fingertip at flared end will be defined as fingertip located at last volume mark on syringe.
N now is total activity in mCi of upper cylinder $= \frac{HN}{h} - \frac{h'N}{h}$ (both-lower)

For both cylinders $K = \frac{H}{r}$ for calculation of G from Table 2.

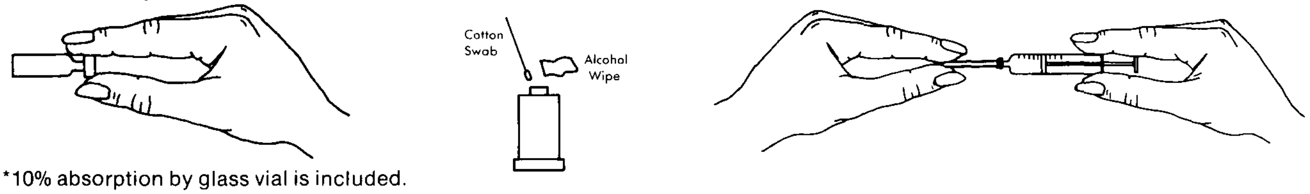
For lower (space) cylinder $k' = \frac{h'}{r}$ for calculation of G′ from Table 2.

Example: 20-mCi Tc-99m in 2 ml, in a 3-cc syringe held at flared end. Fingertip at flared end will have a location defined as the last volume mark on the syringe. Thus for a 3-cc syringe fingertip at flared end is located at the 3-cc mark.
r = 0.44 cm and p = 1.23 (Table 1) and N = 20 mCi.
From Figure 2 we have for both cylinders K = 11 ($11 \times .27$ ml ≈ 3 ml mark); thus G from Table 2 = 2.0052
From Figure 2 we have for lower cylinder $k' = 3.75$ (3.75

TABLE 5. Other Sources of Exposure to the Fingertips from Adjusted Table of G(k,p,0,0) Values

Yearly frequency and exposure time are based on our lab's average per technologist.	Source	Frequency per year	Exposure time (sec)	Exposure rate (mR/mCi-min)	Yearly exposure (R)
Case A: Exposure while handling Xe-133 vial by hand					
—during transfer of vial from dose calibrator to shield	20 mCi	500	2	8.0*	2.6
—during transmission lung trace for patient positioning	20 mCi	500	6	8.0*	8.0
Case B: Exposure during asceptic wiping of Tc-99m vials.					
—when using 6 in. cotton swab dipped in alcohol on eluate vial	500 mCi	500	1	0.04	0.17
—when using alcohol wipe on the eluate vial	500 mCi	500	1	0.33	1.4
—when using 6 in. cotton swab dipped in alcohol on reagent vial	100 mCi	1,000	1	0.04	0.07
—when using an alcohol wipe on the reagent vial	100 mCi	1,000	1	0.33	0.55
Case C: Exposure during changing of hypodermic needle after drawing up a 20 mCi Tc-99m dose (no shield).					
—exposure due to 50μCi average needle activity present	50μ Ci	1,000	2	12.0	0.02†
—exposure due to 2 mCi in needle hub that results when syringe overfill is expelled into hub prior to needle change	2 mCi	500	2	90.0	3.0†
—exposure from the 20 mCi Tc-99m present in the syringe	20 mCi	1,000	2	0.8	0.5†
—exposure to hand holding the 20 mCi syringe during the needle change (use 2 ml in 5-cc syringe average)	20 mCi	1,000	4	0.7	0.9

Case A: Case B: Case C:



*10% absorption by glass vial is included.
†exposure to opposite hand should not be added to other listed exposures.

$\times$ 0.27 ml $\approx$ 1 ml); thus G′ from Table 2 = 1.78

Thus both cylinders minus lower cylinder = 2 ml upper cylinder = Tc-99m.

$$\text{Exposure/mCi} = \frac{5.94}{r^2}\left[\frac{G - G'}{K - k'}\right] = \frac{5.94}{(0.44)^2}\left[\frac{2.0052 - 1.78}{11 \quad - 3.75}\right] = 1.0\ \text{mR/mCi-min.}$$

