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Assessment of Area Radiation Dose for the National Cyclotron and PET Centre at Chulabhorn Hospital in Thailand

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The National Cyclotron and PET Centre at Chulabhorn Hospital offers nuclear medicine diagnostic services using state-of-the-art digital PET/CT and PET/MRI machines as well as other related devices. Additionally, the center plays a vital role by having a cyclotron to produce radiopharmaceuticals, which are used both in-house and in other hospitals throughout the country. Despite the center's strict adherence to international standards regarding the use of radioactive substances in patients, there remains a potential risk of radiation exposure for operators, workers, and the public due to radioactive contamination and emissions from unsealed sources. Hence, it is imperative to assess and continuously monitor radiation levels in the work area to ensure the utmost level of safety for personnel. **Methods:** This study used optically stimulated luminescence dosimeters to measure radiation levels in 17 areas, consisting of 9 controlled and 8 supervised areas. Over a 3-mo period, the average monthly radiation dose was recorded for each location. **Results:** The PET/CT room registered the highest radiation dose within the controlled area, with a monthly average of 1.81 ± 0.29 mSv, equivalent to an annual dose of 21.72 mSv. This higher dose can be attributed to the significant number of patients served in this room. In supervised areas, the nursing counter located between the examination room and the patient waiting area exhibited the highest radiation exposure. The average monthly dose measured at this location was 0.085 ± 0.019 mSv, resulting in an annual dose of 1.015 mSv. **Conclusion:** The evaluation of radiation dose in controlled and supervised areas indicated that the overall radiation level remains within the prescribed limits. However, the slight excess that was observed at the nursing counter indicates the need for improvement to ensure compliance with the as-low-as-reasonably-achievable principle. Continuous monitoring of radiation levels should be conducted annually to maintain safety standards and minimize the risk that workers and the general public will be exposed to radioactivity.

Key Words: radiation survey; OSL nanoDot; nuclear medicine

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The National Cyclotron and PET Centre at Chulabhorn Hospital (https://chulabhornhospital.cra.ac.th/), established in 2006, advances nuclear medicine's diagnostic imaging by offering precise oncology, neurology, and cardiology diagnoses with cyclotrons and PET scanners, emphasizing high-quality care. As an academic research institution, this national center is globally recognized for radiopharmaceutical production, following the good-manufacturing-practice and good-distribution-practice standards of the Pharmaceutical Inspection Cooperation Scheme. Services cover cancer, neurologic diseases, and heart diseases via PET/CT scans, accessible to all patients for equal access. The center prioritizes advanced science and technology for patient well-being.

Currently, the center provides modern nuclear medicine diagnosis using advanced technology such as the digital PET/CT Biograph Vision (Siemens), digital PET/CT Biograph Vision Edge (Siemens), and PET/MRI Biograph mMR 3 T (Siemens) scanners. The center also produces radiopharmaceuticals from a cyclotron, servicing patients in Chulabhorn Hospital and nationwide referrals. Despite strict adherence to international standards for radioactive substance use, radiation exposure still occurs among operators and visitors because of the use of unsealed radioactive sources (*1*).

Although the radiation doses used in nuclear medicine are lower than the limits required to cause radiation sickness or immediate effects on the body, continuous exposure to such low doses for a long time may affect genetic material, resulting in destruction of reproductive cells or a change in body cells to become cancerous (*2*). The most commonly used radiopharmaceutical in PET/CT is ^{18}F-FDG. The FDG is labeled with ^{18}F, which decays to a positron of 630 keV and causes annihilation to a photon of 511 keV for a high-energy γ-ray. This may cause PET/CT staff to receive a higher effective dose than the general nuclear medicine staff from unsealed source radioactive materials and close contact with patients after injection of radiopharmaceuticals (*3*). To provide quality care and safety for patients receiving nuclear medicine services in diagnostic or treatment processes, radiation protection is thus required to prevent those operators and general individuals from receiving a dose in excess of the safe limit (*4*). The International Commission on Radiological Protection has specified that the radiation dose must not exceed the individual acceptable dose limit: 1 mSv/y for general individuals and 20 mSv/y for radiation operators. Moreover, it is required that staff use a personal radiation measurement device to record the cumulative dose received throughout their working time in the radiation area (*5*), in line with a system to monitor radiation contamination in the operational room regularly (*6*).

