Personnel Monitoring Observations

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Objective: Dosimetry information was collected to identify trends in radiation exposure among selected occupational workers and types of radioactive material uses.
Methods: Eighteen months of quarterly exposures were summarized. Clinical nuclear medicine technologists (NMTs), PET NMTs and radiopharmacists were evaluated. Further studies were based on the method of product usage and radiopharmacy unit dose users versus generator system users.
Results: The average annual whole-body exposures are summarized as: nuclear medicine technologists 1.8 mSv (180 mrem); PET technologists 4.1 mSv (410 mrem); and radiopharmacists 1.8 mSv (180 mrem). Extremity to whole-body ratios were calculated at 5:1, 4:1 and 81:1, respectively. Methods of product use showed lower exposures among technologists with radiopharmacy use.
Conclusion: The radiation exposures evaluated for this select group of occupational workers are comparable to data available in recently published materials. Extremity to whole-body ratios may be useful as a tool for comparison to similar radiation safety programs in nuclear medicine and PET.
Key Words: occupational radiation exposure; radiation safety

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NMA Medical Physics Consultation (NMA), an operating unit of Mallinckrodt Medical, Inc., provides medical physics services to many hospitals and clinics located throughout two-thirds of the U.S. In response to questions about what constitutes an average radiation exposure to occupational personnel, individuals are usually referred to several publications that address this subject.

The NRC Regulatory Guide 8.29 (*1*) references a 1975 database that indicates medicine, as an occupational subgroup, receives an average whole-body dose of 320 mrem. The National Council on Radiation Protection and Measurements (NCRP) also has reports that address the subject of occupational exposures. The NCRP Report No. 105 (*2*) states, for example, the annual mean dose equivalent to medical personnel who work with x-rays or radiopharmaceuticals averages 1.0–1.4 mSv (100–140 mrem). Authors of a Canadian publication (*3*) obtained information on Canadian nuclear medicine workers from Canada's National Dose Registry which, in part, showed the mean annual dose equivalent for nuclear medicine workers fluctuated around 1.8 mSv (180 mrem). Others have addressed this issue by evaluating their specific departments. Owens et al. (*4*) evaluated occupational exposure as it related to specific job duties. This study revealed various exposure levels depending on the job assignment, but the population studied was small.

Throughout these publications a concern is suggested that large bodies of data may dilute job specific exposures. Considering the nature of NMA's business and the interest in occupational exposure for a specific group of professional health care workers, we determined we had access to a unique pool of data for observation which further isolates a population of medical personnel, specifically those within nuclear medicine.

As part of the consulting program, an audit of the radiation safety programs is conducted which includes reviews of the personnel monitoring programs and occupational exposures received by workers. To identify potential problems, whole-body and extremity exposures are summarized and documented for clients. Based upon the number of individuals, their geographical dispersion and the specific worker groups, the database appeared large enough for the evaluation of trends in occupational exposure. Clinical NMTs, PET NMTs and radiopharmacists, were included as part of this survey of occupational exposure.

MATERIALS AND METHODS

Seventeen staff members at eleven satellite offices assisted in gathering the quarterly exposures of the respective occupational groups. In total, 852 technologists at 294 client facilities and 103 radiopharmacists at 27 site locations were surveyed. From this information, recorded exposures were selectively organized into known groups of individuals. Categories included nuclear medicine technologists working with byproduct/NARM materials (referred to as byproduct in this article), technologists working with PET isotopes

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TABLE 1
Average Annualized Occupational Exposure Summary

	N	Whole-body exposure (WB)			Extremity exposure (Ext)			Ext:WB
		mSv	mrem	Quarters	mSv	mrem	Quarters	
Technologists								
Byproduct	846	1.8	178	3,381	9.9	988	3,255	6
PET	6	4.1	412	23	17.5	1,745	22	4
Pharmacists								
Byproduct	103	1.8	181	480	145	14,490	480	81
User Types								
Pharmacy	576	1.6	157	2,285	7.6	756	2,197	5
Generator	204	2.3	225	845	15.3	1,530	823	7
Both	56	2.1	215	212	13.1	1,312	196	6
Unknown	10	1.5	151	39	9.9	993	39	7

(i.e., positron emitting materials), and radiopharmacists in commercial radiopharmacies. All clinics, hospitals and pharmacies were located within the U.S. but were geographically dispersed and varied significantly in size of operation.

