

Designing of High-Volume PET/CT Facility with Optimal Reduction of Radiation Exposure to the Staff: Implementation and Optimization in a Tertiary Health Care Facility in India

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Abstract

Positron emission tomography (PET) has been in use for a few decades but with its fusion with computed tomography (CT) in 2001, the new PET/CT integrated system has become very popular and is now a key influential modality for patient management in oncology. However, along with its growing popularity, a growing concern of radiation safety among the radiation professionals has become evident. We have judiciously developed a PET/CT facility with optimal shielding, along with an efficient workflow to perform high volume procedures and minimize the radiation exposure to the staff and the general public by reducing unnecessary patient proximity to the staff and general public.

Keywords: Nuclear medicine procedure and professional exposure, positron emission tomography/computed tomography procedure, radiation dose, radiation safety

Introduction

Stand-alone positron emission tomography (PET) scanners have been available for more than 35 years but their use was not widespread as an independent modality. The fusion of morphological imaging in the form of computed tomography (CT), along with the physiological imaging of PET as an integrated PET/CT scanner brought a new dimension in imaging.^[1,2] This technique, being a noninvasive diagnostic imaging tool, takes advantage of certain metabolites in the form of radiopharmaceuticals to trace the abnormal metabolic activity in the body. At the same time, the small quantity of tracer dose not alter the normal

physiological processes of the body.^[3] In the last few years, PET/CT has made a significant impact on patient management in oncology. Increasing indications of PET/CT in various oncological conditions have made this system an integral part of nuclear medicine departments. However, the increasing workload in nuclear medicine departments has also increased concerns among radiation professionals regarding radiation exposure, and thereby the responsibilities of a Radiation Safety Officer (RSO) to minimize radiation exposure for the professionals, the patients, and the general public. International Council on Radiological Protection (ICRP), International Atomic Energy Agency (IAEA), and other national agencies have published guidelines to limit occupational radiation exposure and prescribed the maximum radiation exposure limit for the professionals, the general public, and the environment.^[4,5] These agencies advocate the implementation of "As Low As Reasonably Achievable" (ALARA). In order to achieve ALARA at workplace, the radiation safety aspect has to be implemented at each and every stage of project planning and implementation. Proper layout and workflow design

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of nuclear medicine facility, along with an optimal isotope procurement and consumption planning may reduce the radiation burden on the professionals, the patients, the general public, and the environment at large.^[6] National and international enforcement agencies have prescribed the layout design of PET/CT and nuclear medicine facility for better workflow management. In India, the Atomic Energy Regulatory Board (AERB) has prescribed the model layout plan for PET/CT facility.^[7,8] However, in our existing tertiary health care facility with old infrastructure and the unavailability of space, implementation of these prescribed layouts was not possible. So we had to design a layout plan in the available space for better implementation of radiation safety norms to achieve ALARA. The new PET/CT facility was to be added to the existing PET/CT and single photon emission computed tomography (SPECT)/CT facilities.

Materials and Methods

The new PET/CT facility was designed in the allotted 156 m² (6 m × 26 m) area across the corridor of our existing department. The model plan [Figure 1] provided by the competent authority in our country, i.e. AERB is meant for a site measuring about 12 m × 13 m (total 156 m²). So, though the area was adequate for a PET/CT facility, the model plan could not be implemented because of its size. Hence, we modified the plan and developed a radiation safety compliant department and designed the entire workflow to perform high-volume work, i.e. around 35 PET/CT procedures every day. We also planned fludeoxyglucose (FDG) procurement schedule, patient appointment for high throughput with minimum amount of radiation exposure to the professionals and the patients. We calculated the expected radiation exposure to the radiation worker working in this department. We also compared radiation exposure received by the radiation workers working in the new and old PET/CT facilities together in 2013 with that of the old PET/CT facility in 2012.

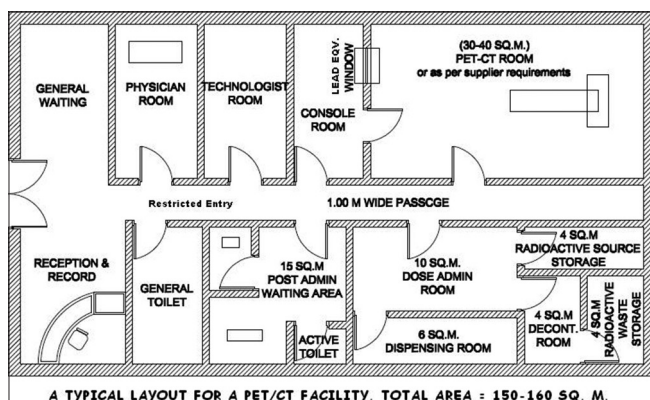


Figure 1: Model plan provided by AERB

The calculated values for expected annual radiation exposure were compared with the actual readings of the staff for 2012 and 2013 to assess the effectiveness of the workflow and facility design in reducing radiation exposure.