In 2011, Al-Haj et al. (*7*) studied the radiation dose in the PET/CT room using thermoluminescent dosimeters (TLDs) placed in different areas. The highest radiation dose, 9.6 μSv, was in the injection room, followed by 4.0 μSv in the hot lab area, 1.0 μSv in the control room, 0.8 μSv in the waiting area, and 0.5 μSv in the entrance area. The data influenced radiation protection practices, emphasizing minimizing contact time with patients for operators and workers. Similarly, in 2014, Shao et al. (*8*) assessed radiation levels around medical nuclear medicine facilities with TLDs, highlighting the importance of radiation safety for staff and the public. Areas with high monthly radiation doses, such as the injection preparation area and the restricted waiting area for PET/CT and SPECT/CT, were identified to ensure compliance with regulatory standards and guidelines.

In 2019, Yin et al. (*9*) measured radiation doses in the hospital's PET/CT center using TLDs and found that cumulative doses along the radiopharmaceutical transport route did not exceed background radiation levels. However, the injection area, patient scan waiting area, and PET/CT room had doses 4–16 times higher than background radiation, suggesting restrictions on these areas for nonpatients and relatives.

In 2019, Wisetnan et al. (*10*) surveyed radiation doses in the nuclear medicine unit using optically stimulated luminescence (OSL), finding doses ranging from 0.60 to 7.33 mSv/y. The highest doses were in the PET/CT room (controlled area, 510 μSv/mo), uptake room (supervised area, 610 μSv/mo), and injection waiting area (nonradiation work area, 450 μSv/mo). The results of this dose survey exceeded the safety limit of 1 mSv/y for general individuals but did not exceed the safety limit of 20 mSv/y for radiation operators as recommended by the International Commission on Radiological Protection.

Presently, personal dosimetry relies on the widespread use of both TLD and OSL dosimeters. Nevertheless, TLDs have uncertainties when measuring low-energy radiation, necessitating careful preselection and calibration to minimize errors (*8*). In this research, radiation was measured using OSL devices, which offer several advantages over TLDs, including the ability to read radiation values multiple times and at room temperature, as well as low signal fading. Various types of OSL devices are available, such as the OSL nanoDot dosimeter (Landauer), which is advantageous because of its small size, user friendliness, high radiation sensitivity, and affordability (*11*,*12*).

Surveying of radiation dose plays an important role in radiation safety control and in preventing radiation hazards. The National Cyclotron and PET Centre at Chulabhorn Hospital has provided diagnostic services to a large number of patients. This study therefore aimed to explore the radiation dose emitted from radioactive substances and the patient to the environment within the PET center building. OSL nanoDot dosimeters and personal radiation meters were to measure the radiation dose in different areas. The results can be applied as guidelines in developing a radiation protection plan according to the standards of the International Commission on Radiological Protection.

MATERIALS AND METHODS

The study was approved by the Human Research Ethics Committee of Chulabhorn Royal Academy, Thailand (project code 058/2565).

Radiation Dosimeter

The OSL nanoDot dosimeters were manufactured in the United States and calibrated by the Thailand Institute of Nuclear Technology. They are specifically designed to be a small device that measures radiation at a single location. Each dosimeter is square-shaped, measuring 10 × 10 mm with a thickness of 2 mm, as shown in Figure 1A. The nanoDot dosimeter consists of a carbon-doped aluminum oxide (Al_2O_3:C) crystal 0.3 mm thick and 7 mm in diameter, enclosed within a thin polyester sheet. To retrieve measurements, a microStarii mobile reader, also developed by Landauer, is used. In a process similar to OSL InLight dosimeters (Landauer), the irradiated dosimeters are stimulated by visible green light emitted from a light-emitting diode. The amount of luminescence emitted is directly proportional to the absorbed radiation and remains relatively stable even after the reading. These characteristics allow nanoDot dosimeters to be read multiple times. The OSL nanoDot dosimeter is capable of measuring radiation within a useful energy range from 5 keV to 20 MeV with an accuracy of ±10% when read by the microSTARii mobile reader as shown in Figure 1B. After readout, each chip converts its response to radiation dose exposure using its built-in sensitivity correction factor (*13–15*).

Data Collection

The installation area for the OSL nanoDot dosimeter was surveyed and allocated by dividing the radiation laboratories in the National Cyclotron and PET Centre at Chulabhorn Hospital into 2 types of areas, in accordance with the international basic safety standards for radiation protection and safety of radiation sources (*16*).

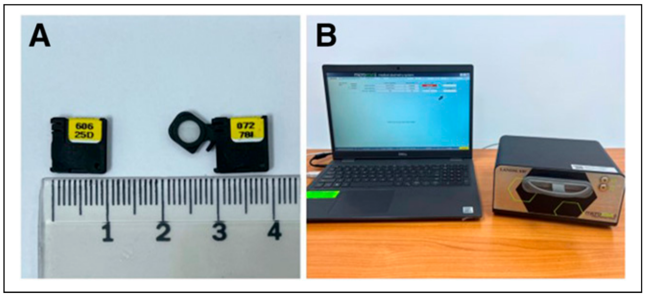

FIGURE 1. (A) OSL nanoDot dosimeter. (B) microSTARii mobile reader.

