Technologist Radiation Exposures from Nuclear Medicine Imaging Procedures

Ronald S. Sloboda, Matthew G. Schmid, and Cynthia P. Willis

Pasqua Hospital, Regina, Saskatchewan, Canada

Radiation exposures incurred by nuclear medicine technologists during diagnostic imaging and scintillation camera quality control were measured on a procedural basis over a 3-mo period using a portable, low range, self-reading ion chamber. A total of more than 400 measurements were made for 15 selected procedures. From these, mean procedural exposures and standard deviations were calculated. The results show that daily flood phantom quality control, at 0.58 mR, and gated cardiac studies, at 0.45 mR, were the two greatest sources of exposure. Other procedures resulted in exposures varying roughly from 0.10 to 0.20 mR. Difficult patients were responsible for doubling technologist exposure for many procedures. Standard deviations were large for all procedures, averaging 65% of the mean values. Comparison of technologist exposure inferred from procedural measurements with the time coincident collective dose equivalent recorded by the thermoluminescent dosimetry service of the Bureau of Radiation and Medical Devices, Department of Health and Welfare, Canada, indicates that approximately half of the collective technologist exposure arose from patient handling and camera flood quality control.

Occupational radiation exposures to nuclear medicine technologists originate from a number of sources, including generator elution, patient dose preparation and injection, and patient handling. Only recently has it been observed that in a large number of radionuclide imaging procedures, the whole body exposure from patient handling can account for 50% or more of the total procedural exposure, when appropriate precautions are taken during patient dose preparation, assay, and injection (*1–3*).

Our investigation was primarily concerned with measuring technologist exposures arising from patient handling, for 14 diagnostic nuclear medicine procedures. The procedures are listed in Table 1 along with the radiopharmaceutical and activity administered. For the purposes of this study, patient handling was considered to involve escorting the patient from the waiting to the imaging area, positioning the patient for the imaging or counting procedure, performing the procedure, and finally escorting the patient out of the imaging area. Except for the brain flow procedure, which requires that an injection be given after the patient has been positioned, exposures due to radiopharmaceutical preparation and administration were not included in the patient handling measurements.

In addition to patient studies, the daily scintillation camera quality control (QC) procedures were monitored. The exposures, involving flood phantom preparation and imaging, were also measured on a procedural basis.

TABLE 1. Diagnostic Procedures Monitored

Procedure	Radiopharmaceutical	Activity (mCi)
Brain flow	^{99m}Tc-glucoheptonate	20
Brain scan	^{99m}Tc-glucoheptonate	20
Brain tomography	^{99m}Tc-glucoheptonate	20
Cardiac wall motion (rest)	^{99m}Tc-pertechnetate	20
Gallium scan	^{67}Ga-citrate	4
Lung perfusion	^{99m}Tc-macroaggregated albumin	3
Liver scan	^{99m}Tc-sulfur colloid	5
Liver tomography	^{99m}Tc-sulfur colloid	5
Lung ventilation	^{133}Xe gas	10–20
Spot bone	^{99m}Tc-methylene diphosphonate	15
Myocardial perfusion	^{201}Tl-thallous chloride	2.2
Thyroid scan	^{131}I liquid	0.05
Thyroid uptake	^{131}I liquid	0.05
Whole body bone	^{99m}Tc-methylene diphosphonate	20
Flood phantom QC	^{99m}Tc-pertechnetate	5–8

MATERIALS AND METHODS

Instrumentation

All exposure measurements were made using the stray radiation dosimeter (STRAD) ion chamber* shown in figure 1. This battery-powered, portable, self-reading instrument possesses a range of 0–2 mR, with a factory calibrated accuracy of ±15% at 120 keV. According to the manufacturer, sensitivity is sufficient to measure 4× background. The cylindrical unit measures approximately 8.8 in in length by 3.0 in in diameter, weighs about a pound, and has a chamber volume of 21.5 in^3. The chamber is not sealed, necessitating temperature and pressure corrections to the readings. The variations in instrument response with elevation angle and incident photon energy are shown in figures 2 and 3, respectively. The angular response curve for 122 keV was mapped out using a cobalt-57 (^{57}Co) calibration source. The remaining information in these two figures was provided by the manufacturer. Three STRADs were used during the course of the investigation.

A ^{57}Co calibration source was used to determine STRAD

For reprints contact: Ronald S. Sloboda, PhD, Nuclear Medicine, Pasqua Hospital, 4101 Dewdney Avenue, Regina, Saskatchewan, Canada S4T 1A5.

