SHORT COMMUNICATION

Radiation protection in fixed PET/CT facilities—design and operation

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ABSTRACT. We describe the design of a fixed positron emission tomography (PET)/CT facility and the use of a simulated instantaneous dose-rate plot to visually highlight areas of potentially high radiation exposure. We also illustrate the practical implementation of basic radiation protection principles based on the use of distance and shielding and the minimisation of time spent in hot areas. Staff whole body doses for 4 years are presented with results of an optimisation study analysing the dose arising from the different phases within each study using direct reading dosimeters. The total whole body dose for all staff for each patient fell from 9.5 μSv in the first full year of operation to 4.8 μSv in 2008. The maximum dose to an individual member of staff per patient decreased over the same period from 3.2 to 0.9 μSv . The optimisation study showed that the highest dose was recorded during the injection phase.

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Positron emission tomography (PET)/CT scanning using 18-F fludeoxyglucose (¹⁸F-FDG) has been shown to have a beneficial impact on patient management and has become an established technique, particularly for the staging of some cancers [1]. Scanners have been installed in or alongside some large Nuclear Medicine departments to take advantage of the clear clinical benefits. However, the layout and logistical arrangements of some new and existing nuclear medicine facilities have proved a challenge. The uptake phase of up to 60 min per patient and the high-energy γ -ray of 511 keV emitted by the radionuclide are particularly challenging in keeping staff doses as low as reasonably practicable (ALARP) [2]. In the UK, dose constraints for staff and members of the public are generally set lower than those adopted in the USA, which creates even greater design challenges in the UK [2, 3]. Shielding has not always been incorporated into the walls of some rest rooms [4] and there are reported examples of existing rooms within a nuclear medicine department being adapted [2].

Staff doses have been reported to be potentially high [4–10], with a range of total dose for all the “hot” steps within a procedure reported to be 5.0–5.7 μSv per procedure [9]. For studies with dose measurements recorded over the working day, the reported dose was 5.5–11.5 μSv per procedure using readings from direct reading dosimeters [5, 8]. From whole body thermoluminescent dosimeter measurements, doses of 3–12 μSv per patient for each

staff member have been reported, which totalled 9–21.6 μSv to all members of staff [4, 6]. This article describes the approaches used to keep the doses to staff and the public ALARP and includes the design of the facility within an existing structure shared with non-radiation workers.

Methods and materials

Facility design

The unit was designed within a limited space in an existing single storey building. A dose constraint of 0.3 mSv per year was adopted in occupied areas and an allowance was made in some cases for occupancy. The distance from the proposed resting bays to the control room was <4 m. The internal walls were constructed from solid concrete blocks (density: 2000 kg m⁻³) and the same material was used for any necessary additional shielding to meet the constraint. Shielding to protect from scattered CT radiation was extended up to the full ceiling height. Attenuation of the 511 keV γ -radiation was calculated using a tenth-value layer (TVL) of 176 mm for the concrete blocks. Injected activity was assumed to be 400 MBq, the dose rate was conservatively assumed to be 65 $\mu\text{Sv h}^{-1}$ at 1 m post-injection [11] and a decay correction was incorporated into the calculations.

The design was developed taking into consideration the flow of the patient through the unit and the relative positions of the radioactively “hot” patients, staff and members of the public including staff working in other

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Figure 1. Diagram of the building showing the positron emission tomography suite and other adjacent areas including the instantaneous dose rates.

areas of the building. The dose rate in corridors and the control room were also designed to be as low as possible (Figure 1).

Dose minimisation during routine operation

Dose was minimised by staff instruction and training to maximise the distance between themselves and the hot patients and to use the protection of lead shielding, walls and the gantry whenever practical. Electronic personal dosimeters were used as a constant reminder of exposure. Shielded dispensing units, syringe shields and carriers were used from the start. Time was minimised by practising operations with inactive material before using radioactive material. The patient injection process was considered to have the greatest potential for high staff exposure because once the material had been injected shielding can no longer be used. Cannulation was adopted as a routine method to reduce the time spent in the rest bays post-injection. Staff position during scan set up was carefully considered. Staff were encouraged to stand in two identified positions, at the end of the bed or to the side of the gantry, to reduce dose. Patient preparation and co-operation were considered to be critical and patients were encouraged to empty their bladder and get on and off beds independently where clinically practical.

