Should Nuclear Medicine Technologists Wear Lead Aprons?

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Nuclear medicine technologists in Manitoba receive annual whole-body doses in the range 100–500 mrem (1–5 mSv) and are classified as Atomic Radiation Workers. A detailed investigation into the sources of this radiation exposure in a department which does not use a $^{99}Mo/^{99m}Tc$ generator has shown that the dominant component arises from radioactivity in the patients undergoing nuclear medicine examinations. Under these circumstances, it is appropriate to ask the question: "Should nuclear medicine technologists wear lead (Pb) aprons to reduce their annual radiation doses?" The wearing of Pb aprons by nuclear medicine technologists, for all (or some) nuclear medicine examinations, could be considered an integral component of an ALARA (as low as reasonably achievable) radiation protection program. In this paper, quantitative analysis is made of the dose reductions that are achievable by utilizing Pb aprons. In addition, the actual practice of Pb apron use in Manitoba is reported. The data presented enable the individual technologist to perform a "cost-benefit" analysis in making a rational decision as to the need for wearing Pb aprons during each component of an imaging procedure.

Annual whole-body radiation doses to nuclear medicine technologists (NMTs) typically fall in the range 100–500 mrem (1–5 mSv) (*1,2*), and are well below the regulatory limits for Atomic Radiation Workers in Canada of 5,000 mrem (50 mSv) yr^{-1} (*3*). Nevertheless, the current radiation protection philosophy, as enunciated by the International Commission on Radiological Protection (*4*) and adopted by North American regulatory agencies (*5,6*), emphasizes the need to keep all radiation exposures in accordance with ALARA (*a*s *l*ow *a*s *r*easonably *a*chievable) principles, social and economic factors being taken into account. Although few would argue with the laudable intent of this concept, the *practical* implementation of the ALARA principle is frequently viewed as being problematic. As an example, it is obvious that the wearing of lead (Pb) aprons will result in reduced doses to NMTs, but much more difficult to determine is whether this action is deemed to be "reasonable." In this paper, we consider one possible application of the ALARA principle in nuclear medicine by examination of the question of whether, and under what circumstances, it should be recommended that technologists wear Pb aprons. The sources of radiation dose to NMTs in a large Winnipeg department are examined, and the impact of utilization of Pb aprons is evaluated. In addition, the actual use of Pb aprons by Manitoba technologists during nuclear medicine procedures is reported.

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MATERIALS AND METHODS

The radiation doses to NMTs in a large Winnipeg department for the period 1982–1983 have been reported in detail elsewhere (*7*), and these data are used in this study. This nuclear medicine department with three stationary gamma cameras, two mobile gamma cameras, and a computer system was considered to be typical of most nuclear medicine departments with respect to the actual procedures carried out and radiation handling techniques employed by the technologists. A total of 6,409 imaging procedures were performed in 1982–1983 by nine technologists who were rotated through the various imaging areas. During that time, annual whole-body doses ranged from 210 mrem (2.1 mSv) to 510 mrem (5.1 mSv), with an average of 330 mrem (3.3 mSv). It is noteworthy that the department's technetium-99m (^{99m}Tc) products are supplied by a centralized radiopharmacy in the city and does not make use of $^{99m}Tc/^{99}Mo$ generators. The study showed that ^{99m}Tc imaging procedures, which constituted 69% of the total imaging procedures performed in the department, accounted for ~ 200 mrem (2.0 mSv)/technologist/annum. The contribution to personnel radiation exposures from the shielded syringes was estimated to be on the order of 1%–2% of the personnel exposure from activity in the patients. The study concluded that the handling of and physical proximity to the patients (injected with up to 27 mCi (1 GBq) of ^{99m}Tc radiopharmaceuticals during the imaging procedures) were the dominant source of technologist exposure and that, provided syringe shields were used during radiopharmaceutical handling, Pb aprons should be worn during imaging rather than while dispensing and injecting radioactivity.

Table 1 provides a summary of the ^{99m}Tc studies, carried out at the Health Sciences Centre during 1982–1983. The estimated imaging times involved in each procedure, with the percentage of total annual imaging time that a technologist spent on each imaging procedure, also are presented. These latter data take into account both the number of procedures performed annually and the procedure imaging time. Table 2 summarizes the reported dose rates both in the near vicinity of the patient and at the consoles and the corresponding data on resultant technologist doses. The latter have been subdivided into three distinct categories:

TABLE 1. Technetium-99m Procedures Peformed at the Health Sciences Centre 1982–1983

Study	Annual no. of procedures (1982–1983)	Average time/ procedure (min)	Procedure imaging time/year (hr)	% total imaging hr
Brain flow—hand-held	242	3	12	0.5
Brain flow—normal	449	3	22	0.9
Static brain—hand-held	242	25	101	4.3
Static brain—normal	449	25	187	8.0
Liver and spleen	1265	25	527	22.6
Perfusion lung	487	15	122	5.2
Rest MUGA*	293	45	220	9.4
Exercise MUGA*	115	60	115	4.9
Bone	1543	40	1029	44.1

* MUGA = multiple gated acquisition blood pool.