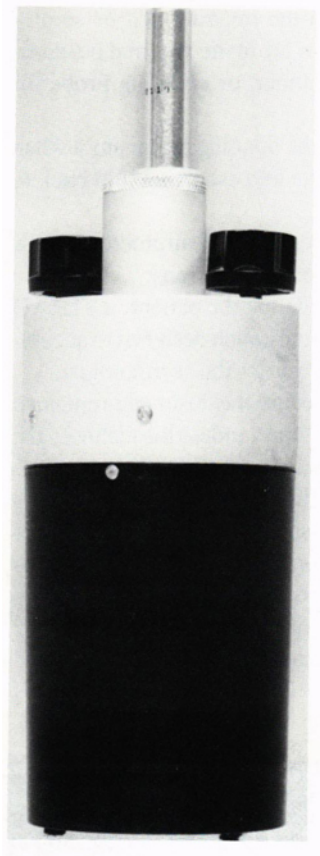

FIG. 1. Model 106 STRAD ion chamber. The unit is approximately 8.8 in. (22 cm) long.

calibration factors at bimonthly intervals and to perform daily QC checks of the instruments. The ^{57}Co principal gamma energy of 122 keV is close to both the STRAD factory calibration energy of 120 keV and the 140 keV gamma ray emitted by ^{99m}Tc, the most frequently used diagnostic radionuclide. For these measurements, source distances and measurement times were selected such that the readings would fall roughly at instrument mid-scale, i.e., near 1 mR.

The daily QC check of the dosimeters involved placing the calibration source and STRAD atop a 6-in thick styrofoam block at a distance of 10 cm, and taking a 3-min exposure reading. This was corrected for decay of the source and compared with previous readings. No temperature or pressure corrections were introduced, since the daily check involved an approximate reading only.

The STRADs were calibrated at approximately 2-wk intervals in order to determine appropriate correction factors to be applied to the exposure readings from each instrument. The calibration source and STRAD were placed atop a styrofoam block at a distance of 45 cm, center to center, and a reading was taken after 1 hr. The source was then removed, the instrument was zeroed, and a 1-hr background and leakage reading was taken. The source reading corrected for background, temperature, and pressure was determined as follows:

$$S_C = (S-B) \times \frac{760 \text{ mm Hg}}{P} \times \frac{T}{295°K},$$

where S_C = corrected source reading
S = raw source reading
B = raw background and leakage reading
P = atmospheric pressure in millimeters of mercury
T = ambient temperature in degrees Kelvin.

The expected source reading was calculated from the formula:

$$S_E = \frac{G \times A}{d^2} \times t$$

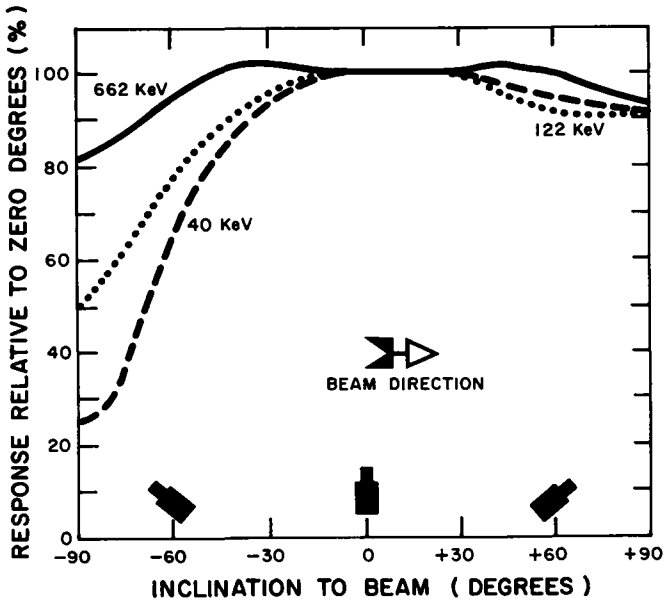

FIG. 2. Angular response of STRAD dosimeter.

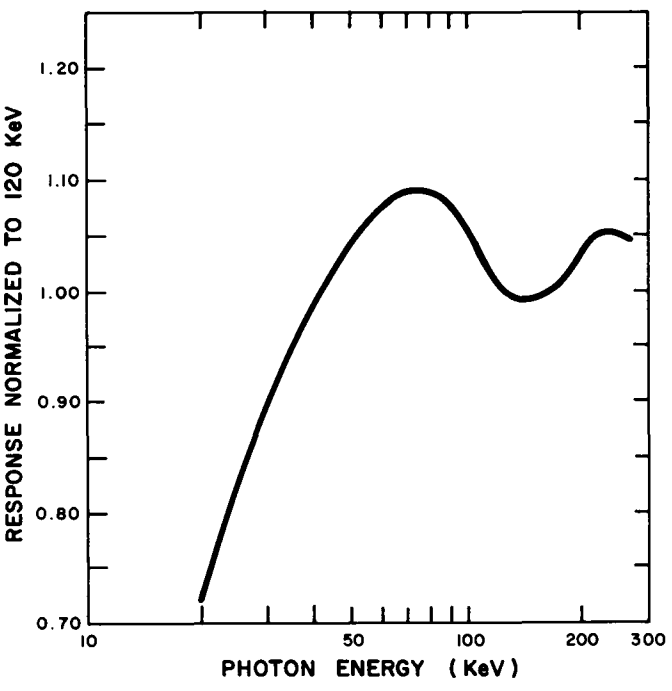

FIG. 3. Energy response of STRAD dosimeter.

where G = exposure rate constant in R cm^2 /hr • mCi
A = source activity in millicuries
d = STRAD to source distance, center to center, in centimeters
t = measurement time in hours.