It was necessary to extrapolate from the G(k, p, μ_sr, b_1) values tabulated by Goussev (*5*) additional G(k, p, μ_sr, b_1) values. These values correspond to sources contained in syringes; namely p = 1.14, 1.17, 1.23, and 1.43 for 10-, 5-, 3-, and 1-cc syringes, respectively, and k = ½ to 25 for small to large volume sources within the syringe. The extrapolated G values are tested by inverse square law for distant points and by published data for local points of exposure on a syringe. The G values are altered and smoothed for best fit so that the final G values (Table 2) fit all published exposure rates and the inverse square law, and still conform to previously cited G values (*5*). For Tc-99m syringe sources, self-absorption μ_sr and the shield factor are negligible and will be given zero value. Thus G(k, p, μ_sr, b_1) becomes G(k, p, 0, 0). Table 2 lists the adjusted G(k, p, 0, 0), as determined by our lab, which will yield exposure rates from a syringe when used with equations 1 and 2. The exposure rates, seen in Tables 3, 4, and 5 are derived from the G values of Table 2.

We shall regard Xe-133 vials as having self-absorption μ_sr and shield factor b_1 equal to zero in order to use the values in Table 2. However, all final Xe-133 vial exposures listed (Table 5) have been reduced 10%. Measurements were taken of Xe-133 vials through glass cylinders of thickness similar to Xe-133 vials. Results show that 10% is an excellent approximation for absorption by the Xe-133 vial's glass wall.

Various exposure rates from sources that are encountered during a typical workday were determined and listed in Tables 3, 4 and 5. Table 6 includes other sources whose exposure rates were found by survey meter or other calculation. Estimates were made for exposure time and frequency. Estimated yearly exposure to the fingertips and whole body was then found and is included in Tables 3 through 6. The net effect of syringe shields and different dose handling techniques is made evident in these tables. Each lab may tabulate its own yearly exposure by substituting its yearly frequency and exposure times into the tables as appropriate.

TABLE 6. Sources of Exposure Determined by Meter or Estimation other than Table of G(k,p,0,0.)

Yearly frequency and exposure time are based on our lab's average per technologist.	Source	Frequency per year	Exposure time	Exposure rate mR/hr	Yearly exposure (R)
Case A: Exposure from patients injected with 20-mCi Tc-99m					
—to fingertips during patient positioning (at torso)	20 mCi	1,000	1 min	20*	0.4
—to whole body and fingertips due to the proximity of a 20-mCi Tc-99m patient (3-ft distance)	20 mCi	1,000	10 min	1*	0.2
Case B: Exposure from 1 μCi Tc-99m contamination on skin —the calculated beta-like surface dose to active skin layer is given (7)	1 Ci	1 per	until	not	5†
Case C: Exposure to fingertips from top of a Tc-99m generator during placement and removal of saline and vacuum vials (1,600 mCi present in generator)	1,600 mCi	250	10 sec	80*	0.06
Case D: Exposure to whole body and fingertips from transfer and set-up of a 500 mCi Tc-99m generator = 2,400 mCi day of arrival.					
—while maintaining a 6 in. minimum distance	2,400 mCi	25	15 sec	30*	0.003
—while in actual contact with generator	2,400 mCi	25	5 sec	300*	0.01
Case E: Whole body estimated exposure for 10 mCi Xe-133 accidental gas escape into room from patient while at a distance of 3 ft from patient)	10 mCi	10	2 min then diluted	3*	0.001
Case F: Additional exposure to whole body when dose preparations of Table 4 are not carried out from behind suitable counter top shield and without use of syringe shields.	20 mCi doses	1,000	12 sec	30*	0.1
	100 mCi	500	12 sec	150*	0.25

*by survey meter.
†not cumulative since it is unlikely that same area will be exposed.