TABLE 2. Doses Received, per procedure, for ^{99m}Tc Imaging 1982–1983

Study	Near dose rate (mrem/hr ± SD*)	Console dose rate (mrem/hr ± SD)	Near cumulative dose/yr (mrem)	Far cumulative dose/yr (mrem)	Mean/ person/ yr (mrem)†	Comments
Brain flow—hand-held	9.2 ± 2.0	—	111.3	—	12.4	3 min procedure 35% of patients
Brain flow—normal	—	0.31 ± 0.05	—	7.0	0.8	3 min procedure 65% of patients
Static brain—hand-held	3.0 ± 0.5	—	302.5	—	33.6	25 min procedure 35% of patients
Static brain—normal	3.0 ± 0.5	0.21 ± 0.07	224.5	23.6	27.6	25 min procedure 10 min positioning 15 min imaging
Liver and spleen	0.33 ± 0.11	0.02 ± 0.01	87.0	5.3	10.3	25 min procedure 50% close for positioning
Perfusion lung	0.55 ± 0.13	0.02 ± 0.01	33.5	1.2	3.9	15 min procedure 50% close for positioning
Rest MUGA	3.4 ± 0.6	0.11 ± 0.02	249.0	16.1	29.5	45 min procedure 15 min positioning 30 min imaging
Exercise MUGA	4.7 ± 0.9	0.16 ± 0.02	180.2	12.3	21.4	60 min procedure 20 min positioning 40 min imaging
Bone	1.1 ± 0.14	0.06 ± 0.02	565.8	30.9	66.3	40 min procedure 50% close for positioning

All doses are given in mrem, to convert to μSv, multiply by 10.
* SD—Standard deviation of 4 or 5 measurements.
† Total mean annual dose per person is 205.8 mrem.

1. Total annual doses received in the vicinity of a patient, such as when the patient is being held or positioned (Column 4).
2. Total annual doses received when the operator is standing at the gamma camera console (Column 5).
3. Resultant mean annual doses, in mrem calculated with the assumption that the total collective dose is evenly distributed between the nine operators and no Pb aprons were worn (Column 6).

All dose rates (Columns 2 and 3) were obtained experimentally using a Victoreen Thyac III exposure meter. On the basis of the data presented in Table 2, it is possible to quantify the impact of wearing Pb aprons on operator doses for any type of imaging procedure.

Pb aprons are commercially available with Pb thickness of 0.25 mm and 0.50 mm Pb at a cost of ~ $120.00 (U.S. dollars). [The mass attenuation coefficient of Pb at the 140 keV photon energy of ^{99m}Tc is 2.56 cm^2 g^{-1} (*8*)]. The effect of Pb aprons on whole-body doses to technologists was taken to be directly proportional to the degree of attenuation achieved by the Pb aprons, which is 52% for 0.25 mm Pb aprons and 78% for 0.50 mm Pb aprons for 140 keV photons. Approximately 35% of all brain studies required the technologist to stand close to the patient, and in these cases it is clearly feasible for the operator to wear a Pb apron for the entire imaging procedure. In all the other imaging studies, including the other 65% of brain studies, the technologist intermittently spends part of the time close to the patient and part of the time near the gamma camera console. In these circumstances, it is not considered practicable to wear a Pb apron when only close to the patient. For the purpose of this study, it was assumed that when a Pb apron was worn it was for the entire length of the procedure (e.g., bone scan).

In order to assess the use of Pb aprons by technologists in Manitoba, and their resultant annual reported whole-body doses measured with thermoluminescent dosimeters (TLD) dosage, a questionnaire was circulated to all working technologists in the province. In this survey the procedures were divided into three distinct categories: dispensing of the ^{99m}Tc radiopharmaceutical; administration of the ^{99m}Tc radiopharmaceutical; and imaging the patient with the ^{99m}Tc radiopharmaceutical. Technologists were asked to indicate their frequency of use of Pb aprons during the three different categories. If their usage was moderate (10%–50% frequency), they were asked to indicate the procedures during which Pb aprons were typically worn. They also were asked to indicate whether doses were routinely drawn up behind lead shielding. In addition, a survey of all nuclear medicine departments in the province was carried out to determine the number of staff members, Pb aprons and gamma cameras, as well as the average reported TLD dosages for each department.