For ^{57}Co, G = 0.93 R cm^2 /hr • mCi. The calibration factor then was calculated as:

$$C = S_E \times S_C^{-1}$$

Typical technologist procedural exposures as reported in the literature are in the 0.10–0.50 mR range (*1*), corresponding to the lower quarter of the STRAD scale. In order to determine the precision of the instrument and to ascertain its linearity within that range, an additional series of calibrations was performed on one of the STRAD units. Different combinations of source distances and measurement times were employed to generate exposure rates and readings similar to the mean procedural values observed clinically.

As evidenced by the entries in Table 1, the majority of the procedures monitored involve ^{99m}Tc, which emits a 140 keV gamma ray. Given the STRAD generic energy response curve in figure 3 and the fact that our routine calibration factors were obtained at 122 keV, it is evident that no additional energy correction factor is required for ^{99m}Tc. For the lung ventilation studies involving xenon-133 (^{133}Xe) with principal photon energies of 31 keV (39% abundance) and 81 keV (37% abundance), the energy correction is estimated to be only a few percent at most. For the myocardial perfusion studies involving thallium-201 (^{201}Tl) with principal photon energies of 69 and 71 keV, figure 3 indicates that an energy correction factor of 0.93 (1/1.08) is appropriate. For studies involving gallium-67 (^{67}Ga) or iodine-131 (^{131}I), both of which emit at least one photon having an energy above 240 keV, figure 3 is incomplete. For these radionuclides a one-time energy calibration was performed. Sources of ^{67}Ga and ^{131}I assayed in a dose calibrator to an accuracy of ±5% yielded energy correction factors of 1.02 and 1.11, respectively.

Three STRAD units, calibrated as described above, were used to measure individual technologist exposures. A pouch made of thin ripstop nylon sewn to the front of a bibbed apron, as shown in figure 4, was used to hold one of the STRADs in an upright position. The apron was worn by a technologist in such a manner that the center of the ion chamber approximately coincided with the bottom of the technologist's sternum. A drawstring at the top of the pouch secured the STRAD. Two such aprons were fabricated, thus enabling two procedures to be monitored concurrently.

Exposure Measurements

Patient handling. Eight technologists participated in gathering exposure data. As a general rule, the patient handling measurements for each of the procedures enumerated in Table 1 included the following actions on the part of the attending technologist:

1. Escorting the patient from the waiting area to the imaging room.
2. Assisting the patient onto the imaging bed or stool.
3. Assisting the patient to sit or lay in the required positions in front of the camera, scanner, or counting probe for each view.
4. Assisting the patient from the imaging bed or stool when the procedure was complete and escorting him back to the waiting area.

For each procedure monitored, the measurement process involved the following sequence of operations:

1. Prior to the technologist meeting the patient, a STRAD was zeroed and placed into the pouch designed to accommodate it on the apron worn by the technologist.
2. During the diagnostic procedure the dosimeter remained with the technologist at all times, unless the technologist was required to perform a task unrelated to the procedure (for instance helping to lift another patient from a stretcher). In this latter case the technologist first proceeded to a designated drop-off station, where the dosimeter remained for the duration of the unrelated activity, and later recovered the instrument before returning to the original patient. A drop-off station was assigned

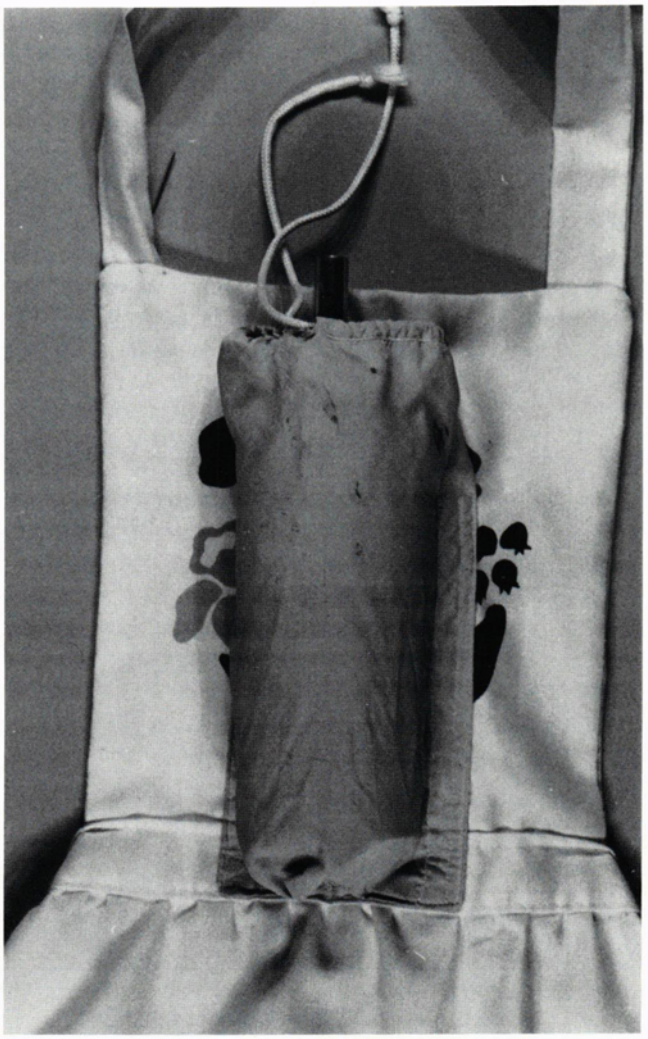

FIG. 4. Apron and pouch holder for STRAD.

for each diagnostic instrument. These sites, taking the form of desks or countertops, were locations from which the technologist would normally observe the patient when not otherwise engaged.