All monitored participants at each location were individually queried to determine their occupational involvement with radioactive materials. At hospitals and clinics, technologists were the main target for the database. Physicians who may be named as users of byproduct materials, for example, were excluded as their direct involvement in clinical activities was expected to vary significantly. Similarly, transporters, secretaries, receptionists and other ancillary personnel were excluded. Concern for the inclusion of these types of workers was also raised by others (*3,5*). It is expected that they traditionally would accumulate much lower occupational exposures simply because of their indirect involvement in nuclear medicine activities. As such, the data could be artificially skewed downward to a lower value than that which would be anticipated for working technologists in nuclear medicine.

Occupational exposures for technologists in clinical PET facilities were also specifically identified. Although the data were limited in quantity because of the few PET centers in operation, the findings were useful for a relative comparison. Furthermore, little exposure information has been made available on these individuals elsewhere.

The occupational exposure data for nuclear medicine technologists at hospital- and clinic-based facilities were further grouped by their type of use; that is, licensees who use a nuclear pharmacy and receive materials in a unit dose form, those who use ^{99}Mo/^{99m}Tc generators exclusively, and those who use both unit doses and generator systems to supply their radiopharmaceutical needs.

Finally, demographics were summarized to characterize the collection of the occupational exposure data within the database. The exposure information accumulated for all individuals covered an 18-month period beginning January 1, 1992 and extending through July 1, 1993. Where an individual wore two badges, whole-body and extremity, the higher exposure was included within this database.

RESULTS

The summary of occupational exposure for 846 nuclear medicine technologists during this 18-month period represents over 3,300 quarters of information. The information for PET technologists was limited, but nevertheless represents 6 individuals over 23 quarters. For the radiopharmacists, more than 100 individuals representing more than 450 quarters of data were monitored. The whole-body and extremity exposures for the occupational groups and user types are summarized in Table 1.

A profile of the database information for clinical nuclear medicine technologists, PET technologists and radiopharmacists is given in Table 2. The information is segmented by quarters, with corresponding percentages, in order to represent the number of individuals and the dispersion of data available for the time period. Table 3 summarizes the demographic data.

DISCUSSION

In viewing the complete database, possible shortcomings were recognized and several areas of concern were identified. First, the acquisition of six quarters of exposure information was the goal. This comprehensive profile was felt to provide a sufficient historical base and individual exposure trends that would accurately reflect average occupational exposures. However, in some instances it was not possible to obtain all six quarters. In some cases, data were recorded from relatively new licensees or new clients (hospitals, clinics and radiopharmacies). These facilities either had not been in operation long enough or had not been associated with the NMA consulting organization long enough to compile a complete six-quarter exposure history.

Also, the transient employment of technologists contributed to gaps in exposure data. Although gaps or incomplete data for the 18-month interval were a concern, it is important to note that more than 80% of the occupational exposure data for nuclear medicine technologists and radiopharmacists contained at least three quarters or more of exposure history for the same individual. As previously mentioned,

TABLE 2
Distribution of Personnel Dosimetry Data

No. of quarters	Nuclear medicine technologists		PET technologists		Radiopharmacists	
	Whole-body	Extremity	Whole-body	Extremity	Whole-body	Extremity
6	141 (16.7%)	125 (14.8%)	2 (33.3%)	1 (16.7%)	51 (45.9%)	52 (50.5%)
5	149 (17.7%)	143 (16.9%)	0 (0%)	1 (16.7%)	21 (20.4%)	20 (19.4%)
4	311 (36.8%)	312 (37.0%)	0 (0%)	2 (33.3%)	5 (4.9%)	4 (3.9%)
3	119 (14.1%)	112 (13.3%)	0 (0%)	0 (0%)	10 (9.7%)	11 (10.7%)
2	67 (7.9%)	73 (8.6%)	1 (16.7%)	1 (16.7%)	4 (3.9%)	3 (2.9%)
1	56 (6.6%)	63 (7.5%)	1 (16.7%)	1 (16.7%)	12 (11.7%)	13 (12.6%)
0	1 (0.1%)	16 (1.9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	844	844	6	6	103	103

the data for PET technologists is limited and, therefore, is not statistically convincing.

