A Real-Time Monitoring Study of the Personal Dose Received By Nuclear Medicine Technologists Administering ^{18}F-FDG in a High Patient Throughput PET Centre

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Abstract.
The rapid growth in PET studies has resulted in an increasing occupational radiation exposure to nuclear medicine staff. This project has used, a real-time, solid-state, 2 second resolution, personal dosimeter to monitor the occupational Hp(10) equivalent dose of nuclear medicine technologist (NMT) staff managing FDG patients. A detailed manual mapping of the patient management procedure, time dependence and distance relationships to the sources of exposure and their magnitudes was undertaken. Experimental results show, that a junior NMT may spend on average 52% of the close contact time (< 2 m) with the patient when administering an FDG dose compared to 36% of that time for the senior NMT. The average daily dose from isotope administration of a junior NMT and senior NMT is 15 µSv and 11.4 µSv respectively. Post-administration, escorting the patient into the scanner room and setting-up the patient on the PET scanner bed, takes approximately 27% of the junior NMT time to perform, which results in an average daily dose of 7.8 µSv. The senior NMT takes approximately 33% of their time for the same task, with an average daily dose of 10.3 µSv. Removing the patient from the scanner room and escorting them from the department takes about 21% of the junior NMT time giving 6.2 µSv of dose and 31% or 9.7 µSv for the senior NMT. At the conclusion of this study the typical daily dose received by NMT staff, working in close contact with FDG patients is approximately 29 µSv for junior NMT (4 - 5 mSv/yr) and 31.4 µSv (5 - 7 mSv/yr) for senior NMT. Currently this centre is performing approximately 3,400 FDG injections per year plus 50 research injections of various positron emitters. This occupational dose load is spread across 3 dedicated PET NMT staff and 1.5 EFT NMT staff rotating through PET centre from the nuclear medicine department and 1 EFT registrar physician.

KEYWORDS: positron emission tomography, occupational dose, real time dose monitoring

1. Introduction

With the increasing success and developing applications of PET-CT, especially in oncology staging and with newly developing work in dementia diagnostic imaging, it is expected, at Austin Health, that the number of PET scans will soon overtake traditional gamma camera scanning as the major nuclear medicine diagnostic imaging procedure. This expected rapid growth in PET studies has resulted in an increasing radiation exposure cost to nuclear medicine technologists (NMT). Previous work has used TLD monitors to measure the radiation dose to NMT staff working in the PET centre [1, 2]. Electronic monitors have also been used to measure the integral dose per procedure. This pilot study discusses the use of a real-time personal dosimeter to monitor the occupational personal dose equivalent Hp(10) of staff as they manage the preparation and delivery of isotope, injection, caring, transfer, scanning and release of patients from the department.

The accurate assessment of NMT occupational PET exposures requires (1) a detailed knowledge of the sources of exposure and their magnitude, and (2) practical methods for handling the known sources of exposure. NMT staff carrying out PET procedures are exposed during (1) individual patient radiopharmaceutical dose dispensing, (2) administration of the radiopharmaceutical to the patient, principally, 370 MBq ^{18}F-FDG with ~110 min physical half-life, (3) positioning of the radioactive patient for imaging, (4) caring for the patient's well-being, and (5) releasing the patient from the department.

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The literature presents occupational doses in various forms that indicate a spread of doses with not enough information to be able to accurately compare similar situations [1-9]. Benatar [3] found that the average whole body NMT dose was approximately 0.02 μSv/MBq injected with an average daily injected activity of 831 MBq. At close contact, defined as less than 2 metres, an average daily effective dose of 14.4 μSv was received by NMT staff. At Austin Health, Robinson [2] using TLD measured an average daily effective dose of 31 μSv in close contact with each NMT injecting around 1280 MBq/day. Roberts [1] using an electronic dosimeter measured an average whole body dose of 0.01 μSv/MBq injected with most dose being received at injection.