3. At the completion of the procedure, the dosimeter was recovered and read. The reading, along with certain ancillary information, was recorded on a data sheet. The additional information included the elapsed time, background reading, attending technologist, difficulty handling the patient, and other administrative data.

For the first procedures monitored, an individual half-hour background reading was acquired for each exposure measurement. However, it soon became apparent that background levels throughout the imaging area were very low, being consistent with the STRAD background and leakage readings obtained during instrument calibrations. The low levels are due to the large distances separating the individual imaging locations, and their collective removal from areas of radiopharmaceutical preparation and handling. Therefore subsequent background readings of 1 hr in duration were acquired once or twice daily as the patient workload permitted, enabling more time to be devoted to the exposure measurements themselves.

Patient handling difficulty was judged by the attending technologist on a scale of 1 to 5 with 1 = easy, 3 = average, and 5 = difficult. Before starting to collect clinical data, the technologists as a group were instructed to exercise their own judgment in assessing how much time they needed to spend close to the patient compared with the norm for that procedure, and to use that criterion to assign the handling difficulty. A total of 395 patient handling exposure measurements were made over a 3-mo period.

Flood phantom quality control. In the department monitored, scintillation camera image quality was checked on a daily basis by acquiring static images of flood phantoms. Two fillable phantoms were used: a large one for two large field of view cameras and another smaller one for a standard field of view camera. The phantoms were each filled daily with 5–8 mCi of ^{99m}Tc and water, agitated manually in order to mix the contents uniformly, and then positioned on the camera collimators for imaging.

The preparation of both phantoms as well as their imaging was included in the exposure measurement, as the preparation involved handling unshielded activity somewhat analogously to patient handling. A zeroed STRAD was placed in its pouch on an apron worn by the technologist before starting the quality control procedure, and recovered after the flood phantoms were placed in their lead-lined storage container at completion. The instrument reading and ancillary information were recorded for analysis. A total of 25 flood phantom QC procedures were monitored.

Data Analysis

Data for both the diagnostic and the flood phantom QC procedures were analyzed using a commercially available software package† that provided complete transcription, archival, analysis, and report generation capabilities (*4*).

Patient handling. In the first phase of analysis of the patient handling data, corrected exposure readings were calculated as:

$$R' = C_N \times C_E \times \left(\frac{760 \text{ mm Hg}}{P}\right) \times \left[R - \left(B \times \frac{Tr}{Tb}\right)\right]$$

where C_N = ^{57}Co calibration factor for STRAD number N
C_E = radionuclide-specific energy calibration factor
P = atmospheric pressure in millimeters mercury
R = exposure reading in milliroentgens
B = background reading in milliroentgens
Tr = length of time for exposure reading in minutes
Tb = length of time for background reading in minutes.

The energy calibration factor C_E is intended to compensate for variations in STRAD response at the different radionuclide photon energies. As shown earlier, this factor is unity to within a few percent for ^{99m}Tc, ^{133}Xe, and ^{67}Ga. As our exposure measurements are no more accurate than this, C_E can be set equal to 1.0 for these radionuclides. For ^{201}Tl and ^{131}I, this is not the case; energy correction factors of 0.93 for ^{201}Tl and 1.1 for ^{131}I were previously indicated to be appropriate. In reviewing the raw exposure data, however, the average readings for both ^{201}Tl and ^{131}I were observed to be very low, being about 0.05 mR for the thallium studies and 0.01 mR for the thyroid scans and uptakes. STRAD readings of this magnitude contain only one significant figure, hence corrections at the level of 10% or less can be ignored because they represent changes to which the instrument is insensitive. Therefore the energy calibration factor C_E was set equal to unity for all radionuclides dealt with in this study. No temperature correction was required as the climate-controlled department was maintained at a constant 22 °C.

The second phase of data analysis involved the extraction of statistical information from the corrected exposure readings plus ancillary data. In one set of calculations, the mean values and standard deviations of corrected exposure readings were obtained for each diagnostic procedure. Another set of calculations determined mean values and standard deviations of corrected exposure readings for normal and difficult patients separately, for each diagnostic procedure monitored. The normal patients were those for which the attending technologist recorded a 1, 2, or 3 for the positioning difficulty. The difficult patients were those receiving a score of 4 or 5. Also calculated were the corrected exposure reading mean values and standard deviations for each individual technologist, for each diagnostic procedure.