Design of PET/CT facility

The initiative of radiation safety should start at the time of designing of the radiation facility and radiation safety must be guaranteed by the facility design itself. The layout plan, patient movement plan, construction materials, and workplace shielding have to be decided keeping in mind radiation safety of the professionals, the patients, and the general public as well as the workload and workflow to achieve the concept of ALARA.

We have designed the PET/CT layout keeping in mind the high throughput with ALARA as the central focus of the concept. A dose constraint of 0.1 mSv per year was adopted in occupied areas. Figure 2 shows the layout plan of our newly developed PET/CT facility. The design was developed taking into consideration the movement of the patient through the unit and the relative positions of the injected patients with reference to the staff and members of the public, which also included those staff working in adjacent departments of the hospital. The layout consists of the nursing station, the radiopharmacy room, the injection room, the postinjection patient waiting room, the radioactive toilet, the postscan holding room, the PET/CT scanner room, and the operating console room.

Design of work area

There are two types of radiation sources present in the nuclear medicine department: (i) radioisotope and (ii) the injected patients. The radioisotope present in the department can be confined and shielded to achieve negligible radiation exposure from it when not in use but during handling, it is necessary to minimize the exposure by means of proper planning of the work by using remote handling equipments and good work practice. Emphasis has been placed on developing each area of the facility keeping in mind the nature of radiation exposure. The source of radiation in various parts of the design is as follows: On the dispensing table, radioactivity in the vials and syringes; in the injection area, radioactivity in

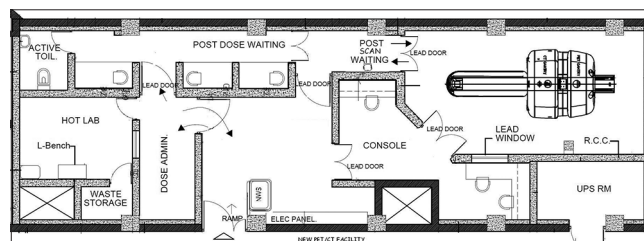


Figure 2: Layout plan of our newly developed PET/CT facility

the syringes and the injected patients; in the postdose waiting area, the injected patients; and in console, the injected patients and scatter from CT.

Dispensing table

We used 100-mm-thick lead bricks to shield the entire dispensing area from all around and L-bench with 50-mm lead equivalent lead glass [Figure 3], along with a 40-mm-thick dispensing module. Dose vial is directly delivered from the on-site cyclotron to our dispensing area by pneumatic chute in a 25-mm-thick lead container in the form of lots. Each lot contains 1850 MBq of ¹⁸F isotope. Six lots amounting to 11.1 GBq are received in total. The surface dose rate from the container containing 1850 MBq of ¹⁸F isotope is 2.48 mSv/h and at 50 cm, the exposure rate is 0.009 mSv/h that is within the prescribed limits. The dose vial is then transferred into the dispensing module and individual doses are dispensed.

Injection area

The injection room is constructed separately with 220-mm-thick reinforced cement concrete (RCC) wall. All the injections are injected in this room. Intravenous (IV) access is obtained and the radiopharmaceutical is injected through an aperture between the injection room and the adjoining radiopharmacy [Figure 4]. The physician and the nursing staff stand in the radiopharmacy room throughout the procedure and are able to inject and monitor the patient through the aperture. This keeps radiation exposure to the professionals at a minimum as they are shielded from the injected patient by the 220-mm-thick RCC wall.^[9]

Postdose waiting area

The injected patient is then directed to the postdose waiting area where he/she can rest comfortably during the uptake period. The walls of postdose waiting area

are made up of 300-mm-thick RCC, resulting in an exposure rate of about 1.22 μ Sv/h (for a patient injected with 300 MBq of ¹⁸F radiopharmaceutical at a distance of about 1 m).