Exposure information on contract technologists or mobile service technologists is another area for concern and such individuals were not identified in this study. Any individual could also have received additional exposure at other job assignments that could not be documented in this study. Further, occupational exposures could be disproportionate due to seasonality of responsibilities, the extent of employment (full-time versus part-time), the amount of clinical responsibilities (imaging versus non-imaging at large versus small institutions), or the type of job responsibilities (product preparation, clinic responsibilities and/or therapy applications of product) and were not identified. Some of the exposures complied within the database could have been received while occupationally performing duties in both nuclear medicine and diagnostic radiology.

The data occasionally contain estimated exposures due to lost, damaged or erroneously exposed badges. Any adjustments to the quarterly exposure reports were not identified and, therefore, exposure estimates are included within the database. However, when necessary, adjustments were generally based on averaging six months prior exposure and should not introduce significant error in average occupational exposures.

It is assumed that personnel properly wore their whole-body and extremity badges while working as required by their license conditions. It is impossible to assess the location, position and consistency with which badges were worn. Overall, there is no way to confirm this other than assuming good professional practices were maintained at all times.

The above reservations aside, the numbers of participants and exposure data collected are informative and noteworthy. The data provide an opportunity for some analysis among various occupational workers in nuclear medicine.

Byproduct Technologists

This specific evaluation of nuclear medicine technologists revealed occupational exposures averaged 1.8 mSv (180 mrem).

NRC Regulatory Guide 8.29 (*1*) estimates annual occupational exposures for the subgroup in medicine to be higher at 320 mrem. Several reasons are suggested as to why the guide numbers are higher. First, is the age of the database. NRC Regulatory Guide 8.29 data was collected and summarized in 1975. Accordingly, occupational workers may not have been as ALARA conscious as today's practicing medical professional. Second, the 1975 database may have been too broad for comparison to our present study wherein more specific groups of workers were identified for comparison. Third, the impact of change in the procedures and workload may contribute to the difference in exposure values.

TABLE 3
Demographic Data for Personnel Dosimetry

Number	Nuclear medicine technologists	PET technologists	Radiopharmacists
Technologists	852	6	103
Quarters evaluated	3,300	23	480
States	33	3	15
Cities	210	4	27
Facilities	294	4	27
Pharmacy users	204	—	—
Generator users	72	—	—
Generator and pharmacy users	11	—	—
Unknown	3	—	—

The Canadian study (*3*) reviewed 850 to 1,100 nuclear medicine personnel during the later five years of their evaluation. Our study reviewed equivalent numbers of individuals, 846 nuclear medicine technologists. However, our period of time was narrower at only 18 months. Nevertheless, the findings in both studies compare favorably. The Canadian publication reports 1.9 mSv (190 mrem), whereas this study finds 1.8 mSv (180 mrem) for nuclear medicine technologists.

NCRP Report No. 105 (*2*) shows that the mean dose equivalent to medical personnel is lower than our findings. It published average exposures of 1.0 to 1.4 mSv (100 to 140 mrem). But the NCRP report states that it included x-ray workers with the radiopharmaceutical workers. This may be a shortcoming as demonstrated in the Canadian database. The Canadian data are from x-ray workers who were occupationally exposed separately from nuclear medicine workers. In their eleven-year study, covering 1978–88, the last five years of data records showed, on average, a 93% lower whole-body dose equivalent was received by x-ray workers than by nuclear medicine workers. Further, the monitored Canadian x-ray workers outnumbered nuclear medicine workers by almost 9 to 1. Therefore, it is possible that combining x-ray and nuclear workers within a database could lower the average occupational exposure to the group as a whole and, thus, explain why the NCRP findings are lower.

PET Technologists

Based upon the limited information available, whole-body exposure and extremity exposure for PET technologists was approximately two times higher than the clinical NMTs, with whole-body at 4.1 and 1.8 mSv (410 and 180 mrem) and extremity at 17.5 and 9.9 mSv (1,750 and 990 mrem), respectively. The extremity to whole-body exposure ratios are similar for technologists in both groups (5:1 for clinical nuclear medicine and 4:1 for PET), even in light of the above twofold differences in whole-body and extremity exposures of the two groups. The production techniques, dose handling mechanisms and photon energy are thought to account for these differences in occupational exposures.