2. Method

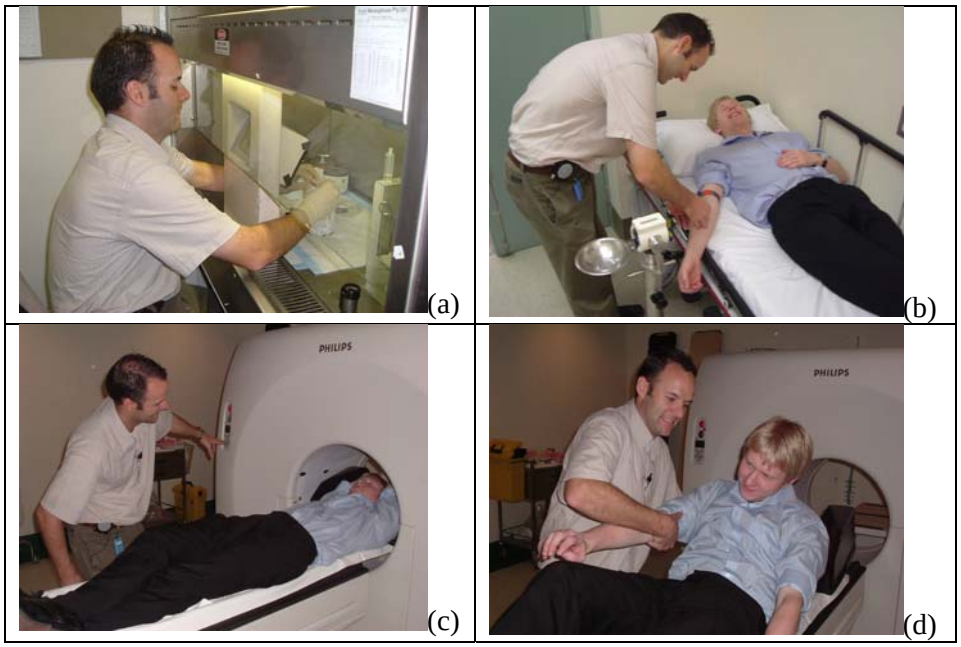
The previous use of thermoluminescent dosimeters (TLD) to measure integral dose provided information that had little temporal and spatial resolution. In this current survey an electronic dosimeter was used with a high temporal resolution of 2 seconds and a careful recording of both action and distance when managing the patient for PET scanning. The electronic dosimeter was an AEGIS-ED2[2] (fig. 1). This unit has the advantage of being compact (H:105 x W:60 x D:20 mm), having a small, solid state detector that can be easily positioned at various anatomical points of interest. It also (i) measures ambient dose equivalent rate (μSv/m), (ii) with a dose range of 0 – 10,000 mSv, (iii) stores data onto an SD[3] card which can be uploaded to a PC, (iv) can sample and store consecutive ambient dosimetry readings at 1 second intervals, (v) has a flat energy response at 511 keV, and (vi) has a good 180° field coverage.

Figure 1: The AEGIS-ED2

During this study the AEGIS-ED2 detector was attached to NMT staff over the sternum. Doses measured with this device were correlated with the standard TLD dosimeter and an additional electronic dosimeter (Polimaster PM1621[4]) worn at the waist. Various NMT staff were asked to wear the dosimeters during a normal working day. The NMTs were classified as experienced and junior as we wanted to investigate the possible dosimetry differences between efficient, experienced staff and staff undergoing training. All NMT staff were shadowed by a junior physicist who noted NMT activities, distances to sources and time spent performing the various functions (fig. 2). This data was then correlated with the continuous AEGIS-ED2 acquisitions. As the device has an internal clock data, function and distance correlation was quite simple.

[2] John Caunt Scientific Ltd., Oxford, UK. [www.johncaunt.com]
[3] The SD card stores user name, user id, instrument serial number, detector serial number, data storage and data fields.
[4] Polimaster Ltd., Minsk, Republic of Belarus. [www.polimaster.com]