Operating console room

The wall separating the console room from the PET/CT scanner room is a 300-mm-thick RCC wall with 4-mm lead equivalent lead glass window.

The shielding effectively reduces the exposure to about 0.19 μ Sv/h (RCC) and 3.1 μ Sv/h (lead glass).

Workflow management

Planning and streamlining the workflow properly and consistently can effectively minimize radiation exposure to the professionals [Figure 5]. At the same time, effective sharing of the workload among the professionals may also be introduced to minimize individual radiation exposure.

The patients referred for a PET/CT study are attended at a dedicated counter for appointments. Appointment is scheduled by the trained staff present at the counter and detailed scan-specific instructions are provided to the patient at the time of appointment. On the appointed date, the patient reports at nursing station where the nurse in charge verifies the patient details and tests prescribed, and refers him/her to the resident doctors for documenting relevant clinical history. Relevant instructions are provided to the patient regarding the prescan and postscan precautions. He/she then proceeds to the injection room. A continuous flow of patients is maintained with a patient being injected approximately every 20 min.

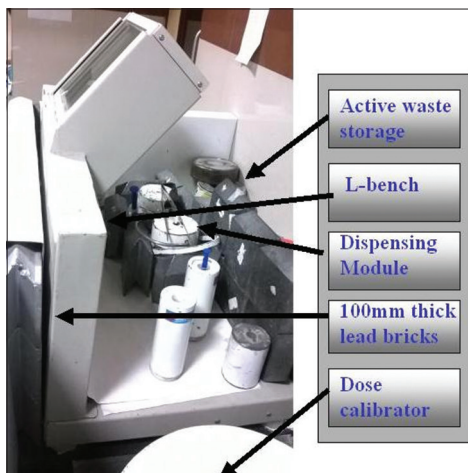


Figure 3: Radioisotope dispensing table



Figure 4: Injection area with aperture for injections (a) staff nurse is fixing IV line, (b) patient is extending hand through aperture, (c) doctor is injecting radiopharmaceutical, and (d) injection process is finished

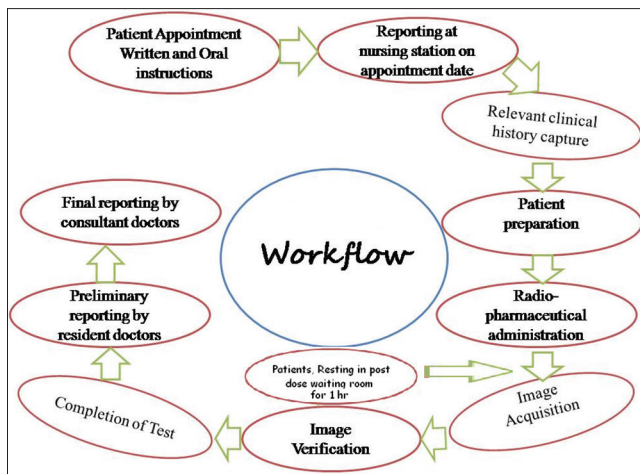


Figure 5: Workflow design of department

After injection, the patients wait in the postinjection waiting area in isolation during the uptake period. During this time, the patient is monitored on closed circuit television (CCTV). The patient can communicate with the staff at any time using an audio system remotely. After 60 min of injection, the patient is instructed on the audio system to void his/her bladder and come to the machine room for scan.

Subsequent to the scan, the patient is instructed to wait in the postscan waiting area until the acquired images are verified by the physician. Once the study is deemed to have been acquired adequately, the patient is instructed to leave the department.

Planning workflow and dose calculation

We planned for 35 patients per day for 5 days a week and with 52 weeks in a year, with the total number of patients to be scanned per year as $35 \times 5 \times 52 = 9100$. Each patient is injected on an average of 225 MBq. The approximate time required for dispensing one dose of isotope is 15 s. The time for injection is again 15 s. The time required to remove the IV cannula is 15 s. The total time spent with one patient for patient positioning is 60 s. The average time spent by the technologists or the nurses with the patient during uptake time for giving any special instruction is around 60 s. The average time spent by the nuclear medicine physician with the patient after imaging to take any important clinical history is around 60 s.

Dose calculation

Prior to the injection, the required dose of radiopharmaceutical has to be transferred from the vial to the syringe. This operation is carried out behind the lead shield. The shields used in this case are lead bricks and lead glass, but the hands remain unprotected.

