Personnel Exposure from Flood Phantoms and Point Sources During Quality Assurance Procedures

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Nuclear medicine technologists routinely use flood phantoms containing 5 to 10 mCi (185-370 MBq) of Tc-99m to perform quality assurance tests on scintillation cameras. This paper presents the results of a study that measured the radiation exposure received by three individuals from a Tc-99m flood phantom during the daily performance of flood-field uniformity tests on three scintillation cameras. The extrapolated annual personnel exposure to the anterior trunk and the back of the hand were 172 mR and 220 mR, respectively. Additional measurements indicate that personnel performing these tests with a 10-mCi Co-57 flood disk source or a 200-μCi point source would receive approximately 25% and 1%, respectively, of the exposure from a 10-mCi Tc-99m flood phantom. These exposure levels should be considered when evaluating personnel radiation exposure in a nuclear medicine clinic.

J Nucl Med 24: 629–632, 1983

Daily quality assurance testing of scintillation cameras is required in many nuclear medicine clinics (*1*). These tests often include extrinsic uncorrected and, when applicable, corrected flood fields to check the uniformity response of the cameras. More extensive testing (spatial resolution, linearity, etc.) is performed less frequently. These extrinsic camera measurements are performed with a flood phantom containing between 5 and 10 mCi of Tc-99m or a Co-57 flood disk source, although a low-activity point source of Tc-99m can also be used for intrinsic measurements.

Several articles have appeared in the literature concerning radiation exposure to nuclear medicine personnel from generator handling and elution, radiopharmaceutical preparation, transportation and administration of the dose to the patient, and total annual radiation exposure (*2–5*). However, no data are available concerning personnel exposure during quality assurance testing. This article presents the results of a study measuring the radiation exposure received by nuclear medicine personnel from a Tc-99m flood phantom, a Co-57 disk source, and a Tc-99m "point" source during daily quality assurance testing of three scintillation cameras.

MATERIALS AND METHODS

The study used two digital pocket dosimeters* equipped with small, remote Geiger-Mueller tubes calibrated at Cs-137 energy. The dosimetry system was calibrated for Tc-99m energy by measuring the exposure at various distances from several different point and vial sources of Tc-99m to obtain a correction factor between the actual dosimeter reading and the expected dosimeter reading as calculated from the specific exposure rate constant (*6*). The dosimeters, designated "A" and "B", were found to have correction factors of 0.30 and 0.38 expected mR per measured mR, respectively. These correction factors agreed well with those calculated and measured using a Co-57 standard (122 keV). The factors reduced the dosimeter readings to correct for the increased efficiency of the Geiger-Mueller tubes at the 140-keV Tc-99m energy compared with the 662-keV calibration energy of Cs-137. The dosimeters demonstrated no saturation when checked with activity levels three times those encountered in the clinical study.

Two nuclear medicine technologists, who were performing the quality assurance tests on our clinic's three scintillation cameras, were provided with the dosimeters and instructed as to their proper use. Additional data were collected by a physicist who also performed quality assurance tests on the same cameras.

Dosimeter A (with the smaller correction factor) was worn waist-high on the anterior body trunk, and dosimeter B was attached to the back of the hand. The technologists were supplied a data sheet and requested to record the following information: date, name, flood-phantom activity, estimated time in close proximity to the phantom, estimated total quality assurance test time, and dosimeter readings for the trunk and hand. The flood-phantom activity was determined by having the technologists measure and record the count rate obtained when the flood phantom was centered on a mobile scintillation camera and then normalizing this value to a count rate obtained on the same camera

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Received Sept. 24, 1983; revision accepted Feb. 28, 1983.

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for an accurately predetermined phantom activity.

Dosimeters A and B were also used to measure the exposure profile in air of the Tc-99m flood phantom to ascertain the decrease in exposure with distance from the phantom surface. The Plexiglas flood phantom was of standard design with an exterior frame size of 45.7 × 45.7 × 2.5 cm and a diameter of 43.2 cm for the active disk. The palmar hand exposure was estimated from the back-of-the-hand exposure by simulating the hand with a 2.5-cm-thick slab of Plexiglas. A ratio was calculated using the exposure at the edge of the phantom with a slab behind the detector for backscatter, and the exposure at the radiation exit surface of the slab.