Commercial Radiopharmacists

Full-time radiopharmacists received the same whole-body exposures of 1.8 mSv (180 mrem) compared to nuclear medicine technologists. However, they had almost 15 times greater extremity exposures, 145 versus 9.9 mSv (14,500 versus 990 mrem). By comparison, much of the radiopharmacist's duties are devoted to "hot lab" responsibilities such as the elution of generators, preparation of reagent kits and the dispensing of unit doses. Hence, a significant amount of their work is conducted behind lead-lined L-shields. The shadow of the L-shield should explain why the radiopharmacist's whole-body exposure is comparable to that of a nuclear medicine technologist. Likewise, due to the responsibility of product preparation and dispensing of larger quantities of radioactivity at a much greater frequency, the radiopharmacist accumulates a greater extremity exposure.

Unit Dose Versus Generator User

For obvious reasons, the use of a unit dose service from a local nuclear pharmacy results in a reduction in occupational exposure compared to those individuals who are using a generator system and compounding their own materials. It was anticipated that occupational exposure for NMTs using unit doses would be less for whole-body and extremity exposures. This evaluation showed whole-body exposure for unit dose users was 70% lower than for generator users, at 1.6 mSv versus 2.3 mSv (160 mrem versus 230 mrem), respectively. Similarly, a 50% reduction was seen in extremity exposures between unit dose users (7.6 mSv or 760 mrem) and generator users (15.3 mSv or 1,530 mrem).

The data for nuclear medicine technologists, who use both generator systems and radiopharmacy unit doses, suggest that their accumulated occupational exposure is more for a generator user than for a unit dose radiopharmacy user. For those individuals within this database in which user type was not identified, their accumulated exposure implies unit dose radiopharmacy use.

Extremity to Whole-Body Ratios

Observation of the extremity to whole-body ratio for exposure is deemed to have some utility. There appears to be a recognizable trend between whole-body and extremity exposure between each of the groups. Clinical NMTs demonstrated an average ratio of 6 to 1, PET technologists were similar at 4 to 1, and radiopharmacists showed ratios of 81 to 1. Therefore, depending on user type, one would expect to see typical ratios between extremity and whole-body readings on personnel dosimetry reports.

Excluding exemplary technique, a minuscule workload or other special circumstances, absence of the expected ratio could indicate one of the following. Workers receiving normal whole-body exposures and no ring badge dose might be suspected of not wearing their ring badge when manipulating radiopharmaceuticals. Workers receiving normal whole-body exposures and very high extremity doses might be suspected of not using syringe shields during injection or dose manipulation, or be suspected of receiving contamination directly to the badge itself. Workers not receiving a whole-body nor extremity exposure when other workers demonstrate occupational exposures might be suspected of not wearing any personnel monitors, or possibly not working in the vicinity of radioactive materials. Workers receiving atypically high whole-body and extremity doses may be suspected of not using time, distance and shielding to their best advantage. Of course, there are always exceptions to these scenarios and it may be helpful to establish the pattern of exposure at your own site.

CONCLUSION

Taking into consideration the occupational groups evaluated for personnel dosimetry, this study showed whole-body exposures for NMTs compared favorably with some of the recently published literature. We concluded the average whole-body exposure to a typical NMT is 1.8 mSv (180 mrem) annually.

This evaluation also provided an opportunity to review exposures of technologists working with PET radiopharmaceuticals. Although their exposures were approximately twice that of occupational exposures in clinical nuclear medicine, their average exposure was well within ALARA limits.

Radiopharmacists are yet another group-specific worker within the nuclear medicine profession. It is interesting to note the similarities and differences in occupational exposures as they compare to other occupational workers within this medical discipline. Also, the evaluation of radiopharmacy unit dose users and generator system users, as a specific group of occupational workers, demonstrated a unique difference in average occupational exposures based on user type.

Finally, extremity to whole-body ratios were evaluated as a means of troubleshooting the efficacy of a radiation safety program for NMTs and radiopharmacists.

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