Because of the high effective dose rate constant associated with positron-emitting radionuclides, hand

dose to the individuals drawing up and administering PET radiopharmaceuticals can be substantial. The dose rate at 5 cm from an unshielded syringe source with the typical administered activity of 225 MBq is

$$D = (\Gamma \cdot A) / (d^2)$$

$$= (0.000139 \text{ mSv m}^2/\text{hMBq} \cdot 275 \text{ MBq}) / (0.05 \cdot 0.05)$$

$$= 15.29 \text{ mSv/h}$$

where,

D = dose rate at 5 cm

Γ = dose rate constant of ^{18}F isotope at 1 cm^[10]

A = total activity

d = distance.

Technologists

Transferring radioactivity container (hot capsule) from pneumatic chute to L-Bench

Assuming that all hot capsules contain 1850 MBq of activity and the time taken to transfer the capsule from pneumatic chute station to L-Bench is 10 s,

$$t = 10 \text{ s} = 10 / (60 \cdot 60) \text{ h}$$

Hot capsules are received six times in a day and 240 days in a year, resulting in a total of 1,440 times in a year (T)

The surface dose rate from hot capsule (R) = 2.48 mSv/h (for extremity dose calculation)

The dose rate at 50 cm from hot capsule (R_1) = 0.009 mSv/h (for whole body dose calculation)

So, the annual dose received by the technologists in transferring the hot capsule is

$$\text{Extremity} = (T \cdot R \cdot t)$$

$$= (1440 \cdot 2.48 \text{ mSv/h} \cdot 10) / (60 \cdot 60)$$

$$= 9.92 \text{ mSv}$$

$$\text{Whole body} = (T \cdot R_1 \cdot t)$$

$$= (1440 \cdot 0.009 \text{ mSv/h} \cdot 10) / (60 \cdot 60)$$

$$= 0.036 \text{ mSv}$$

Transferring radioactivity vial from hot capsule to dispensing module in L-Bench

Assuming that all hot capsules contain 1,850 MBq of activity and the time taken to transfer the capsule from the hot capsule to dispensing module is 10 s.

The dose rate from dose vial at 50 cm (R) = 1 mSv/h (for extremity dose calculation)

So, the annual dose received by the technologists in transferring the hot capsule is

$$\begin{aligned} \text{Extremity} &= (T * R * t) \\ &= (1440 * 1 \text{ mSv/h} * 10) / (60 * 60) \\ &= 4 \text{ mSv} \end{aligned}$$

The whole body dose rate outside the L-Bench is negligible.

Dispensing of a single dose

Assuming that each dispensing may take 10 s (1/240 h), the total hand dose received by all the technologists together during dispensing in 1 year would be

$$\begin{aligned} \text{Extremity} &= (R_2 * t * N) \\ &= 15.29 \text{ mSv/h} * 1 / 360 \text{ h/pat} * 9100 \text{ pat/year} \\ &= 386.5 \text{ mSv/year} \end{aligned}$$

where,
 R_2 = 15.29 mSv/h is the dose rate at 5 cm from 275 MBq activity (average activity of ^{18}F radiopharmaceuticals for injection)
 t = time in hour (10 s = 1/360 h)
 N = number of patients in a year.

The whole body radiation exposure outside the lead bench is negligible.

Dose received during patient positioning and planning

Assuming that a technologist may spend a cumulative time of 5 min with every patient at 50 cm distance during patient positioning, planning, or for any other purpose, the dose to the technologist would be

$$\begin{aligned} D &= [\Gamma * A / (d^2) * t * N * K * R_i * T] \\ &= ((0.000139 \text{ mSv m}^2/\text{h MBq} * 275 \text{ MBq}) / (0.5 \text{ m})^2) * 1 / 12 \text{ h/pat} * 9100 \text{ pat/year} * 0.64 * 0.643 * 1 \\ &= 47.72 \text{ mSv/year} \end{aligned}$$

where,
 Γ = 0.000139 mSv m²/h/MBq is the dose rate from the injected patient at a distance of 1 m
 A = injected activity (275 MBq)
 d = distance from the patient
 t = time in hour (5 min = 1/12 h)
 N = number of patients in a year

K = 0.64 (patient attenuation)^[11]
 R_i = dose reduction after 1 h = 0.643^[11]
 T = 1 (full occupancy).