RESULTS

Theoretical

The theoretical average annual technologist dose saved by wearing 0.25 mm Pb and 0.5 mm Pb aprons for all nine types of ^{99m}Tc imaging procedures are shown in Table 3. If technologists do not wear Pb aprons at all, the annual dose due to ^{99m}Tc in the patients they are imaging will be, on average, 206 mrem (2.06 mSv) (Table 2), and account for 62% of the total annual exposure. By wearing a 0.25-mm Pb apron for all the nine imaging procedures listed in Table 4, this annual dose could be reduced to 97 mrem (0.97 mSv) or 45 mrem (0.45 mSv), depending upon whether the thickness of lead employed is 0.25 mm or 0.50 mm. Between these two extremes, it is clearly possible for technologists to selectively choose to wear Pb aprons for the higher dose rate imaging procedures. In this context, it is possible to assign a Pb apron—time efficiency parameter, E, which is defined for a given imaging procedure as:

$$E = \frac{\text{Radiation dose saved by wearing Pb apron}}{\text{\% of total imaging time Pb aprons are worn}},$$

where the denominator in this expression is listed as the last column of Table 1. Relative values of E, normalized to a figure of 100 for hand-held brain flow studies, are listed in Table 3, together with overall efficiency parameter E relative ranking (rank 1 corresponds to most efficient). These data clearly show that hand-held brain studies (flow and static) are the most "efficient" in terms of the relative effectiveness of Pb aprons and that liver/spleen and perfusion lung studies are the least "efficient." These data have been plotted on a cumulative basis in Figure 1 where the abscissa is the cumulative % imaging time for which Pb aprons are worn and the ordinate is the corresponding operator radiation dose. In this diagram, the data have been generated (left to right) according to the efficiency ranking scheme given in Table 3 so that a technologist would successively choose the most "efficient" imaging procedure for which to wear a Pb apron. Data in Table 3 and Figure 1 quantitatively show the overall impact of wearing Pb aprons for any given subset of ^{99m}Tc imaging

TABLE 3. Pb Apron Efficiency in Reducing Operater Doses from ^{99m}Tc Procedures

Study	Mean annual operator dose saved, in mrem, by wearing Pb apron: 0.25 mm†	0.5 mm‡	Pb apron time efficiency* E	Efficiency ranking
Brain flow—hand-held	6.4	9.7	100	1
Brain flow—normal	0.4	0.6	3.5	7
Static brain—hand-held	17.5	26.2	31.4	2
Static brain—normal	14.4	21.5	13.8	4
Liver and spleen	5.4	8.0	1.8	9
Perfusion lung	2.0	3.0	3.0	8
Rest MUGA	15.3	23.0	12.6	5
Exercise MUGA	11.1	16.7	17.5	3
Bone	34.5	51.7	6.03	6

All doses given in mrem. To convert to μSv, multiply by 10.

* Relative to brain flow (hand held) equal to 100.

† Total saved 109 mrem.

‡ Total saved 160.4 mrem.

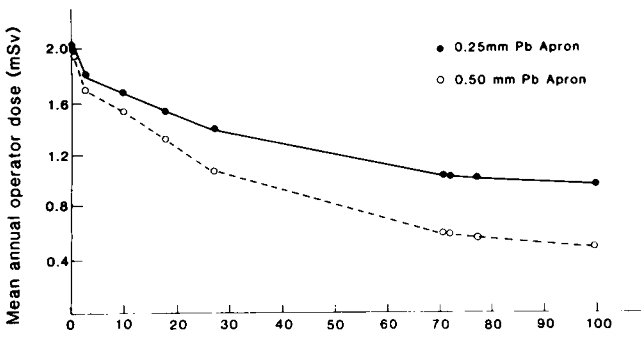

FIG. 1. Mean annual operator dose from ^{99m}Tc imaging procedures in a large nuclear medicine department as a function of the percentage of the total imaging time for which a Pb apron is worn.

procedures and enable each technologist to choose an individual radiation protection strategy vis-a-vis the wearing of Pb aprons.

