A survey of radiation exposure to technologists within the nuclear medicine department at the Victoria General Hospital

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This study monitored radiation exposures received by technologists and examined job rotations in the department to determine, on average, which contributed the most to the radiation dose received. Thermoluminescent dosimeters were used in a sixteen week time period to monitor the dose obtained by technologists on a weekly basis. An occupancy factor was used to account for jobs not done on assigned rotations. The patterns of dose distribution for both cameras and individual technologist were examined by looking for trends and variations within the collected data. The greatest exposure came on a camera rotation which involved the technologists doing a large number of cardiac wall motion and bone scans with this camera. This study showed the radiopharmacy rotation to contribute the least. Though no high radiation levels were observed, further conscious effort on the part of the technologists will afford greater protection.

Currently, the Nuclear Medicine Department in the Victoria General Hospital (VGH) typically administers approximately 300 diagnostic examinations or jobs per week to both inpatients and outpatients. A job is defined here to be any procedure where a patient is injected with a radiopharmaceutical, scans are taken of the radiopharmaceutical distribution within this patient and appropriate computerized workups are performed. There are nine nuclear medicine technologists who regularly administer radiopharmaceuticals and oversee the scans done on seven different cameras at the VGH. Each technologist is assigned a particular camera for a period of one week, with two technologists assigned to be spares or "floats". There are also two technologists who work in the Radiopharmacy.

The department is a full capacity facility that offers over 30 different diagnostic techniques and uses a variety of radiopharmaceuticals. At the VGH, technologists are exposed to ionizing radiation primarily during radiopharmaceutical preparation and assay, radiopharmaceutical administration and imaging procedures. When dealing with a radioactive source it is always in the best interest of those who are working with the source to know what jobs afford the most exposure, so that all reasonable steps are taken to reduce the induction of some cancers (1). While there are guidelines in place to keep technologist's doses below designated limits (50 mSv/yr; 1,2), it is the practice of the VGH's Radiation Safety Program to identify and eliminate unnecessary exposure to technologists. This is consistent with ALARA, a principle of dose limitation based on keeping exposures "As Low As Reasonably Achievable", economic and social factors taken into account (3).

The survey of radiation exposure received by technologists was conducted over a four month period. The study's aims were to determine the personal radiation dose received by a technologist on a weekly basis and to examine the rotations' attributable doses and see if any were responsible for increased dose levels. These results could then be used to scrutinize the technologists' radiation hy-

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giene from an ALARA standpoint.

As the technologist is continually moving between the camera console, the patient and the hallway beyond the room, there is a considerable difficulty in obtaining a per job radiation dose, hence very few studies have been done to measure the effective doses given by each individual job. One such study suggests that cardiac wall motion, brain and bone scans accounted for the larger portion of radiation exposure in the department and measured them at 0.45 mR (4), 0.20 mR and 0.13 mR per job respectively (5). While our research did not examine on a dose per job basis, this study by Sloboda et al. may be used to explain the readings obtained during our project.

MATERIALS AND METHODS

To measure the radiation exposure received by the technologists, sensitized TLD (7)-100 (6) chips from Atomic Energy of Canada Limited's Chalk River Laboratory (CRL) were rented and technologist exposure readings were collected in the sixteen week study period from January to April, 1994. All exposure readings were corrected for background by using control badges. Four control badges issued with every set of weekly badges received from CRL were used to correct for background exposure accumulated while shipping and while within the VGH. They were stored in an area not exposed to the radiation of the department. To prevent the technologists' badges from picking up any stray radiation, they were kept in a lead-lined box (at least 4 mm thick at all points) when the technologists were not in the department. Each morning when the technologists came in they were instructed to pick up their badge and return it to the drop-off box at the end of the day . The TLD badges were worn by technologists over their chest or abdomen. When technologists wore lead aprons, badges were attached outside of the apron at the chest or abdomen. At the end of the week, the badges were collected and shipped back to CRL for processing.