Physician

Assuming that each injection may take about 5 s, the total hand dose received by the nuclear medicine physicians together due to injection in 1 year would be

$$\begin{aligned} \text{Extremity} &= R_2 * t * N \\ &= 15.29 \text{ mSv/h} * 1 / 720 \text{ h/pat} * 9100 \text{ pat/year} \\ &= 193.25 \text{ mSv/year} \end{aligned}$$

where,
 R_2 = 15.29 mSv/h is the dose rate at 5 cm from 275 MBq activity (average activity of ^{18}F radiopharmaceuticals for injection)
 t = time in hour (5 s = 1/720 h)
 N = number of patients in a year.

Assuming that the nuclear medicine physicians may spend 1 min with every patient during the injection process, the whole body dose would be

$$\begin{aligned} D &= [\Gamma * A / (d^2) * t * N * K * R_i * T] \\ &= ((0.000139 \text{ mSv m}^2/\text{h MBq} * 275 \text{ MBq}) / (0.5 \text{ m})^2) * 1 / 60 \text{ h/pat} * 9100 \text{ pat/year} * 0.64 * 1 * 1 \\ &= 14.84 \text{ mSv/year} \end{aligned}$$

where,
 Γ = 0.000139 mSv m²/h/MBq is the dose rate from the injected patient at a distance of 1 m
 A = injected activity (275 MBq)
 d = distance from the patient
 t = time in hour (5 min = 1/12 h)
 N = number of patients in a year
 K = 0.64 (patient attenuation)^[10]
 R_i = dose reduction just after injection = 1
 T = 1 (full occupancy).

Likewise, assuming that the nuclear medicine physicians may spend 2 min with every patient after scan for taking relevant history if required, then

$$\begin{aligned} D &= [\Gamma * A / (d^2) * t * N * K * R_i * T] \\ &= \{(0.000139 \text{ mSv m}^2/\text{h MBq} * 275 \text{ MBq}) / (0.5 \text{ m})^2\} * 1 / 30 \text{ h/pat} * 9100 \text{ pat/year} * 0.64 * 0.643 * 1 = 19.09 \text{ mSv/year} \end{aligned}$$

where,
 Γ = 0.000139 mSv m²/h/MBq is the dose rate from the injected patient at a distance of 1 m

A = injected activity (275 MBq)
 d = distance from the patient
 t = time in hour (2 min = 1/30 h)
 N = number of patients in a year
 $K = 0.64$ (patient attenuation)^[11]
 R_t = dose reduction after 1 h = 0.643^[11]
 $T = 1$ (full occupancy).

Nurses

Assuming that the nurses may spend 2 min with every patient just after injection,

$$D = [\Gamma * A / (d^2) * t * N * K * R_t * T]$$

$$= ((0.000139 \text{ mSv m}^2/\text{h MBq} * 275 \text{ MBq}) / (0.5 \text{ m})^2) * 1/30 \text{ h} / \text{pat} * 9100 \text{ pat/year} * 0.64 * 1 * 1 = 41.56 \text{ mSv/year} = 29.68 \text{ mSv/year}$$

where,

$\Gamma = 0.000139 \text{ mSv m}^2/\text{h/MBq}$ is the dose rate from the injected patient at a distance of 1 m

A = injected activity (275 MBq)

d = distance from the patient

t = time in hour (5 min = 1/12 h)

N = number of patients in a year

$K = 0.64$ (patient attenuation)^[11]

R_t = dose reduction just after injection = 1

$T = 1$ (full occupancy).

Assuming that the nurses may spend 2 min with every patient at the end of the scan at around 1 h postinjection,

$$D = [\Gamma * A / (d^2) * t * N * K * R_t * T]$$

$$= ((0.000139 \text{ mSv m}^2/\text{h MBq} * 275 \text{ MBq}) / (0.5 \text{ m})^2) * 1/30 \text{ h} / \text{pat} * 9100 \text{ pat/year} * 0.64 * 0.643 * 1 = 19.09 \text{ mSv/year}$$

where,

$\Gamma = 0.000139 \text{ mSv m}^2/\text{h/MBq}$ is the dose rate from the injected patient at a distance of 1 m

A = injected activity (275 MBq)

d = distance from the patient

t = time in hour (2 min = 1/30 h)

N = number of patients in a year

$K = 0.64$ (patient attenuation)^[11]

R_t = dose reduction after 1 h = 0.643^[11]

$T = 1$ (full occupancy).