Practical

Table 4 lists all nine nuclear medicine departments in the province of Manitoba and the availability of Pb aprons within each. Also listed are the number of gamma cameras and the mean operator dose for 1985. It is of interest to note that the mean operator dose for the Health Sciences Centre has dropped from a level of 330 mrem (3.3 mSv) in 1982 to 230 mrem (2.3 mSv) in 1985. During that time, the availability of Pb aprons has doubled and the frequency of usage has increased noticeably. The mean operator dosage in the various departments ranges from 20 mrem (0.2 mSv) to 460 mrem (4.6 mSv), with an overall mean of 180 mrem (1.8 mSv). Individual doses range from a maximum of 550 mrem (5.5 mSv) to a minimum of 0 mrem (0 mSv). In the majority of departments, the number of Pb aprons is equal to, or greater than, the number of working technologists. Most technologists, therefore, have a Pb apron readily available to them at all times.

TABLE 4. Survey of Manitoba Nuclear Medicine Departments

Department	Number of gamma cameras	Number of technologists	Mean dose in 1985*†	Number of Pb aprons and Pb thickness
HSC	5	9	230	4 (0.5 mm)
STBGH	4	6	190	4 (0.5 mm)
MGH	1	2	100	3 (0.5 mm)
VGH	1	3 (2 part-time)	140	4 (0.5 mm)
GGH	1	2	90	4 (0.5 mm)
SOGH	1	1		1 (0.5 mm)
BGH	2	5 (3 part-time)	460	5 (0.5 mm)
MA	2	2	230	2 (0.5 mm)
WC	2	3	200	3 (0.5 mm)
Total	19	33	Mean 180	30

* See Ref. (2) for detailed analysis of operator doses in Manitoba.
† To convert to mSV, divide by 100.

TABLE 5. Reported Pb Apron Usage by Manitoba Nuclear Medicine Technologists

Procedure	Pb apron usage	%
Dispensing ^{99m}Tc radiopharmaceuticals*	Never	8
	< 10%	21
	10%–50%	21
	>50%	50
Administering ^{99m}Tc radiopharmaceuticals	Never	11
	< 10%	21
	10%–50%	15
	> 50%	53
Imaging patient with ^{99m}Tc radiopharmaceutical	Never	12
	< 10%	29
	10%–50%	24
	> 50%	35

The majority of technologists use syringe shields for all dose preparation and administration, but there is some variation in the use of syringe shields for low-dose procedures (e.g., liver and lung scans).
* 82% of technologists draw up all doses behind a Pb glass shield.

Table 5 summarizes the results of the technologist survey regarding the wearing of Pb aprons. Thirty-three technologists were surveyed. In all three categories (dispensing, administration, and imaging), the highest proportion of technologists wear Pb aprons >50% of the time while the lowest proportion never wear Pb aprons. Only 8% for dispensing to 12% for imaging state that they never wear Pb aprons. By contrast, 50% of the technologists usually wear a Pb apron for dispensing, 53% usually wear one for administration of doses, and 35% usually wear one for imaging. In all three categories, where specific procedures were indicated for Pb apron usage, brain scans, bone scans, and multiple-gated acquisition blood-pool (MUGA) scans were those most frequently mentioned. Other high dose procedures such as red blood cell venograms and gastrointestinal bleed scans also were mentioned by a number of technologists as indicators for the wearing of Pb aprons. In addition, a number of technologists stated that Pb aprons were used particularly when close patient contact is required. It is interesting to note that a higher proportion of technologists usually wear Pb aprons during the preparation of radiopharmaceuticals than during patient imaging. As over 80% of technologists prepare doses behind a Pb shield with an attenuation factor typically of > 99% in addition to using a Pb syringe shield with a typical attention factor of > 97%, the resultant emissions reaching the body of the technologist are already reduced by a factor of virtually 100%. The additional attenuation achieved by the wearing of a Pb apron in this instance would be insignificant.

DISCUSSION

The average radiation dose of 180 mrem (1.8 mSv) yr^{-1} received by technologists in Manitoba in 1986 is more than an order of magnitude lower than the regulatory dose limits [5 rem (50 mSv) yr^{-1}] and comparable to the average natural background level of 200 mrem (2.0 mSv) yr^{-1} in North America (*1*). The serious risks that are normally attributed to this level of exposure are carcinogenesis and genetic effects in the offspring of irradiated individuals. The ICRP have recommended a risk factor of 1.65×10^{-6} rem $^{-1}$ for use in radiation protection when the exposed group is an adult working population (*4*). On this basis, therefore, the average annual risk to a technologist is $\sim 3 \times 10^{-5}$. It is noteworthy that this level of risk is lower than the annual fatality rate in industries that are generally regarded as being "safe" (*4*). However, it is important to note that the radiation risk estimate is largely theoretical and associated with large uncertainties (*9*), and that the ICRP value of the radiation risk factor is considered to be conservative because it is primarily based on a *linear* extrapolation of observed (carcinogenic) effects at high doses and high dose rates (*4*). In addition, the radiation risks are currently being revised on the basis of new dosimetry for the survivors of the A-bomb attacks on Hiroshima and Nagasaki (*10,11*). Despite these uncertainties, current radiation protection practice requires adherence to the ALARA principle because all "unneccessary" exposures, and their assumed risks, should be eliminated. In these circumstances, the wearing of Pb aprons in nuclear medicine departments is clearly a legitimate area of investigation.