To determine what jobs each technologist did during each week, the computerized database (DuPont MicroRadiology Manager - Managerial 5.0 Module) containing productivity records of the department was polled on a regular basis and the data entered into a spreadsheet (Microsoft Excel 4.0). The personal dose readings were compared with various work statistics obtained from the database. The database reports included information about which camera was used for each job performed.

During the study, it was discovered that some technologists were frequently moving from room to room performing jobs on cameras that were not assigned to them by the weekly rotation schedule (covering for other technologists, emergencies, vacations). To account for the problem, an Occupancy Index (OI) was introduced for each camera that would show the actual number of jobs done by the technologist in the assigned room, thus giving a rough approximation of how much of a rotation's radiation dose was actually attributed to that camera. The OI was tabulated as the fraction of total number of jobs done in the room corresponding for that rotation over the total number of jobs done in the sixteen week period. This OI would also account for circumstances where the cameras were broken and the technologists assigned to those cameras were placed as temporary floats. When a person was on the Float Rotation all the jobs done were considered to be attributable to the rotation, regardless of the room where the study occurred. In all cases the OI neither looked at what kind of jobs were done, the time taken to complete the job, nor how much radiopharmaceutical was used. This limitation of the OI prevented direct correction of attributable dose to reflect the actual dose afforded by the rotation. Also, the OI only looked at whether or not a study was performed in the assigned room or elsewhere (non-specific).

The Radiopharmacy has an OI of 100% because there are no injections nor patient contact associated with this rotation and thus there are no jobs to be done at a camera per se. Therefore the entire exposure for technologists on that rotation is received from working in the Radiopharmacy.

The bar representing the Float Rotation in Figure 1, denoted "Float" is one half of the total value recorded for the rotation since two technologists are placed in this rotation per week.

The technologist's work habits were examined in the form of a questionnaire. The form asked technologists questions regarding their years of experience, how often they did jobs on patients who required a close contact (i.e. those needing help getting to and from the table, or requiring assistance with positioning on the table), and where they waited while the scans were in progress. The questionnaire was used to help interpret the results obtained.

RESULTS

The data collected from the TLD dosimeters for technologists' exposures was compiled and attributed to the rotation for which they were assigned for that week (Fig. 1). Figure 2 shows the OI for each rotation and must be used with Figure 1 to interpret the results.

An individual breakdown of dose per week per camera is given in Table 1. Inspection of the rows for the emission computed togography (ECT) C rotation shows it accounts for a large portion of the upper end range of exposures. ECT C provided 44.7μSv (s.d.=±23 μSv) per week, significantly higher ($p<0.005$) than the average weekly doses per camera 26.3 μSv per week (s.d.=±10.3 μSv) and would lead to a radiation dose of 2.49 mSv/year if this rotation was assigned on a yearly basis. This exceeds the average dose (1.76 mSv/year)

Table 1. Radiation doses (μSv) per week per rotation*

Rot\week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Tot.	avg.	s
gCamera A	40	30	30		10	30	30	20	10		10	40	20	30	60	30	390	27.9	±14
gCamera B	10	50	40	20	30	10	10	20	20	30	40	30	10		60		380	27.1	±16
gCamera C	70	30	20	0	30	30	10	20	50	20	0	0	80	10	30	20	420	26.3	±23
ECT§ A	0	10	10	10	20	0	30	10	40	10	0	40	40	10	40	40	310	19.4	±16
ECT B	0	10	10	0	20	10	70	30	20	10	0	20	20	0	20	20	260	16.3	±17
ECT C	70	30	80	20	30	60	60	10	30	50	80	40	60	30	20		670	44.7	±23
Wet Lab	20	50	40	0	10	40	30	80	100	60	0		30	0	40	50	550	36.7	±29
Radiopharm	20	0	10	0	0	30	10	20	10	20	0	30	0	0	0	20	170	10.6	±11
Float1	40	20	40	0	10	50	30	20	60	20	10	40	40	40	10	50	480	-	-
Float2	10	20	30	0	20	50	0		20	60	20	40		0	40	40	350	-	-
Total Float	50	40	70	0	30	100	30	20	80	80	30	80	40	40	50	90	830	27.7†	±28
Tot.Dose (μSv)	280	250	310	50	180	310	280	230	360	280	160	280	300	120	260	330	3980	249	±83