Flood phantom quality control. For the flood phantom QC measurements, corrected exposure readings were calculated as:

$$R' = C_N \times \frac{760 \text{ mm Hg}}{P} \times \left[R - \left(B_i \times \frac{T_i}{30 \text{ min}}\right) - \left(B_l \times \frac{T_l}{30 \text{ min}}\right)\right]$$

where C_N = ^{57}Co calibration factor for STRAD number N
P = atmospheric pressure in millimeters mercury
R = exposure reading in milliroentgens
B_i = 30-min imaging area background reading in milliroentgens
B_l = 30-min lab background reading in milliroentgens

T_i = measurement time spent in imaging area in minutes

T_l = measurement time spent in lab in minutes.

No temperature correction was required, as the department was maintained at 22°C. The mean flood phantom QC exposure and standard deviation were determined from the corrected readings.

RESULTS AND DISCUSSION

STRAD Performance

In general the three ion chambers displayed very good stability in response. For the daily QC checks, the standard deviations in decay-corrected readings expressed as percentages of the corresponding mean values were 3.4%, 5.0%, and 3.7% for the three STRAD units. The instrument calibration factors determined on a bimonthly basis exhibited similar stability, with no factor deviating from the mean value for that unit by more than 2%. Accordingly, average calibration factors for each STRAD were used to calculate corrected exposure readings.

The results of the measurements for simulated clinical exposure rates and measurement times are summarized in Table 2. For the exposure range 0.10–0.50 mR, where most of the clinical readings are expected to fall, instrument precision is at the level of 0.01 mR. Furthermore, variations in the instrument calibration factor with exposure, which reflect changes in instrument linearity, are confined to the ±5% level.

Although the ion chambers proved to be fairly reliable in service, two specific problems were encountered during the monitoring period. The first, involving excessive leakage in one of the units, was detected during daily STRAD QC. The difficulty was promptly remedied by baking out the unit at 50°C for 48 hr, as per the manufacturer's instructions. The second problem involved loss of the quartz fiber in the electrometer section of another unit, necessitating its return to the manufacturer for repair.

Exposure Measurements

The results of analyzing the patient handling exposure measurements are summarized in Tables 3 and 4, and in figure 5. Table 3 gives the mean exposure and standard deviation for each of the procedures listed in Table 1, along with the number of measurements and mean imaging time. It is immediately apparent that gamma camera QC and cardiac wall motion studies contribute the most to technologist exposure on a per procedure basis. For the cardiac wall motion studies the amount of activity used (20 mCi), in combination with the length of time that the technologist must spend close to the patient carefully positioning him for four sequential views, accounts for the exposure. The positioning time in this particular instance is partially determined by the instrumentation: the cardiac camera's motor-driven T stand makes camera head positioning a tedious operation compared with the counterbalanced heads of the other two cameras, which can be maneuvered manually. Except for the thyroid and myocardial perfusion studies, which result in low exposures due to the small amount of activity present, the remaining average procedural exposures fall roughly within the range 0.10–0.20 mR.

Also noteworthy are the relatively large standard deviations for all procedures, which vary from 33% of the mean value for cardiac wall motions to 109% for the lung perfusion studies. The standard deviation for the majority of procedures, however, is relatively constant at about 65% of the mean value. One might have expected a certain amount of variability *a priori* on the basis of differences in patient uptake of the radiopharmaceutical, patient cooperation, and individual technologist working habits. The results in Table 3 confirm that such variability is present to a considerable extent for all diagnostic procedures. Instrumental uncertainty is limited to approximately 10%, as indicated in Table 2, and thus contributes minimally to the observed standard deviations.

Of the 395 patient studies monitored, 49 (roughly 12%) were identified by the technologists as involving difficult patients according to the criterion outlined earlier. Table 4 contains the procedural mean values and standard deviations for both the average and difficult patient groups considered separately. For the brain flow, lung ventilation, and thallium studies, exposures in the difficult group did not differ significantly from those in the average group as gauged by Student's t-test. For other procedures involving difficult patients, however, higher exposures for the difficult group were confirmed as being significant at the 10% level for brain tomography and cardiac

TABLE 2. Precision and Linearity of STRAD Number 1*

Source distance (cm)	Measurement time (min)	Exposure rate (mR/hr)	Mean reading (mR)	Maximum deviation (mR)	Calibration factor
20	4	3.24	0.21	0.01	1.05
45	15	0.64	0.17	0.01	0.95
45	60	0.64	0.64	0.01	0.99†
70	30	0.26	0.13	0.01	1.01
70	60	0.26	0.26	0.01	0.98

*As gauged by maximum reading deviations and instrument calibration factors, respectively. Six readings were taken for each different combination of source distance and measurement time.

†Setup corresponding to the standard calibration protocol.