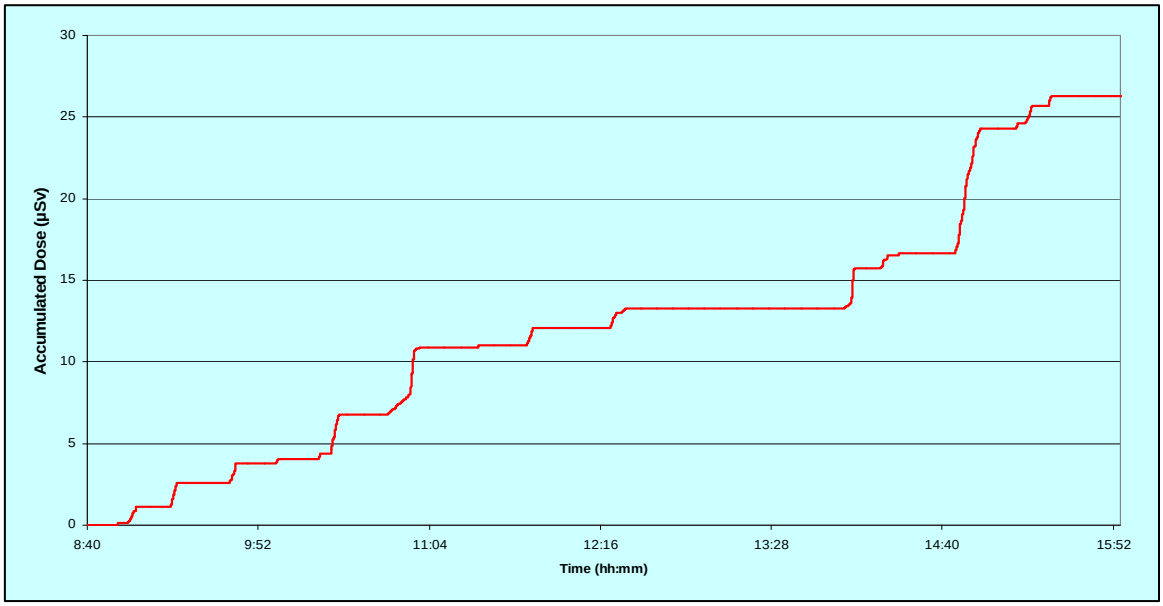
Figure 2: Principal NMT activities in PET scanning – (a) dispensing, (b) administration, (c) positioning, (d) general assistance.



3. Results

Figure 2, (c) and (d), demonstrates the positioning of the AEGIS-ED2 detector at the level of NMT central chest, while (b) and (c) shows the positioning of the TLD and second electronic dosimeter at waist level. The close proximity of NMT staff to source and the various source configurations are also clearly demonstrated in the figure. Figure 3 shows an integral NMT accumulated dose (26.3 μSv) over the course of an average day.

Figure 3: Typical accumulated NMT daily dose (26.3 μSv).



NMT patient management starts at around 08:30 and continues till around 16:00 with clearly punctuated periods of exposure throughout the day. It should be noted that this exposure is only from PET isotopes as PET NMT do not work in the general nuclear medicine department while allocated to

PET. Applying a simplistic, worst case calculation of working 5 days per week for 48 weeks per year yields an annual occupational exposure of 6.3 mSv

Due to its fine temporal resolution the data from the AEGIS-ED2 was used to expand the dose per function in PET scanning. Figure 4 correlates dosimetry with function and time spent in its performance for a junior NMT.

Figure 4: Typical time (min) and instantaneous contributions to the daily dose for a junior NMT.