Measurements were also performed to estimate the exposure to personnel when running quality assurance tests with a Co-57 flood disk source or a Tc-99m point source. The Co-57 activity was 3.2 mCi ± 10%, uniformly contained in an active diameter of 47 cm with thickness 3.8 mm.† An exposure profile in air for the Co-57 flood disk source was measured and compared with that obtained from the Tc-99m flood phantom. Simulated quality assurance tests with a high-activity Tc-99m point source were performed and the personnel exposure expressed in mR/mCi. These tests were performed using appropriate time and distance parameters established for quality assurance tests using normal activity. High-activity point sources were needed to provide for adequate detector response; normal activities were 100–200 μCi.

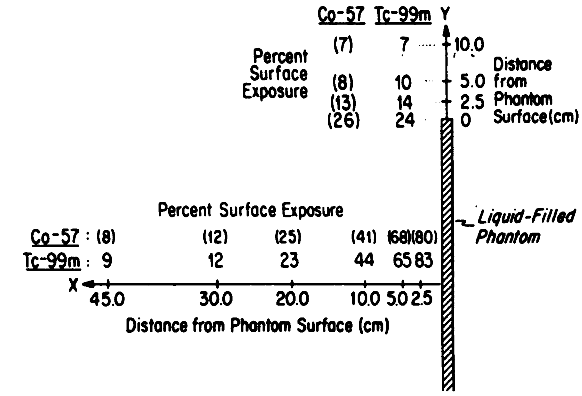

FIG. 1. Percent exposure normalized to values measured on central axis at 5 mm from surface of flood phantom filled with Tc-99m and, in parentheses, for a Co-57 flood phantom. Measurements were made with digital pocket dosimeter‡ equipped with small remote Geiger tube.

RESULTS

Table 1 presents the results for the two technologists and the physicist when using the Tc-99m flood phantom. The average measured daily exposure to the anterior trunk at waist height was 0.7 mR, and to the back of the hand 0.9 mR. The average background exposure in the laboratory during the course of this study was 0.07 mR/hr which, since the average preparation time for the phantom in the hot lab was 5 min, represents an insignificant contribution to the personnel exposure. The exposure profiles in air for the Tc-99m flood phantom and the Co-57 flood disk source are shown in Fig. 1. The values are all normalized to the exposure at 5 mm from the phantom or disk surface on the x-axis. The exposure at the normalization point was 0.12 ± 0.004 mR/mCi-min for the Tc-99m flood phantom and 0.14 ± 0.005 mR/mCi-min for the Co-57 flood disk source. The higher surface exposure for the Co-57 source is probably because the active volume is closer to the surface of the phantom. Both the flood phantom and disk source showed approximately the same decrease in exposure with distance. Measurements with 2.5 cm of Plexiglas to simulate the hand indicated that the palmar hand exposure during handling of the Tc-99m flood phantom at the midpoint of one edge is approximately twice the exposure to the back of the hand. The factor of two difference in the exposure results from attenuation by the tissue of the hand, a decrease in the exposure level at 2.5 cm distance, and backscatter toward the palm. These measurements assume that the individual handling the phantom is holding it at the middle of one edge, which is approximately 1 cm from the active volume. The corner of the square frame enclosing the circular active volume is 4 cm from the active volume, and the exposure level at the corner is 10% of that at the midpoint of an edge on the frame.

DISCUSSION

There was no apparent simple correlation between the technologists' hand and body exposures and the three clinical variables: flood-phantom activity, time in close proximity, or total test time. The average values for these three quantities were approximately 10 mCi, 12 min, and 35 min, respectively. The times, however, were only estimated by the technologists. The difference in average anterior trunk exposure between individuals is probably because technologist DB removed the air from the phantom (to make the sides flat) during mixing by compressing the phantom on a counter top at waist height, whereas technologist KG compressed the phantom against the wall at knee height. The physicist, RL, compressed the phantom much as DB did. The physicist used a stopwatch and recorded separately the times and exposures during the various phases of his using the flood phantom. These more precise recording procedures clearly demonstrated that 70% of the anterior trunk exposure and 80% of the exposure to the back of the hand were received during the preparation of the flood phantom—i.e., the filling and mixing phase. The remaining 30% and 20%, respectively, were received during the transportation of the phantom and its placement on the scintillation camera.