TABLE 3. Procedural Exposure Mean Values and Standard Deviations

Procedure	Number of studies	Mean exposure (mR)	Standard deviation (mR)	Mean time (min)
Brain flow	28	0.19	0.13	4
Brain scan	23	0.21	0.13	25
Brain tomography	11	0.16	0.11	51
Cardiac wall motion (rest)	33	0.45	0.15	43
Gallium scan	6	0.06	0.03	61
Lung perfusion	31	0.11	0.12	13
Liver scan	9	0.11	0.07	29
Liver tomography	30	0.09	0.06	32
Lung ventilation	29	0.13	0.08	16
Spot bone	28	0.11	0.11	31
Myocardial perfusion	30	0.04	0.04	32
Thyroid scan	28	0.01*	0.01	13
Thyroid uptake	25	0.01*	0.02	6
Whole body bone	84	0.15	0.11	51
Flood phantom QC	25	0.58	0.10	26

*Values consistent with zero.

TABLE 4. Procedural Exposure Mean Values and Standard Deviations for Average and Difficult Patients

Procedure	Patient positioning	Number of studies	Mean exposure (mR)	Standard deviation (mR)	Mean time (min)
Brain flow	Average	22	0.18	0.12	4
	Difficult	6	0.23	0.13	4
Brain scan*	Average	20	0.17	0.08	26
	Difficult	3	0.47	0.04	19
Brain tomography†	Average	8	0.13	0.08	50
	Difficult	3	0.25	0.15	54
Cardiac wall motion (rest)†	Average	30	0.44	0.13	43
	Difficult	3	0.59	0.22	48
Gallium scan*	Average	6	0.06	0.03	61
	Difficult	0	0.00	0.00	0
Lung perfusion*	Average	24	0.09	0.07	12
	Difficult	7	0.19	0.20	14
Liver scan*	Average	7	0.08	0.05	29
	Difficult	2	0.20	0.07	28
Liver tomography*	Average	27	0.08	0.03	29
	Difficult	3	0.18	0.16	58
Lung ventilation	Average	26	0.13	0.08	16
	Difficult	3	0.12	0.10	14
Spot bone*	Average	23	0.08	0.06	29
	Difficult	5	0.25	0.19	41
Myocardial perfusion	Average	28	0.04	0.05	32
	Difficult	2	0.01	0.01	27
Whole body bone*	Average	72	0.12	0.08	51
	Difficult	12	0.32	0.13	51

*Difference significant at the 5% level.
†Difference significant at the 10% level.

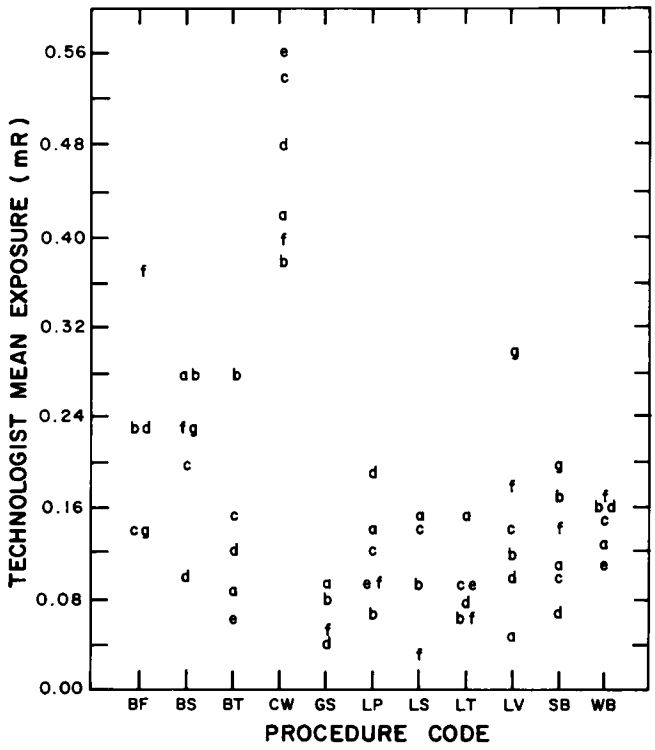

FIG. 5. Scatter plot of technologist mean exposure versus procedure. Technologists are coded a–h.

wall motion studies, and at the 5% level or better for all remaining studies. The increases ranged roughly from 30% to 200% and were not always reflected in the mean imaging times, the brain scan procedure being a good example of this. The lack of an increase in technologist exposures in the case of difficult lung ventilation patients may be understood in that the ^{133}Xe gas is only administered after the patient has been initially positioned; thus problems related to initial positioning and to acclimatizing the difficult patient to the breathing apparatus do not normally involve the technologist being exposed to radiation for greater lengths of time than for average patients. Similarly, for the brain flow studies, the radiopharmaceutical is administered only after the patient's head has been immobilized. The very low exposures for the thallium studies render an average vs. difficult comparison somewhat meaningless. For the majority of procedures, the standard deviation expressed as a percentage of mean value for the average patient group is nearly the same as for both groups considered together (Table 3). This implies that factors other than patient cooperation are largely responsible for the observed variability in technologist exposures.

Figure 5 illustrates the breakdown of technologist exposures by procedure and by individual technologist, for selected procedures. It can be observed that for the brain and lung imaging procedures, mean exposures are quite variable, whereas for the cardiac wall motion studies and whole body bone scans, they are much less so. Further examination of figure 5 reveals that no one technologist consistently received higher procedural exposures than the others.