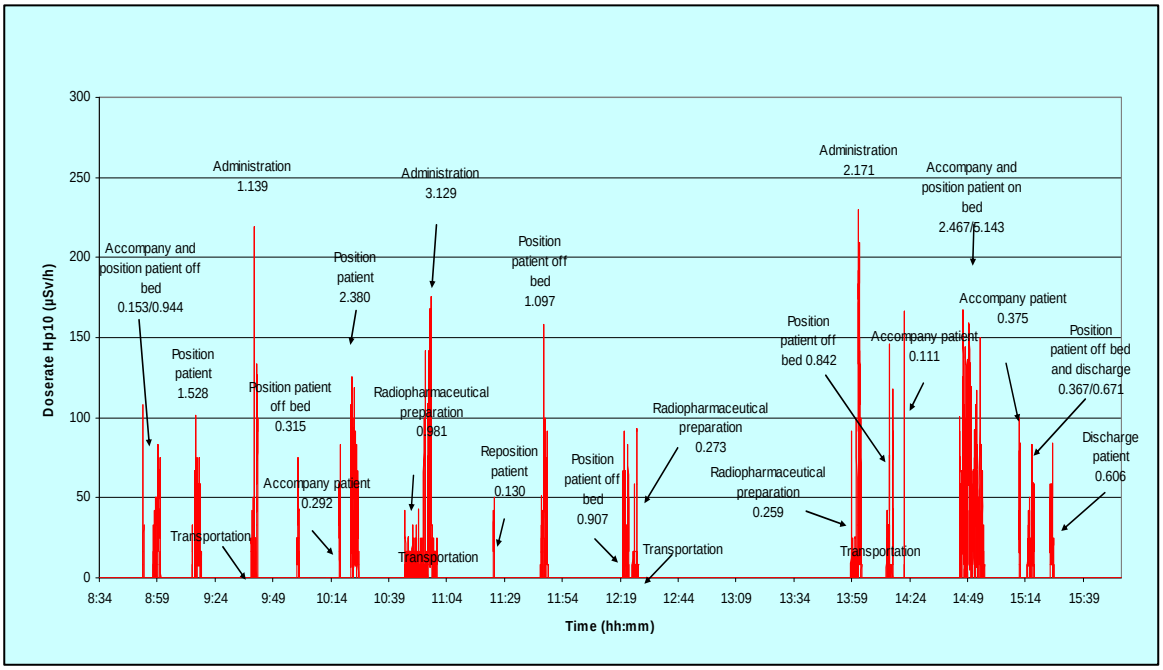
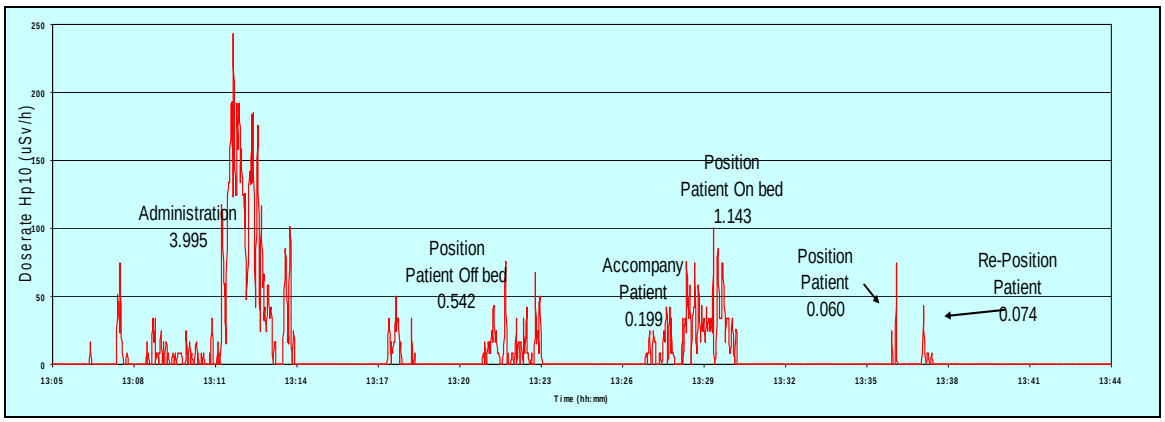


Figure 5 increases the temporal resolution and shows the time dependent exposure of NMT from a single patient.

Figure 5: NMT dose from a single patient.



While typical average figures may give a clear indication from where and when the NMT exposure is being generated, it is also instructive to investigate the range of exposures over many patients delivered across the range of functions that is required to obtain a successful PET scan (table 1). Many factors contribute to this spread of dose, (i) NMT experience and efficiency, (ii) patient compliance, (iii) patient mobility, and (iv) patient support requirements. Table 1 quantifies the great variability in the NMT exposures due to the various factors. The two greatest variables in the dose contribution are the time spent with the patient and the distance that is maintained for the specific function that is being undertaken.

Table 1: Range of NMT doses (μSv) received per activity per patient.