The first were the controlled areas: PET/CT room 1, PET/CT room 2, the PET/MRI room, the injection room, uptake room 2, uptake room 5, uptake room 8, the patient bathroom, and the scan waiting area. The second were the supervised areas: the nursing counter, the patient waiting area on the first floor, PET/CT control room 1, PET/CT control room 2, the PET/MRI control room, the staff bathroom, the area in front of the elevator on M floor, the patient waiting area on the first floor, and the imaging room, as shown in Figure 2.

In total, 5 OSL nanoDot dosimeters were installed at different locations on the walls in each area. All were installed at a height of 110 cm as a reference for personal radiation meters, which are commonly placed at waist level. Radiation doses were measured and reported every month from October to December 2022 (*10*) and were then analyzed to evaluate the radiation level and safety.

Statistical Analysis

The radiation doses are statistically presented as mean, maximum, minimum, and SD. All statistical analyses were performed with SPSS software (IBM).

RESULTS

The mean radiation doses, ranging from 0.041 to 1.810 mSv/mo, for each area of the nuclear medicine department are shown in Table 1. Doses were higher in controlled areas than in supervised areas. The controlled area with the highest dose was PET/CT room 1 (1.810 ± 0.288 mSv/mo, equivalent to 21.720 mSv/y), and that with the lowest radiation dose was the PET/MRI room (0.116 ± 0.020 mSv/mo, equivalent to 1.392 mSv/y) (Fig. 3). In the supervised areas, the highest radiation dose was at the nursing counter (0.085 ± 0.019 mSv/mo, equivalent to 1.020 mSv/y) and the lowest was in PET/MRI control room 2 (0.039 ± 0.021 mSv/mo, equivalent to 0.468 mSv/y) (Fig. 4).

DISCUSSION

Radiation surveys play a crucial role in radiation safety control and serve as a preventive measure against radiation hazards. Such surveys allow for risk assessment and appropriate radiation use. This study was conducted using OSL nanoDot dosimeters to measure radiation doses at the National Cyclotron and PET Centre at Chulabhorn Hospital between October and December 2022. The radiation dose in the various areas ranged from 0.492 to 21.720 mSv/y. PET/CT room 1 had the highest radiation dose among controlled areas, whereas the nursing counter had the highest radiation dose among supervised areas.

Categorization of radiation zones into controlled and supervised areas ensures proper management of radiation safety, adhering to the international basic safety standards for radiation protection and safety of radiation sources (*16*).

Controlled areas require specific safety measures for routine operations, contamination control, and exposure reduction during operational incidents and accidents. Thai radiation safety regulations classify controlled areas as locations where individuals might receive radiation doses equal to or exceeding three tenths of the limit doses set for radiation occupation (*1*). The radiation survey in this study identified PET/CT room 1 as having the highest radiation dose among controlled areas, reaching 21.720 mSv/y. This higher dose was attributed primarily to the greater number of patients served in this room than in other examination areas.

Supervised areas are defined as areas not classified as controlled but subject to continuous assessment of occupational radiation exposure. Generally, supervised areas do not require specific protective measures or safety provisions. Thai radiation safety regulations specify that supervised areas

FIGURE 2. Floor plans for first floor and M floor of National Cyclotron and PET Centre at Chulabhorn Hospital. QC = quality control.

TABLE 1
Average Radiation Dose for Each Area of Nuclear Medicine Department

Area	Average radiation dose ± SD (mSv) Monthly	Annually
Controlled area		
PET/CT room 1	1.810 ± 0.288	21.718
PET/CT room 2	0.833 ± 0.251	9.994
PET/MRI room	0.116 ± 0.020	1.390
Injection room	0.169 ± 0.053	2.024
Uptake room 2	0.226 ± 0.052	2.713
Uptake room 5	0.317 ± 0.215	3.808
Uptake room 8	0.465 ± 0.105	5.582
Patient bathroom	0.482 ± 0.118	5.786
Scan waiting area	0.272 ± 0.065	3.264
Supervised area		
Nursing counter	0.085 ± 0.019	1.015
PET/CT control room 1	0.041 ± 0.012	0.493
PET/CT control room 2	0.046 ± 0.030	0.551
PET/MRI control room	0.039 ± 0.021	0.471
Staff bathroom	0.082 ± 0.029	0.986
Lobby, in front of elevator	0.056 ± 0.021	0.677
First floor patient waiting area	0.058 ± 0.023	0.690
Imaging processing room	0.047 ± 0.023	0.563
Control set	0.055 ± 0.017	0.663

have the potential to expose individuals to radiation doses exceeding the limits set for the general population who are not receiving medical services (*1*). The area with the highest radiation dose among supervised areas was the nursing counter, at 1.020 mSv/y, primarily because it was located between the uptake room and the PET/CT room, which is a pathway for patients who have received radiopharmaceuticals and are undergoing scans. This area had radiation levels higher than the prescribed limit, indicating the need for improvements to comply with radiation safety standards, such as adjusting management of patient services and the physical space to reduce the radiation dose received by workers. Additionally, relatives and caregivers should not be permitted to stay in the area for a long period unless needed to assist the patient.