*blank spaces on table denote that no technologist was on that rotation
†the rotation's average is halved since two people's readings are summed to determine Total Float
§ECT (emission computed tomography)

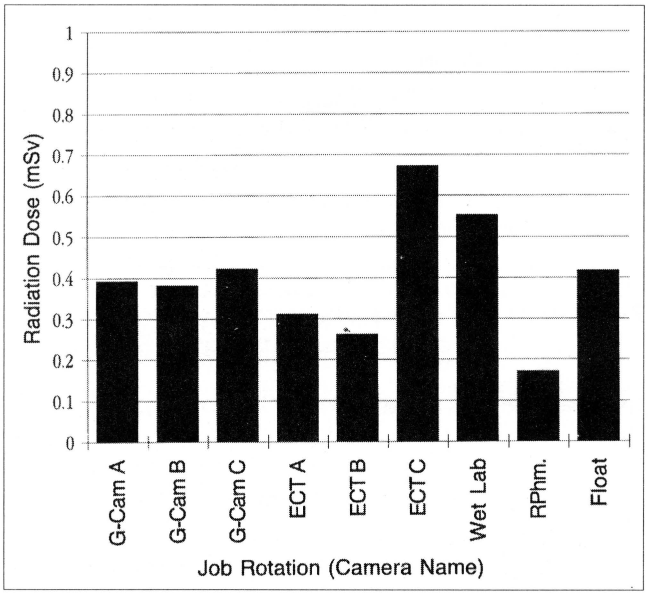

Figure 1: *Graph of total radiation dose (mSv) received from rotation.*

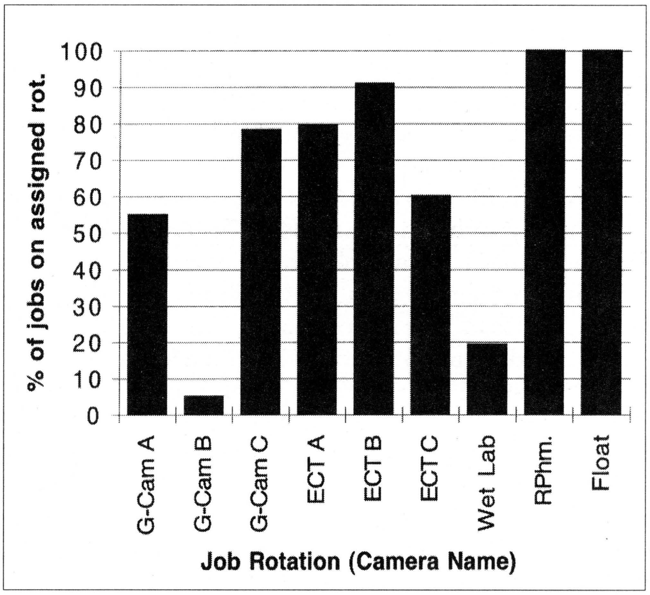

Figure 2: *Graph of occupancy factor for each rotation.*

for nuclear medicine technologist workers across Canada (8). Weekly data tables showed this rotation to be associated with 16.8% (670 μSv / 3980 μSv) of the total dose received and 21% (252 GBq(9) / 1304 GBq) of all the radioactivity handled during the survey period. This camera was used on average for 26% (317/1133) of all the wall motion, and bone scans done in the trial period.

In order to determine the distribution of TLD readings and obtain an average weekly dose irrespective of camera, a distribution plot was done on individual readings (Fig. 3). The distribution of readings ranged from 0 to 100 μSv, with a skewed distribution to the lower end with an average of 28.6 μSv (s.d.=±23 μSv).