The individual accuracy of the corrected exposure readings is estimated to be about 10% for readings of 0.15 mR or greater and about 20% for readings in the vicinity of 0.10 mR. At ^{99m}Tc energies, the STRAD calibration factor varies only ±5% for our clinical exposure rates and readings; however, the variation in response with inclination angle (Fig. 2) indicates that our diagnostic exposure measurements may be slight underestimates in some circumstances due to the presence of activity within an imaginary 40° cone emanating from the top of the instrument. The latter situation is thought to be very uncommon, however, and if present it usually exists for only a short time. Inaccuracies should hence be confined to the levels cited above. Furthermore, the anterior wearing of the STRADs will offset this latter bias to some extent as the instruments are nearly always positioned closer to the patient than the technologist, and thus encounter slightly higher radiation fields.

Comparison with Bureau of Radiation and Medical Devices Records

All of the nuclear medicine technologists who participated in the present study were classified as atomic radiation workers during the data collection period. The radiation dose equivalents they received were monitored on a quarterly basis by the thermoluminescent dosimetry service of the Bureau of Radiation and Medical Devices (BRMD), Department of Health and Welfare, Canada. The information contained in the BRMD report coinciding with our measurement period, combined with the mean procedural exposures measured and the numbers of each procedure performed, permit an estimate to be made of the fraction of collective technologist exposure attributable to patient handling and flood phantom quality control.

The BRMD collective dose equivalent for the eight participating technologists measured over the monitoring quarter is 480 mrem. As the external exposure involves gamma photons exclusively, the corresponding exposure estimate is 480 mR. The collective technologist exposure due to patient handling is estimated by multiplying mean procedural exposures by the number of procedures performed during the BRMD recording period, and then summing the results.

The actual situation was slightly more complicated because the technologists were also employed on a rotating basis in a second single-camera nuclear medicine department, but wore the same TLD badge in both locations. If the assumption is made that the same procedural mean exposures were received in the second department, and the number of studies done there is included in the calculations, a collective patient handling exposure estimate of 157 mR results. Similarly, assuming one-half of the measured QC exposure for the second department, as only one flood phantom was in use, the collective exposure due to flood phantom QC is estimated to be 53 mR. Together the operations of patient handling and quality control account for 210 mR, or 44% of the collective dose equivalent measured by BRMD during the quarterly monitoring period. It is important to note that this percentage does not take into consideration exposures incurred when a technologist is involved in assisting another technologist with

a patient, as may frequently happen with immobile or infirm patients. Furthermore, about 3% of all patient studies conducted during the monitoring period involved procedures other than those enumerated in Table 1. The figure of 44% thus represents a lower limit on the fraction of exposure arising from patient handling and gamma camera QC. The remaining exposure (<56%) can be attributed to radiopharmaceutical handling, patient dose preparation, dose administration including radioiodine therapies and ablations, and natural background. Generator elution is specifically excluded as a source of exposure in this instance, as the resident radiopharmacist performed this task.

Comparison with Other Published Data

A number of other studies have measured the exposures received by technologists during the performance of their duties. Although the majority of this previous work concentrated on the contribution to the total exposure from the preparation and handling of radiopharmaceuticals (*5–8*), a few reports of the exposure due to the imaging component have been published (*1–3*). Monitoring strategies have involved either measuring exposures directly or inferring these from measurements of exposure rates.

In a recent study by Boutcher and Haas (*3*), technologist exposures during imaging were measured by sampling the radiation field with an exposure rate meter at a number of points on the body surface of the technologist. Exposure values for a typical study were then derived by estimating the amount of time that a technologist spent in each of two locations during the study, either near the patient or at the camera console. Further assumptions were made about the percentage of patients that required special attention (e.g., holding) to derive a final value for the average exposure per technologist per annum. We have extracted average procedural exposures from the annual procedural exposure estimates and the number of studies performed. Comparative exposure values for procedures common to the Boutcher study and the present investigation are reproduced in Table 5. Also shown are corresponding exposure values obtained by Barrall and Smith (*1*). The latter values were measured directly using a high sensitivity Geiger–Mueller counter in a manner similar to that employed in this study. The procedures are ranked in order according to exposure from highest to lowest, based on our measurements.

TABLE 5. Average Procedural Exposures Reported in the Literature*

Procedure	Boutcher and Haas (3)	Barrall and Smith (1)	Present study
Cardiac wall motion (rest)	0.89	—	0.45
Brain scan	0.80	0.22	0.21
Brain flow	0.17	0.05	0.19
Whole body bone	0.39	0.54	0.15
Liver scan	0.07	0.03	0.11
Lung perfusion	0.07	0.09	0.11

*All values are expressed in milliroentgens.

Boutcher and Haas (*3*) found that the gated cardiac studies were responsible for the highest technologist exposure on a procedural basis, as we did. However, the value that they quote is about twice as high as ours. This is understandable, as they assume that the technologist remains within 6 ft of the patient during the entire study, and is close to the patient for 15 min of the 45-min study. This was rarely the case for studies monitored here, as the room in which the cardiac studies are performed allows the technologists to situate themselves more than 6 ft away from the patient.