Task	Dose (μSv)			
	Min	Max		Mean
Dispensing	0.26	1.14		0.65 ± 0.37
Transportation	0.34	0.88		0.53 ± 0.25
Administration	1.14	4.02		2.33 ± 0.87
Accompany patient	0.03	2.47		0.39 ± 0.52
Patient positioning	0.03	5.14		1.08 ± 1.0
Caring for patient	0.01	0.49		0.16 ± 0.15
Discharge Patient	0.02	0.67		0.36 ± 0.27

As mentioned previously one contributing variable to NMT occupational dose is the experience of the individual in doing this work. The Centre for PET has an established full time staff who also take junior rotations from the nuclear medicine department. It would not be unexpected that an experienced NMT would have a higher efficiency in performance that may lead to a reduced dose. However, it may also be true that they are more likely to take on the load of more patients, and/or the more difficult, time consuming patients, as well as, the additional time it takes to train the junior staff (table 2).

Table 2: Comparative doses (μSv) from junior and senior NMT staff.

Task	Dose (μSv)	
	Junior NMT mean dose (μSv)	Senior NMT mean dose (μSv)
Dispensing	0.72 ± 0.42	0.49 ± 0.21
Transportation	0.70 ± 0.26	0.35 ± 0.02
Administration	2.49 ± 0.68	2.26 ± 0.98
Accompany patient	0.61 ± 0.84	0.31 ± 0.30
Patient positioning	1.31 ± 1.41	0.95 ± 0.65
Caring for patient	0.43 ± 0.36	0.16 ± 0.15
Discharge Patient	0.72 ± 0.42	0.30 ± 0.22

Table 2 does show diverse readings between junior and senior NMT staff for all activities with the exception of isotope administration.

Clearly, there are significant dose savings for experienced NMT staff in most aspects of source and patient management. One reason may be that junior staff may also take longer with the more social aspects of patient management and PET scanning and may be simply too chatty with the patients. Taking advantage of the time tracking mode of the electronic dosimeter allowed us to tabulate the average time that a NMT spends in close proximity (< 2 metres) to the patient (table 3).

Table 3: Average daily time spent in close proximity (< 2 m) to patients.

	Administration (min)	Pre-scan (min)	Post-scan (min)
Junior NMT	29 (52%)	15 (27%)	12 (21%)
Senior NMT	20 (36%)	18 (33%)	17 (31%)

However, the difference in close proximity time is not simply reflected in the dose per function for the junior and senior NMT staff (table 2). For example, there is a 9 minute average difference in the time spent in close proximity with the patient for administration between junior and senior NMT staff. This is not reflected in the comparative dose per administration of 2.5 μSv for junior NMT staff and 2.3 μSv for senior NMT staff (table 2). As mentioned above, dose savings through the time efficiency of senior NMT staff may be spent on more difficult patients and staff training. Another measure of efficiency is to assess the dose per activity delivered. Once again experience is an important determinant of occupational dose (table 4).

Table 4: NMT dose per MBq injected (μSv/MBq).

	Daily Dose (μSv)	**Mean injected activity per day (MBq)**	**Dose per minute at close contact (μSv/min)**	**Mean dose per injected activity (μSv/MBq)**
Junior NMT	25.0 ± 3.3	1112 ± 589	0.52 ± 0.06	0.03 ± 0.02
Senior NMT	31.6 ± 5.9	2166 ± 322	0.57 ± 0.05	0.014 ± 0.001

Table 3 and 4 indicate the importance of the appropriate use of time and distance in minimising occupational doses. Senior NMT staff spend less time working with the various sources, inject more activity per day and receive a lower dose per injected activity than junior staff. However, their daily dose is higher principally due to the higher and more complex workload.

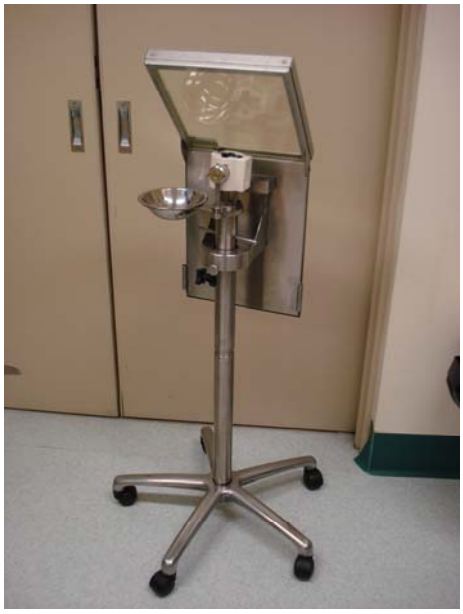
4. Discussion

Table 5: Trends in occupational annual dose (mSv) to PET technologists

Year	**Patients per day**	**Patients per annum**	**Occupational dose per annum (mSv)**	**Number of Technologists**
2002/03	8	1907	3.1 ± 0.3	2.5
2006	14	2800	6.1 ± 1.2	2.5
2007	16	3200	6.8 ± 0.9	3.5