More extensive quality tests, i.e., resolution and linearity, were performed on four of the dates listed in Table 1, but no increased average personnel exposure was evident. This is because most of the personnel exposure is received during the filling, mixing, and transportation of the flood phantom, procedures that remain constant whether simple uniformity checks or more extensive tests are performed. The in-air exposure profile shows that in the x direction the exposure falls to 9% of the surface exposure at 45 cm distance and in the y direction to 7% at a distance of 10 cm. The profile clearly demonstrates that the greatest personnel exposure will be received in the handling of the phantom, and only minimal exposure will result from the technologist's presence in the camera room during these tests.

The accuracy of the dosimeters at Tc-99m energy is estimated to be within ±25%. This was determined using the propagation of error principle and assuming a dosimeter accuracy of ±15% (manufacturer's specification) and an energy response of ±20% over the energy range of interest. In calibrating the detectors with point and vial sources of Tc-99m, the exposure rate constant (which includes gamma rays, characteristic x rays, and internal bremsstrahlung) with a lower energy limit of 11.3 keV was used instead of the specific gamma-ray constant (which includes only gamma emissions). This was done because the exposure rate constant best describes the expected exposure rate from extended sources (*4,5*). The respective values for the specific gamma-ray constant and the exposure rate constant used in this study are 0.55 and 0.72 R-cm^2/hr-mCi. Corrections were not applied to the clinical data for absorption of low-energy photons in the flood phantom, and the estimated error was included in the ±20% energy response.

TABLE 1. CLINICAL STUDY VALUES

Tech	Flood phantom activity (mCi)	Minutes in close proximity	Total minutes of QA tests	Exposure (mR) trunk	Exposure (mR) hand
DB	9.3	13	30	0.9	—
DB	10.0	12	30	0.9	0.7
DB	10.0	12	30	0.7	1.4
DB	10.0	10	25	0.7	0.8
DB	10.4	10	35*	0.7	0.8
DB	9.5	10	30	0.9	0.8
DB	9.3	15	30	0.9	1.2
DB	8.9	10	30	0.9	0.8
DB	7.8	10	45	0.9	0.8
KG	10.2	15	50	0.3	0.8
KG	12.1	10	30	0.7	1.2
KG	11.0	20	55*	0.7	0.8
KG	10.0	10	25	0.3	0.8
KG	10.5	10	30	0.7	0.8
KG	8.6	10	50*	0.3	1.2
RL	10.4	9.5	24.5	0.9	0.8
RL	10.1	12.0	39.0*	1.1	1.2
RL	11.2	9.0	24.0	0.9	1.2
RL	9.8	9.5	25.0	0.7	0.8

* Represents days on which more extensive quality assurance tests, i.e., linearity and resolution, were performed. Corrected and uncorrected flood fields were performed on all other days.

Scintillation camera flood-field images can also be obtained using a Tc-99m point source of considerably lower activity (e.g., 200 μCi) compared with the flood phantom. Personnel exposure using a Tc-99m point source to perform the same procedures on the three cameras as performed with the Tc-99m flood phantom were found to be 0.02 mR for the anterior trunk and 0.08 mR for the back of the hand, each per mCi of point-source activity. The point source was prepared behind a lead-lined drawing station and, after assay in the dose calibrator, was transported through the clinic in a shielded syringe holder. Given these safety procedures, approximately 80% of the technologist's exposure will be received in drawing up and assaying the point source. The personnel exposure from performing the quality assurance tests with a point source of 100–200 μCi of Tc-99m is ~1–2% of the exposure from using a 10 mCi Tc-99m flood phantom.

Performing the quality assurance test with a Co-57 flood disk source will also result in lower personnel exposure. The Co-57 disk source has a slightly higher surface exposure per mCi than the Tc-99m flood phantom, but approximately the same decrease in exposure with distance (see Fig. 1). The Co-57 source, however, does not require any preparation before use, and can be removed directly from its shielded storage case and placed on the camera. This also removes the potential for contamination by accidents or leaks. Since approximately 70 to 80% of the technologist's exposure when using a Tc-99m flood phantom results from the phantom preparation, the use of the Co-57 flood disk source should reduce a technologist's exposure to about 25% of that received from a Tc-99m flood phantom of equal activity. The measured personnel exposure during quality assurance testing with the Co-57 flood phantom (3.2 mCi) was 0.10 mR for the back of the hand and 0.06 mR for the anterior trunk. Table 2 summarizes the relationships.