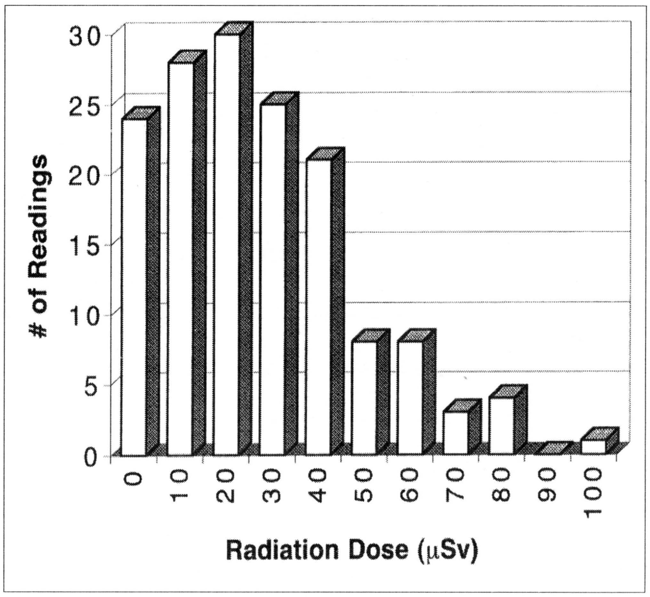

Figure 3: *Distribution plot of individual readings, to determine average weekly dose.*

DISCUSSION

The wall motion and bone scans are two common tests and use an amount of radioactivity (852 MBq) that is on the upper end of the spectrum for administered radioactivity in the department. Further, this high degree of radioactivity may have some bearing on the elevated doses attributed to the ECT C rotation. Two other studies found that cardiac wall motion studies contribute the most to technologist exposure on a per job basis (5,10).

The relatively low OI for the Camera B rotation is explained by the fact the camera is a spare and used only if all the other cameras are being used. It was used for only 5% of the entire jobs done within the department during the study period. Thus, because the assigned technologist is doing only 5% of the jobs in their assigned rotation, it must be concluded that almost all of the exposure attributed to this rotation is acquired by the use of other cameras for jobs. Therefore the gamma Camera B rotation should be considered similar to a Float rotation.

In most cases, the technologists at the VGH were below the national Canadian average of 1.76 mSv/year (8), and all were within the established safety limits (see Table 2)(1). The low values for Technologists 'E' and 'I' are due to the fact they share one full time position in the radiopharmacy and only work there preparing the radiopharmaceuticals. The Radiopharmacy Rotation does not involve "jobs" (i.e. injecting patients or being in their proximity while scans are being performed). It is for this reason that they are excluded from Table 3 and Figure 4 which deal with a job/dose ratio. To demonstrate the uniformity of technologist's radiation hygiene, a comparison was made by calculating the number of jobs* an individual could do for 1 μSv of radiation (Table 3). By using this method to rate hygiene efficiency, all technologists became standardized and the variance in the number of jobs they did (and thus the amount of radiation handled) is negated. The ratios are plotted in Fig. 4 in comparison to an average ratio value (mean=1.27 jobs/μSv).

The high job/dose ratio of Technologist 'H' was attributed to a conscious effort on her part to limit her contact with the radiopharmaceuticals and injected patients as she was pregnant. Just by limiting her contact with injected patients Technologist 'H' was able to attain a yearly dose of 0.29 mSv. This is remarkable because a study conducted for Laval's Nuclear Medicine Department showed the receptionist there, who did no injections, received an annual dose of 1.1 mSv/year, over 3 times what Technologist 'H' received. This high dose for a non radiation worker was attributed to the fact that the patient waiting area was right outside the receptionist's door and the walls had no protective barrier to reduce the exposure from the radioisotopes in the patients' bodies (11).