A small study was undertaken to investigate the dose from each stage of the process. Doses were measured for a cohort of 140 patients using direct reading dosimeters during July 2007. Thermo EPD Mk2 dosimeters (Thermo Fisher Scientific, Waltham, MA) with a minimum display of $1 \mu\text{Sv}$ were used. The readings and exact timings were recorded at the beginning and end of each phase of the workflow (Figure 2).

To reinforce the work instructions, a dose rate map around the facility was developed for display within the unit from January 2008. This was simulated using Excel (Microsoft Corporation, Redmond, WA) assuming a single point source of radiation, isotropic emissions and using the inverse square law. The spreadsheet was set up to mimic the layout of the unit and calculations were based on an assumed dose rate of $45 \mu\text{Sv h}^{-1}$ at 1 m immediately post-injection [5]. This value was also confirmed by local measurement. Attenuation through barriers was also taken into account and corrections were made for source decay. The calculated data were then displayed as a surface colour plot.

The spreadsheet was semi-automated so that different scenarios could be considered. These included the number and position of patients in the unit at any one time and the dose rates from patients at different stages in the process. They also reflected the realistic interval between injections.

Figure 2. Positron emission tomography/CT workflow diagram showing phases of staff exposure in red. FDG, fludeoxyglucose.

Results

Based on the shielding calculations, walls of 75–215 mm solid concrete blocks were constructed within the unit. An additional floor was added to an adjacent building during construction, but calculations and measurements confirmed that this did not affect the design of the unit.

Typically, three members of staff who were core trained PET/CT staff and assistants worked each day in the unit. Staff whole body doses were collated from the results of the approved dosimetry service and are shown in Table 1. Badges were changed monthly and were reported to have a minimum reading of 0.1 mSv until the end of 2008, when the minimum reported dose was reduced to 0.05 mSv. The maximum recorded dose to an individual member of staff divided by the number of patients examined in the facility is also reported.

The mean dose for each phase of the examination from the doses recorded in the optimisation study of 140 patients is shown in Figure 3. The mean total dose per patient was $5.1 \pm 0.3 \mu\text{Sv}$.

The dose rate plot around the facility is shown in Figure 1, which illustrates the worst case scenario for staff with full occupancy within the unit. The coloured plot uses green to indicate dose rates of $<7.5 \mu\text{Sv h}^{-1}$ and darker shades of red to show higher dose rates. The staff positions adopted for patient set up were confirmed to be optimum. The indications on the dose rate plot of areas where dose rates were higher, visually reinforced the established local practice, in particular, avoiding standing in the opening to the rest rooms to call patients through to empty their bladder before scanning and the corridor by the entrance to the scanner.

Discussion

Consideration of the dose rates and transmission properties of PET radionuclides suggest that, when PET/CT scanning is introduced, some additional shielding is likely to be required within the facility so that staff and members of the public are protected. Publications since the construction of the unit support this [2, 3] despite the constraints and dose limits in the USA being higher than those in the UK. Without structural shielding between hot patients and the control room being incorporated into the design, staff would have been exposed to an additional dose of up to 10 mSv per annum because most of their time is spent in this area. The choice of dose rates and attenuation properties of different material can be a matter of judgement, with a number of publications quoting a range of values for each [2, 4, 5, 11]. The value of dose rate from the patient chosen for this design of $65 \mu\text{Sv h}^{-1}$ at 1 m now seems somewhat conservative. A more appropriate figure is thought to be $45 \mu\text{Sv h}^{-1}$ at 1 m. However, the attenuation value used was a TVL of 150 mm for concrete (density, 2350 kg m^{-3}). This value was estimated in conjunction with a number of other radiation protection advisors working with PET radionuclides from published data available at the time for a TVL in concrete for ^{137}Cs [12] of 163 mm (γ -emission at 662 keV). The value of 150 mm was then corrected for the concrete blocks by scaling using the ratio of physical density. Recent information suggests the TVL for ^{18}F is 176 mm [2] using Monte Carlo simulations.

This work describes the approach to the design and operation within the unit to give staff dose the highest priority while ensuring patient comfort and safety. The

Table 1. Doses per annum and number of patients

Year	Total dose to all staff/ TLD results (mSv)	Number of patients	Total dose to all staff per patient (μSv)	Maximum dose to an individual staff member per patient (μSv)
2005	5.3	558	9.5	3.2
2006	7.3	919	7.9	2.6
2007	5.8	1056	5.5	1.3
2008	6.1	1272	4.8	0.9

TLD, thermoluminescence dosimeter.