Austin Health has had an active PET scanning program for the past 16 years. In 2002 the numbers of scans were averaging 8 per day. At that stage it was thought prudent to use time efficiency as the prime dose saving method for the various sources. TLD monitoring of staff supported this decision with a quarterly dose to NMT staff of much less than 1 mSv/quarter. However, as mentioned previously and demonstrated in Table 5, with the increasing utility and applications of PET scanning for oncology staging and its potential development in primary dementia diagnosis, as well as, an active and growing research program, the steadily increasing patient throughput has necessitated the use of additional mobile shielding for isotope transport and administration (fig. 6).

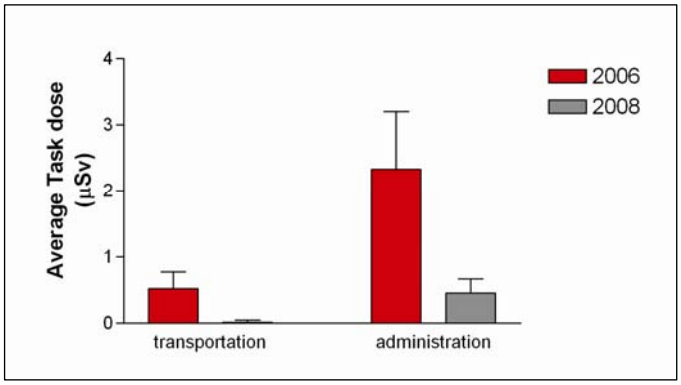
Figure 6: Mobile PET shield[5]



Recently, NMT staff have been using a mobile shield for isotope transport and administration (fig. 6). The shield has 3 shielded sections (i) a 10 mm lead body shield (370 mm x 300 mm), (ii) a 8 mm lead equivalent glass window shield (280 mm x 280 mm), and (iii) 20 mm lead syringe holder. The predominant isotope in use is ^{18}F which has a half-value layer and tenth-value layer thickness of 6 mm and 17 mm of lead respectively [10]. The use of the additional shielding has resulted in an indicative dose reduction of approximately 90% and 75% in transport and administration respectively (fig. 7) [11]. The PET centre at Austin Health is currently undergoing refurbishment to install another PET system to be used primarily for head scanning. Currently the Centre for PET has 2 PET cameras. With the addition of another camera and its consequent increase in patient and isotope load, we expect to find a measurable increase in NMT occupational dose if there is not a range of practical measures instituted to minimise occupational exposure. One obvious addition would be the purchase of mobile shields for patient positioning in the scanner rooms.

Figure 7: Mobile PET shield dose savings per task

Future work will focus on the contribution of mobile sources, principally human, and the input these make to an expected increase in area background dose.



In 1992, when the Centre for PET was initiated, structural shielding calculations were for one PET camera and two administration rooms, made with what were thought to be appropriate conservative assumptions. Then an additional PET/CT was purchased with 2 additional administration rooms and soon there will be another additional PET scanner for research. This will require further isotope administration uptake rooms with multiple patient sources walking through the PET centre as essentially unshielded sources. These human mobile sources are expected to add a measurable radiation burden to the current background radiation within the department. These mobile sources will be mapped with an area survey technique of continuous monitoring to assess their contribution to staff occupational dose. There will also be an increasing focus on the occupational exposure of our radiopharmacists, especially finger and extremity doses.

5. Conclusion

The current survey has shown that a significant range of source contributions to occupational dose can be expected across NMT staff working in a PET centre. Dose variations are heavily dependent upon the experience of the NMT staff, their inherent level of performance efficiency and the provision of appropriately shielded equipment.

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