Total estimated dose for the nuclear medicine technologists, physicians, and nurses are as follows:

Nuclear medicine technologists

Total whole body radiation exposure to all the technologists together in 1 year = 0.036 mSv/year + 47.72 mSv/year = 47.76 mSv/year

Total extremity (hands) radiation exposure to all the technologists together in 1 year = 9.92 mSv/year + 4 mSv/year + 386.5 mSv/year = 400.42 mSv/year

Nuclear medicine physicians

Total whole body radiation exposure to all the physicians together in 1 year = 14.84 mSv/year + 19.09 mSv/year = 33.93 mSv/year

Total extremity (hands) radiation exposure to all the physicians together in 1 year = 193.25 mSv/year

Nuclear medicine nurses

Total whole body radiation exposure to all the nurses together in 1 year = 29.68 mSv/year + 19.09 mSv/year = 48.77 mSv/year.

The total annual extremity dose for all the nurses together will be equivalent to the total annual whole body dose, as they personally do not handle the radioisotopes.

Results

Our department already had PET/CT and SPECT/CT facilities, operational since 2005. The new PET/CT facility was constructed in 2012 and started operating from January 2013. A total of 12 nuclear medicine physicians, 6 nurses, and 11 nuclear medicine technologists were deployed on radioactivity-handling and patient-handling duties in 2012 in the old PET/CT and SPECT/CT facilities. Similarly, 13 nuclear medicine physicians, 7 nurses, and 11 technologists were deployed in 2013 in both the new as well as the existing PET/CT and SPECT/CT facilities [Table 1]. Whole body annual exposure to the staff was calculated for the period of 2012 and 2013, as shown in Table 2. The total number of nuclear medicine procedures and PET/CT scans performed in 2012 and 2013 were recorded and are shown in Table 3. The annual average radiation dose received per staff is shown in Table 4. Since the staff was rotated in all the three facilities (old PET/CT, new PET/CT, and SPECT/CT), it was not possible to calculate the dose received per PET/CT procedure. Hence, the dose received was normalized to 1.657 PET/CT + 1 nuclear medicine procedure in 2012 and 2.112 PET/CT + 1 nuclear medicine procedure in 2013, as shown in Table 5. The expected exposure has been compared with the actual exposure in Table 6.

Discussion

Technetium-99m (^{99m}Tc) radiopharmaceuticals are the most commonly used radiopharmaceuticals for diagnosis in diagnostic nuclear medicine and iodine – 131 (¹³¹I) pharmaceuticals are the most commonly

used therapeutic radiopharmaceuticals in therapeutic nuclear medicine.^[12] With the advent of PET/CT imaging, an increasing number of PET radiopharmaceuticals are also being used in nuclear medicine. Of these, ¹⁸F radiopharmaceuticals are the most widely used. The dose rate constant and the penetration power of ^{99m}Tc is much lesser than that of the any PET radioisotope.^[13] ¹³¹I also has a lesser dose rate and penetration power than any of the PET radioisotopes. Thus, the increasing number of PET cases adds to the radiation burden among the staff in a nuclear medicine department. Considering the high dose rates and transmission properties of PET radionuclides, PET facilities require an extra amount of shielding to protect the patients, the professionals, and the general public from radiation.^[14,15] Various publications have stressed on the need for added structural shielding in PET facilities to isolate the postinjected patients from the staff and the general public in order to minimize the radiation dose.^[11,15] Various publications have also shown that the staff would have been exposed to an additional dose of up to 10 mSv dose annually if the patients are not confined in the postinjection waiting area during the uptake time. In our previous study we have found that, radiation dose received by the radiation professional is significant during the injection process.^[16] Additionally, a number of publications have enumerated the attenuation properties of shielding materials for various radioisotopes.^[5,8,11-15] The choice of shielding material is ultimately a matter of judgment and feasibility depending on the isotope used and the number of studies performed.

Our institution is a tertiary care referral center in India and is one of the foremost oncology centers in Southeast Asia. The limited availability of adequate health care facilities for the diagnosis and treatment of cancer in this region puts a significant demand on our department. At our center, the number of scans performed per day per scanner is almost double to that of our western counterparts. This puts the staff at an increased risk of additional radiation exposure.

To optimize radiation exposure to achieve ALARA, we have adhered to and implemented the radiation safety concept right from the initial phases of planning the layout and workflow design while keeping time, distance, and shielding as the core of our decision-making without compromising on patient care. All possible methods have been implemented to achieve the goal of ALARA. The patient movement has been optimized to reduce the need for unnecessary contact and interaction with the staff and the general public until the completion of their scans.