There are several problems, however, associated with the Co-57 flood disk source. The principal disadvantage is its high cost and limited useful life ($T_{1/2}$ = 270 days). The Co-57 will also be contaminated with high-energy impurities such as Co-56 and Co-58. This requires that the disk source be stored for several months after manufacture to allow these contaminants to decay to an acceptable level. In addition, the 122-keV photons of Co-57 produce an image with slightly degraded spatial resolution, for statistical reasons, when compared with the 140-keV photons of Tc-99m (*7*). Finally, the Co-57 disk source's thin construction does not provide sufficient scatter material to simulate a clinical situation (*8*).

There are also numerous problems associated with using a Tc-99m point source for performance testing. Point-source measurements are of the intrinsic flood field (i.e., without the collimator), and furnish no information about the collimated system. In addition, the intrinsic measurements necessitate removing the collimator and attaching a mask to the crystal, which requires additional technologist's time. Studies have also shown that the extrinsic flood field provides a more clinically representative flood field (*8,9*) for cameras that incorporate uniformity correction circuitry. In general we prefer the Tc-99m flood phantom for obtaining flood-field images, although its use results in higher personnel exposure. The Tc-99m flood phantom simulates most closely a clinical source, i.e., Tc-99m dispersed in a scatter medium.

The individual technologist's exposure from a Tc-99m flood phantom can be reduced by rotating the technologists involved in the test. The exposure profiles in Fig. 1 demonstrate the rapid reduction in exposure with distance, and technologists should limit both time and proximity in handling the flood phantoms. A vise could hold the phantom during filling, and it could be carried to the camera by the corners, or on a cart.

A comparison of the technologist exposure received during quality assurance testing with the total annual exposure is difficult because of the large variation in annual exposure received by technologists in different clinics. This variation is due to factors such as: number and types of procedures performed, type of equipment, technologist rotation schedules, use of shielding (i.e., around generators and syringes), established radiation safety procedures, etc. Anger (*5*) and Lis (*3*), however, have compiled annual whole-body and hand exposures to the nuclear medical technologists employed in their respective institutions. Anger reports for the year 1976 average annual whole-body and hand exposures of 792 mR and 4.6 mR, respectively. Lis estimates the unavoidable annual technologist's exposure from all sources for the year 1981 to be 1 R to the whole body and 11 R to the finger tips. These studies suggest that the described control testing with a Tc-99m flood phantom will add only a small fraction to a technologist's yearly exposure. Analogous controls using a Co-57 flood disk (10 mCi) or a Tc-99m small source (200 μCi) should not contribute anything significantly.

SUMMARY

The personal exposure to nuclear medicine technologists from a Tc-99m flood phantom, a Co-57 disk source, and a Tc-99m point source have been measured with an estimated accuracy of ±25%. The magnitude of the exposure from any of the three sources is not large enough to constitute a separate radiation health hazard. However, it does represent a source of personal exposure in the nuclear medicine clinic that has not previously been addressed in radiation safety publications. Based on this study, a technologist

TABLE 2. MEASURED RELATIVE PERSONNEL EXPOSURE FROM DIFFERENT QUALITY ASSURANCE RADIATION SOURCES

Source	Activity (mCi)	Daily exposure (mR)		Relative % exposure		Exposure per mCi	
		Trunk	Hand	Trunk	Hand	Trunk	Hand
Tc-99m Flood phantom	10.0	0.9	0.7	100	100	0.09	0.07
Co-57 Disk source	3.2	0.10	0.06	11.1	8.6	0.03	0.02
Tc-99m Point source	0.20	0.016	0.004	1.8	0.6	0.08	0.02

running daily quality assurance tests with a 10 mCi Tc-99m flood phantom on three scintillation cameras would receive an average monthly exposure of 14 mR to the anterior trunk, and 18 mR to the back of the hand. The magnitude of the technologist's exposure is essentially independent of the extent of the testing—i.e., simple flood uniformity or also tests of linearity and resolution—because 75 to 80% of the exposure is received during preparation of the phantom. Measurements indicate that the exposure to personnel performing these tests with a Co-57 flood disk source (10 mCi) or a 200-μCi Tc-99m point source would be approximately 25% and 1%, respectively, of the exposure from the Tc-99m flood phantom.

FOOTNOTES

* Technical Associates model PDR-1b digital pocket dosimeters.
† New England Nuclear model NES-392.
‡ Technical Associates Model PDR-1b.

ACKNOWLEDGMENTS

Author R.L.L. acknowledges the support provided to him by the United States Navy. The authors also acknowledge the support of the Veterans Administration.

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