The concern for radiation exposure to unborn children is especially important because the embryo/fetus is a collection of radiosensitive cells. The amount and type of damage to the fetus is dependent upon the stage of development of the fetus and the absorbed dose it receives (1). The International Commission on Radiation Protection (ICRP) has now recommended that the fetus should be treated as a member of the general public, and therefore the relevant dose figure becomes 1 mSv in a year, with a maximum 2 mSv occupational dose to the mother's abdomen during pregnancy (1). During the survey period, two of the workers were pregnant; one operated the cameras and injected patients and the other worked in the Radiopharmacy. Both made efforts to reduce their exposure by wearing lead aprons and minimizing their contact with injected patients. Recent

Table 3. Jobs per exposure during the study period

Tech	A	B	C	D	F	G	H	J	K	TOT.
Total jobs	339	599	693	590	529	453	426	630	585	4844
Total Dose (μSv)	440	540	410	460	760	270	90	550	290	3810
Job/dose (#/μSv)	0.77	1.11	1.69	1.28	0.7	1.68	4.73	1.15	2.02	1.27

Average JOB/DOSE 1.27 jobs/μSv

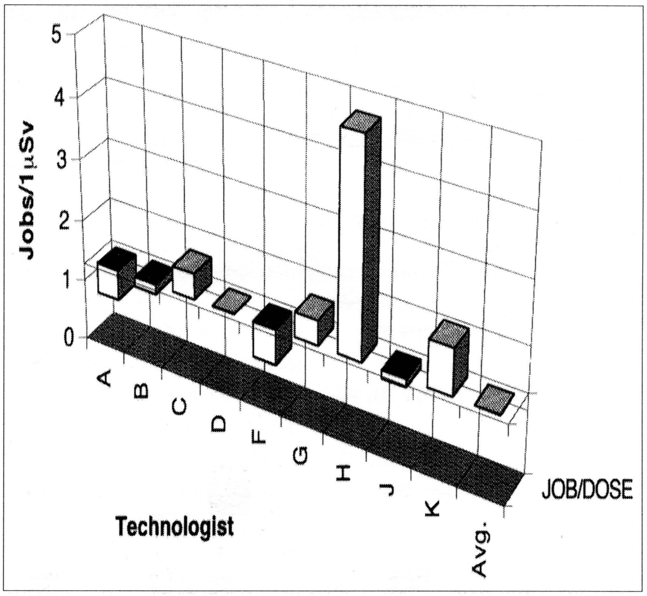

Figure 4: *Ratio of number of jobs an individual could do for 1 μSv of radiation as compared to an average ratio value.*

Table 2. Summary of Exposure Measured during Study and Projections for a Yearly Dose

Tech	A	B	C	D	E	F	G	H	I	J	K	TOT.
Exposure (μSv)	440	540	410	460	70	760	270	90	100	550	290	3980
mSv/yr	1.43	1.76	1.33	1.5	0.23	2.47	0.88	0.29	0.33	1.79	0.94	19.9

* In this case a "job" is a generic term where an average of 269 MBq were handled. All technologists (except E and I) rotated through all of the camera positions, therefore they all had the potential to the same procedures. In the 16 week period 1304 Gbq of radioactivity were handled in 4844 jobs

studies have shown that it is unlikely that there should be a need to change the duties of pregnant technologists to remain within safety limits (12). Technologist 'H' supports this statement, for no changes were made for her in rotations, but rather her own conscious awareness reduced her risk. It should be of comfort to pregnant technologists to know that they can effectively reduce the risk to their unborn child without switching rotations to accommodate the fetus' safety.

Technologist 'F's' relatively low hygiene efficiency was attributed to her high degree of patient contact as she indicated on the survey that 80% of the patients she worked with required some assistance when being scanned (i.e. helped to and from the table or required the technologist to position the patient for different views). She also responded to the question regarding where a technologist should wait while the job was going on, by stating that she waited with the patient. Similar results were reported by Sloboda et al. as they found difficult patients were responsible for a doubling of technologist exposure for many jobs (5). Technologist 'A' indicated that she waited in the room with the patient, perhaps explaining her reduced efficiency. Although no high dose levels were recorded, Figure 4 shows that exposures could be reduced by a conscious effort by the technologists to reasonably limit their contact with injected patients.