In our design, we have considered the attenuation properties of the shielding material to ascertain its thickness considering the type and quantity of radioisotopes to be used, the number of studies to

Table 1: Total number of staff working in the department who were deployed on radioactive work in 2012 and 2013

	Nuclear medicine physicians	Nuclear medicine technologists	Nuclear medicine staff nurses
2012	12	11	6
2013	13	11	7

Table 2: Total annual whole body radiation dose received by staff working in our Department of Nuclear Medicine in 2012 and 2013

	All nuclear medicine physicians (mSv)	All nuclear medicine technologists (mSv)	All nuclear medicine staff nurses (mSv)
2012	24.42	21.19	18.3
2013	15.9	22.8	17.4

Table 3: Annual number of procedures performed in the Department of Nuclear Medicine in 2012 and 2013

	SPECT/CT	Old PET/CT	New PET/CT
2012	3813	6320	
2013	4784	3612	6492

SPECT: Single photon emission computed tomography; PET: Positron emission tomography; CT: Computed tomography

Table 4: Average annual WBRD received by staff working in the Department of Nuclear Medicine in 2012 and 2013

	Nuclear medicine physicians (mSv)	Nuclear medicine technologists (mSv)	Nuclear medicine staff nurses (mSv)
2012	2.04	1.92	3.05
2013	1.32	1.75	2.49

Table 5: Average radiation dose received by staff performing PET/CT and nuclear medicine procedure in 2012 and 2013

	All nuclear medicine physicians (µSv)	All nuclear medicine technologists (µSv)	All nuclear medicine staff nurses (µSv)
2012 (1.657 PET/CT+1 nuclear medicine procedure)	6.40	5.56	4.8
2013 (2.112 PET/CT+1 nuclear medicine procedure)	3.32	4.77	3.64

PET: Positron emission tomography; CT: Computed tomography

be performed, and the number of staff. In order to achieve this, we opted to build a concrete wall (density, 2350 kg/m³) of 225-mm thickness for shielding our PET/CT facility.^[8] Further, the walls of the postinjection patient waiting area and the operating console were made 300 mm thick to provide additional shielding. We have designed the dispensing and injection

Table 6: Total annual WBRD received by all staff working in the Nuclear Medicine Department in 2013 is compared with calculated radiation dose

	All nuclear medicine physicians (mSv)	All technologists (mSv)	All staff nurses (mSv)
Expected for 9100 PET/CT procedures	33.93	47.76	48.77
Actual for 10104 PET/CT and 4784 NM* procedures	15.9	22.8	17.4

*NM: Nuclear Medicine; PET: Positron emission tomography; CT: Computed tomography

areas to provide improved shielding and dose reduction during dispensing and injection. The dose dispensing area was customized such that the dose rate outside the L-bench is negligible. The injection area was also designed to minimize radiation exposure to the staff during injection of the radioisotope as described above.

We have also developed an optimized workflow to decrease professional exposure in our newly developed PET/CT unit. Effectiveness of the new design of our PET/CT facility and workflow design is shown by the result [Table 6] where it can be seen that the actual exposure was less than half of the expected exposure levels. This can be attributed to the fact that the actual time spent with the patient is much lesser than the calculated time.

The annual whole body radiation exposure while performing 6320 PET/CT and 3813 nuclear medicine procedures was 24.42 mSv/year for the doctors, 21.19 mSv/year for the technologists, and 18.3 mSv/year for the nurses in 2012. In 2013, despite an increase in the number of scans to 10,104 PET/CT and 4,784 nuclear medicine procedures, the annual whole body radiation exposure reduced to 15.9 mSv/year for the doctors and 17.4 mSv for the nurses, but marginally increased to 22.8 mSv/year for the technologists. This can be attributed to the better facility design and streamlined workflow as described in the "Materials and Methods" section.

Conclusion

The growing popularity of PET/CT studies has resulted in an increase in the risk of radiation exposure to the staff in a nuclear medicine department. We have conclusively shown that an increase in the number of cases does not necessarily mean an increase in radiation exposure to the staff. Judiciously designing the facility with optimal shielding, along with an efficient workflow to reduce

unnecessary patient proximity to the staff enables a reduction in professional radiation exposure.

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