Mean Dose (μSv) for each task per patient

Figure 3. Mean dose for each phase of the examination.

optimisation study shows that the total dose from all stages of the process (mean, $5.1 \mu\text{Sv}$ per patient) to the staff involved while in contact with the patient are similar to those reported at another site [9].

Total dose to all staff is in line with another study within the UK [5] despite injecting 370 MBq rather than 320 MBq , but is much lower than those quoted in other countries [6, 8]. A recent study from Canada [4] indicates the total dose to two technologists was $21.6 \mu\text{Sv}$ per patient and flags that no shielding was incorporated into the rest rooms. Doses in the first full year of operation in 2005 in this study were $9.5 \mu\text{Sv}$ per patient. The optimisation study took place in 2007 and resulted in an emphasis placed on all staff to minimise contact after injection. During 2008, when the dose rate plot was on display, doses to all staff were measured at $4.8 \mu\text{Sv}$ per patient.

The introduction of the dose rate plot reinforced the hotter and colder areas and demonstrated the optimum positions for the staff to stand during patient set up and at the end of the rest phase when patients leave the rest bays. It was felt that novel ways of communicating the hazard to staff in PET units can reinforce the basic message of distance, shielding and time. As the plots appear helpful to staff working in the unit, there is a plan to extend this work by looking at the distribution of lower dose rates to investigate if further optimisation is possible and to compare results with Monte Carlo modelling.

Conclusion

The design of a fixed PET/CT facility and the use of a simulated instantaneous dose rate plot within that facility to visually highlight areas of potentially high radiation exposure have been described. The importance of a robust design using shielding where appropriate has been highlighted. Detailed measurements can identify the processes where the highest doses are received and optimisation can occur. A number of simple but effective tools

can be used to optimise each stage of the process. Dose rate maps can be an additional powerful tool in maintaining doses ALARP with visual reminders to minimise the time spent in hot areas and to use the inverse square law and structural shielding wherever possible.

References

1. Ell PJ. The contribution of PET/CT to patient management. *Br J Radiol* 2006;79:32–6.
2. Madsen MT, Anderson JA, Halama JR, Kleck J, Simpkin DJ, Votaw JR, et al. PET and PET/CT shielding requirements AAPM Task report 108. *Med Phys* 2006;33:4–15.
3. Health and Safety Executive. Work with ionising radiation. Ionising radiations regulations 1999. Approved code of practice and guidance. London: Health and Safety Executive, HSE Publication L121; 2000.
4. Zeff BW, Yester MV. Patient self attenuation and technologist dose in PET. *Med Phys* 2005;32:861–5.
5. Benetar NA, Cronin BF, O'Doherty MJ. Radiation dose rates from patients undergoing PET implications for technologists and waiting areas. *Eur J Nucl Med* 2000;27:583–9.
6. Guillet B, Quentin P, Waultier S, Bourrelly M, Pisano P, Mundler O. Technologist radiation exposure in routine clinical practice with F18 PET. *J Nucl Med Tech* 2005;33:175–9.
7. Roberts FO, Gunawardana DH, Pathmaraj K, Wallace A, Paul LU, Mi T, et al. Radiation dose to PET technologists and strategies to lower occupational exposure. *J Nucl Med Tech* 2005;33:44–7.
8. Chiesa C, De Sanctis V, Crippa F, Schiavini M, Fraigola C, Bogni A, et al. Radiation dose to technicians per nuclear medicine procedure. *Eur J Nucl Med* 1997;24:1380–9.
9. Alsafi K, Groontoonk S, Roberts F, Spyrou NM. Radiation exposure of technical staff operating mobile PET/CT scanners. *Nuc Med Comm* 2007;28:A31.
10. White S, Binns D, Johnston M, Fawcett B, Greer B, Ciavarella F, et al. Occupational exposure in nuclear medicine and PET clinical positron. *Imaging* 2000;3:127–9.
11. Delacroix D, Guerre JP, Leblanc P, Hickman C. Radionuclide and radiation protection data handbook. *Rad Prot Dos* 1998;76:24.
12. Handbook of radiological protection. Part 1 Data. Her Majesty's Stationery Office, 1971.