A few points on the tables were compared to measured published values as a spot check of the accuracy of the tables. LiF-Teflon measurements (*7*) list the exposure rate for 10-mCi Tc-99m in a 10-cc syringe at 12 mR/mCi-min on the surface for a 3-ml volume; TLD measurements (*2*) report the exposure rate for 10-mCi Tc-99m in a standard hypodermic syringe at 11.4 mR/mCi-min at the surface. The values obtained from Table 3 for 10-mCi Tc-99m in a 3-ml volume are 14.7 mR/mCi-min at the surface of a 10-cc syringe and 13.8 mR/mCi-min at the surface of a 5-cc syringe (standard syringe). Our table values are slightly higher than the measured values. Husak (*8*) has calculated the exposure rate from 10-mCi Tc-99m in a 2-cc syringe at 13 mR/mCi-min and in a 10-cc syringe at 4.6 mR/mCi-min. These values are comparable to the Table 3 value of 14.6 mR/mCi-min for 10 mCi in 2 ml in a 3-cc syringe and 6.2 mR/mCi-min for 10 mCi in 10 ml in a 10-cc syringe. Our calculated values are slightly higher than Husak's. Henson (*9*) has determined by computer program the exposure rate from 10-mCi Tc-99m in 1 ml in a 2-cc syringe to be 40 mR/mCi-min at the surface. Table 3 yields a value of 27.4 mR/mCi-min for 10 mCi in 0.8 ml in a 3-cc syringe. Henson (*9*) has listed the exposure rate from 10-mCi Tc-99m in 1 ml in a 5-cc syringe at 35 mR/mCi-min at the surface. From Table 3 we obtain an exposure rate of 24.4 mR/mCi-min for 10 mCi in 0.8 ml in a 5-cc syringe. Our calculated values are substantially lower than those of Henson (*9*).

The exposure rate from small volume sources at a significant distance can be estimated by inverse square law and used to check the accuracy of the tables. By inverse square law, the exposure rate from 10-mCi Tc-99m in 0.8 ml in a 3-cc syringe is 0.58 mR/mCi-min when held at the flared end. Table 3 concurs with a value of 0.50 mR/mCi-min. The exposure rate from 10-mCi Tc-99m in 0.8 ml in a 10-cc syringe when held at the flared end is 0.28 mR/mCi-min by inverse square law. Table 3 is in good agreement with a value of 0.26 mR/mCi-min.

Summary

Exposure to a technologist's hands may substantially exceed the MPD set by the National Council on Radiation Protection of 75 rems to the hands in one year (*10*). With respect to minimizing exposure to technologists, we conclude:

1. Hold syringes at the flared end whenever possible.
2. Use larger syringes whenever possible and avoid filling syringes more than half full.
3. Use syringe shields at all times if possible.

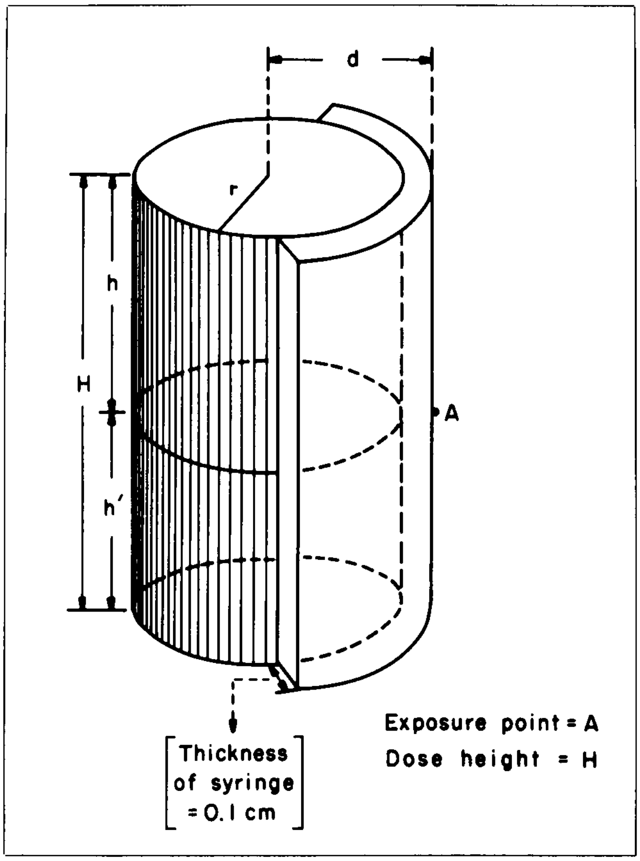


Fig. 1. Geometry for cylindrical volume source with exposure point A located laterally between base planes of source. Exposure to point A comes from activity contained in shaded cylinder, which is Tc-99m dose contained in lower cylinder (height h′) and upper cylinder (height h).