Brain scans are second on our ranked list. The data of Boutcher and Haas (*3*) support this finding, although as in the case of the cardiac studies, our measured value is considerably lower than theirs. They assume that 35% of the patients require holding and that the technologist spends 10 min of the 25-min study in close contact with the patient. The patient dose used in the Boutcher study was 24 mCi with imaging occurring 2 hr after injection. The present study shows that only 3 of 23 patients (13%) were identified as being difficult (i.e., required holding). We obtained brain images 3 hr after an injection of 20 mCi. The lower patient dose and much lower percentage of patients that were held are likely the major reasons why our reported exposure is lower. Our value agrees well with that given by Barrall and Smith (*1*).

The third entry on our ranked list is the brain flow procedure. In this case, our measured value for the exposure agrees well with that measured by Boutcher and Haas (*3*), although it is significantly higher than the value given by Barrall and Smith (*1*). One would expect Boutcher's value to again be higher because the injected activities were the same as for the static brain studies, although in our case the technologist being monitored was always present during the injection of the radiopharmaceutical, and frequently performed the injection. This probably raised our measured exposures somewhat.

The exposure value for the whole body bone scans measured in this study was again lower than the other reported values. The data of Barrall and Smith (*1*) were gathered while multiple spot views were taken to cover the whole body. In our case, an automatic scanning system was used, which greatly decreases the amount of time that the technologist must spend in close proximity to the patient. Boutcher and Haas (*3*) assume that the technologists are close to the patient 50% of the time and 6 ft away during the remainder. In our department this is certainly not true, as the positioning time is much less than half of the total scan time and the patient–technologist observation distance is usually greater than 6 ft.

The difference between our liver and lung perfusion results and those of Boutcher and Haas (*3*) may be explained on the basis of a difference in the injected activity.

Many factors might contribute to a difference in technologist exposure among the various nuclear medicine departments involved in the studies referenced above. As Barrall and Smith (*1*) give few details of the protocols used in their study, in many cases it is not possible to explain why our results differ from theirs. In spite of this, the results of the different studies are generally roughly consistent.

As noted earlier, Boutcher and Haas (*3*) made measurements of the exposure rates at various points of interest near the patients. It is interesting to observe that their measured exposure rates display relatively small variations in comparison with the standard deviations of the exposure measurements made in this study. Although they only acquired data during four studies for each procedure, the variation (usually about 20% of the mean value) may be interpreted as reflecting differences in patient uptake. The much larger variation (65% of the mean value, on average) in our measured exposures would thus appear to arise primarily from differences in the specific handling requirements of individual patients, as instrumental uncertainties were at a fairly low (~10%) level.

The average daily flood phantom QC exposure of 0.58 mR measured here agrees well with a similar determination by La Fontaine et al. (*9*), who found an average exposure of 0.7 mR. In both cases three gamma cameras were tested; however, the department monitored by La Fontaine et al. (*9*) used a single flood source, whereas we used two such sources.

SUMMARY

A highly sensitive, portable, direct-reading ion chamber was used to measure procedural radiation exposures to nuclear medicine technologists during patient handling and gamma camera flood phantom QC. Flood phantom QC and equilibrium gated cardiac studies yielded the largest average exposures at 0.58 and 0.45 mR, respectively. The majority of other procedures resulted in exposures roughly in the range 0.10–0.20 mR. These findings are in general agreement with a limited number of similar investigations reported in the literature, given our knowledge of the different circumstances and assumptions that prevailed when they were undertaken.

The variability in exposure for individual procedures as gauged by the standard deviation in the measurements was high, being roughly 65% of the mean exposure. As far as we are aware, this finding represents new information on the distribution of technologist exposures. Considered along with the finding of Boutcher and Haas (*3*) that for a given procedure, exposure rates measured at fixed distances from patients vary only about 20% from patient to patient, and with our determination that instrumental uncertainties are roughly at the 10% level, it implies that most of the exposure variability stems from the unique handling requirements of each individual patient.

For the majority of diagnostic procedures, difficult patients typically doubled a technologist's exposure. Removal of this patient group from consideration did not noticeably decrease the variability in procedural exposures, however, which remained close to 65% of the mean values. This finding further supports the idea that even among average patients, individual handling requirements result in large variations in technologist exposure.

Comparison of our measurements with those of the thermoluminescent dosimetry service of the Bureau of Radiation and Medical Devices, Department of Health and Welfare, Canada, yields a lower limit for the fraction of collective technologist exposure due to patient handling and flood phantom QC of 44%. This figure does not account for situations where two technologists receive coincident exposures from a single patient, however, which can occur when aged or infirm patients are involved. Moreover, the large size of the imaging area in which the present measurements were made renders it likely that this fraction would increase for smaller departments where distances between patients and technologists are reduced.

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NOTES

*Dosimeter Corporation, Cincinnati, OH.
†Innovative Software, Inc. (SMART Data Manager), Overland Park, KS.

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