All the other technologists had doses above those measured for non-radiation hospital workers (0.6 mSv/year) (11), but have the potential to have similar doses as those who do not inject nor have close contact with patients after injection. While it may not be practical to reduce the levels to those attained by Technologist 'H', there is room for improvement. Four technologists responded to the survey by saying that they waited either with the patient or in the room at the console while waiting for the test to be finished. Recommendations to wear a lead apron and/or have better placement of the computer console such that there is a degree of separation between the patient and the technologist would be consistent with ALARA principles.

For those technologists whose job/dose hygiene ratings are especially low, such as Technologist 'A' and Technologist 'F', it may be advisable for these technicians to begin wearing lead aprons to reduce their body exposure especially while on the rotation that yield high exposure levels (ECT C). Further planning may include extra training sessions that could be given by means of an informal talk presented by a technologist who has demonstrated exceptionally good radiation hygiene. Other suggestions that would be pertinent to these technologists are shown in Table 4.

The technologists who are in charge of the Radiopharmacy typically elute approximately 1240 GBq of sodium pertechnetate ($Na^{99m}TcO_4$) per month. The combined estimated radiation dose for both technologists for the year is 0.56 mSv (see Table 2). In order to

Table 4. Some suggestions for satisifying ALARA principles11

- Regular time and motion studies of radioactive patients
- Examination of test sequencing such that patients requiring multiple administrations of radioactivity can be handled efficiently and minimize their contribution to the environmental radioactivity in the department.
- Information and education should be provided for all hospital workers likely to be exposed to radioactive patients and their excreta.

be compared with other studies, the dose received by the technologists in the Radiopharmacy must be combined with the dose from the Wet Lab (projected to be 1.9 mSv), as the other study had the two rotations combined into one. The total dose is 2.46 mSv per year, which is remarkable, as other comparable studies looking at dose attributable to radiopharmacies suggest whole body doses ranging from 4.43 to 8.37 mSv/year for 325.3 GBq of technetium-99m eluted per month (13). In an another study, annual doses less than 6 mSv were reported for 2375 GBq of pertechnetate eluted per month (14). In the VGH department the following safety precautions are used when eluting the technetium-99m: lead shielding is at least 50 mm thick surrounding the isotope, protected syringes are used, and lead plate glass is used when preparing the isotope. In comparison, in the pertechnetate Jansen et al study was prepared at a bench where a 50 mm thick stacked lead brick partition complemented a lead shield 1.5 mm thick . Lead tongs and shields were used for remote handling but no lead lined syringes were used (13). A study conducted by Branson et al showed that syringe shields have been demonstrated to reduce exposure levels by a factor of 3 or more and may explain why the exposure levels found in Jansen et al.'s study were so high compared to those found at the VGH and other places where syringe shields were used (15). The common assumption that the Radiopharmacy is the job where most exposure occurs is grossly misrepresented and in fact is the rotation that provides, with appropriate precautions and experience, the least amount of exposure. A possible explanation for lowered dose rates at the VGH may result from the fact that the technologists who share the job have their office in another area of the building and spend a greater proportion of time in that area than in the Radiopharmacy where the exposure is larger. Although the dose levels experienced by Technologist 'E' and 'I' are well below the national average, a further suggestion to reduce the Radiopharmacy's exposure levels may include the purchase of an automated system to elute the pertechnetate (14). In the VGH's situation, this is not appropriate ALARA intervention, as its economic disadvantages outweigh the potential benefice gained by the technologists.

Since the early part of January 1994, the Radiopharmacy rotation has been shared exclusively by Technologist 'E' and 'I'. Current literature states that the doses attributable to the Radiopharmacy can be minimized if repetitive and efficient elution and dispensing routines are used; further, they suggest that radiopharmacies should be centralized so that many diagnostic centers may have one common dispensary(15). Centralization may also be of benefit because extra protection such as leaded glass in fumehoods is not practical in individual hospital situations (16). Such a policy is similar to that used at the VGH whose Radiopharmacy should be used as a model for others, as it can handle a large amount of radiation without posing elevated risk to the technologists who operate it.

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