In evaluating the need for Pb aprons, consideration must be given to both the benefits and costs resulting from the introduction of Pb aprons. The former are readily evaluated as the saved radiation dose (e.g., using the data in Table 3 and Figure 1). The latter, however, are more problematic. Clearly there is a financial cost which currently is ~ $120.00 (U.S.) per Pb apron. Assuming a total of six Pb aprons were purchased for a department such as the H.S.C. in Winnipeg and each had a lifetime of ten years, the total financial cost would be $720.00. The (maximum) collective dose saving from ^{99m}Tc imaging procedures over the same time period is estimated to be 9 man-rem (10 yr × 9 operators × 100 mrem person^{-1} yr^{-1}). This (admittedly crude) calculation shows that the department would be spending approximately $80.00 (U.S.) to save a man-rem, which is less than the generally reported range of values ($100.00–$200.00 per man-rem) that are currently recommended by the ICRP for optimization purposes (*12*). In addition to the financial cost of Pb aprons, it is necessary to consider the "cost" to technologists of carrying a heavy load of between 5 and 10 lbs. This cost is the general inconvenience and the possible risk of physical harm such as a strained back. Although these nonmonetary "costs" have an important subjective component, they are difficult to quantify and compare, in commensurate terms, with the benefit obtained in terms of technologist dose reduction. These problems would be even further compounded if consideration were to be extended to technologists who were pregnant! Quantification of nonmonetary "costs" associated with Pb aprons is difficult because it involves subjective value judgements by individual technologists (i.e., whether the reduced radiation dose is worth the extra effort and possible risk of carrying heavy loads involved in wearing Pb aprons). For this reason, it is of interest to sample the opinions of technologists on this topic. The data gathered from technologists in the province of Manitoba indicates that there is a wide variation in the frequency of use of Pb aprons, which is to be expected considering the value judgements mentioned above. However, the majority of technologists do wear Pb aprons for at least some procedures. They appear to be making rational and informed choices as to which procedures are most 'cost effective' in terms of radiation protection by wearing Pb aprons predominantly during high dose procedures such as brain and bone scans, particularly when patient proximity is required.

Some of the parameters that play an important role in determining the dose savings to technologists from the use of the Pb aprons include the amount of activity (^{99m}Tc) administered to the patient, the total number of procedures performed, the imaging times employed, and the location of the technologist vis-a-vis the patient being scanned. The results produced in this study are obviously dependent on the values adopted for these parameters. However, since they have all been explicity given here (in Tables 1, 2, and 3) or in reference (*7*), it is possible for other institutions to perform comparable calculations using parameter values that apply to their own circumstances. Major differences in other departments may be expected to arise from the use of ^{99m}Tc/^{99}Mo generators with their high photon energies and high dose rates, and the relative contribution of non-^{99m}Tc nuclear medicine procedures.

Obtaining knowledge of where operators receive their doses in a nuclear medicine department is the key step in developing appropriate strategies to employ the ALARA principle. For departments similar to those in Manitoba, it is clear that ^{99m}Tc-labeled pharmaceuticals in patients are the dominant cause of operator exposure and that the use of Pb aprons can be effective in reducing the operator doses. Radiation protection strategies available to individual technologists range in a continuum from not wearing Pb aprons to wearing Pb aprons for all imaging procedures. It is impossible to develop universal "rules" for wearing Pb aprons, since the balancing of costs (i.e., carrying heavy loads) and benefits (i.e., reduced operator doses) is highly subjective and will vary from technologist to technologist. Nevertheless, these data in this report strongly suggest that Pb aprons do have a role to play in the radiation protection procedures of typical nuclear medicine departments. Furthermore, the survey conducted in Manitoba suggests that the majority of technologists are already opting for a selective usage of Pb aprons for high dose rate procedures, in accordance with the data summarized in Table 3 and Figure 1.

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