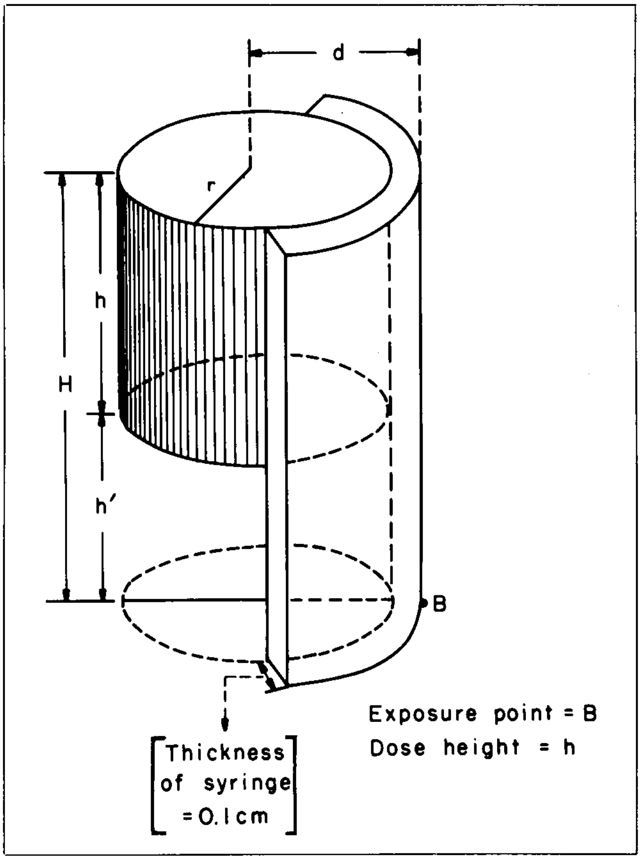


Fig. 2. Geometry for cylindrical volume source with exposure point B located laterally outside base plane of source. Exposure to point B comes from activity contained in shaded cylinder, which is Tc-99m dose contained in cylinder height h only.

4. Use lead containers that securely support vials when inverted for dose withdrawal.
5. Wear gloves and change them often.
6. Use tongs whenever transferring vials.
7. Do not expel excess activity of syringe into needle hub prior to needle change.
8. Rotate all personnel through all radiation handling procedures to spread out the exposure over the greatest number.

Ring badge reports should be multiplied by nine to obtain an approximate value for exposure at fingertips. Our yearly unavoidable exposure to fingertips is about 11 R and this occurs only if every precaution is taken to minimize exposure. The maximum yearly exposure to the fingertips may exceed 170 R when minimal precautions are taken to minimize exposure for the frequency and exposure times cited in our lab.

Acknowledgments

Special thanks to Linda Douglas for her help in preparing this article.

References

1. Burr JE, Berg R. Radiation dose to the hands from radiopharmaceuticals—preparation versus injection. *J Nucl Med Technol* 1977; 5: 158–60.

2. Neil CM. The question of radiation exposure to the hand from handling Tc99m. *J Nucl Med* 1969; 10: 732–34.

3. Howley JR, Green MV, Dickenson MB, et al. Radiation safety in nuclear medicine. *J Nucl Med Technol* 1974; 2: 65(A).

4. Lombardi MH, Beck WL, Cloutier RJ. Survey of radiopharmaceutical use and safety in sixty nine hospitals. DHEW Publication (FDA) 73-8029.

5. Blizzard EP, Foderraro A, Goussev NG, et al. Monography-extended radiation sources. *Engineering Compendium on Radiation Shielding*, Vol 1, Heidelberg, Springer-Verlag Berlin, 1968; 377, 398, 399.

6. Wagner HN. Physical data for a number of radioactive nuclides. In *Principles of Nuclear Medicine*, Philadelphia, W.B. Saunders, 1968; 864.

7. McEwan AC. Radiation doses in the handling of short-lived radionuclides. *Brit J Radiol* 1969; 42: 396.

8. Husak V. Exposure rate at the surface of syringes containing radioactive material. *J Nucl Med* 1971; 12: 574–75 (L).

9. Henson PW. Radiation dose to the skin in contact with unshielded syringes containing radioactive substances. *Brit J Radiol* 1973; 46: 972–77.

10. National Council on Radiation Protection and Measurements. 1971: Basic Radiation Protection Criteria *NCRP Report No. 39:* 91.