In considering the individual exposure limit of 20 mSv/y for radiation workers, as specified by the International

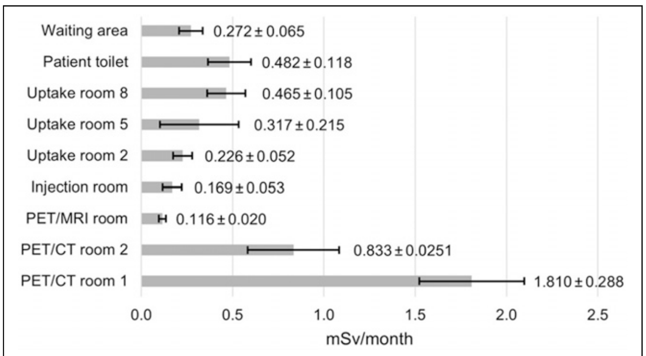

FIGURE 3. Radiation dose in controlled areas.

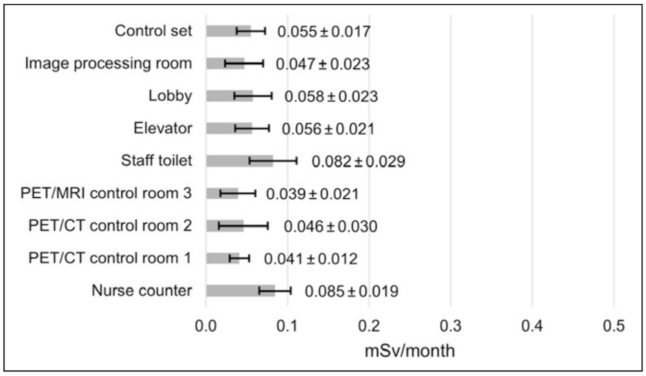

FIGURE 4. Radiation dose in supervised areas.

Commission on Radiological Protection and adopted in Thailand (*1*,*5*), we noted that radiation operators were not usually in the PET/CT room at all times. They would be in the room for about 2–3 min per examination while helping to position patients. The operators in each room also were rotated every week and were required to wear a personal radiation dosimeter, which showed that the average monthly radiation dose did not exceed the limit (Table 2).

The operators also underwent complete blood count testing every 6 mo. In addition, the PET/CT scanners (Biograph Vision and Biograph Vision Edge) and the PET/MRI scanner (Biograph mMR 3 T) had an automatic quality control function, which could be manually applied so that the PET scanner could assess its own quality when not in use. By this means, the radiation dose that operators received during daily quality control using a cylinder standard source could be reduced. Reduction of the dose of radiopharmaceutical administered to patients could also reduce the radiation dose received by patients and operators. By reducing time spent near patients or contact with patients, operators could also reduce the radiation dose they received, increasing the distance to minimize the dose.

The numbers of patients who visited the nuclear medicine department in November, October, and December 2022 were 1,092, 1,168, and 1,084, respectively. When studying the relationship between the number of patients and the average cumulative radiation dose in each examination room, we found that the dose varied with the number of patients. PET/CT room 1 comprised the highest number of patients per month, at an average of 516, and had the highest radiation dose, at 1.810 ± 0.288 mSv/mo. The number of patients receiving services in each examination room is shown in Table 3.

Our results were consistent with those of Yin et al. (*9*), who investigated the radiation dose in the environment and the hospital's PET/CT center using TLDs. They found that the PET/CT room, patient scan waiting area, and injection area had higher cumulative radiation doses than other areas. The radiation dose was highest in the patient scan waiting area. Wisetnan et al. (*10*), who surveyed the radiation dose in the nuclear medicine unit of Srinakarin Hospital Khon Kaen using OSL dosimeter plates, found that the controlled

TABLE 2
Average Radiation Dose Received by Operators per Month

Occupational group	*n*	Effective dose (mSv)	Eye lens dose (mSv)	Skin dose (mSv)
Technologist	14	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Nurse	17	0.01 ± 0.02	0.13 ± 0.25	0.13 ± 0.49
Radiochemist	13	0.09 ± 0.10	0.09 ± 0.10	0.09 ± 0.10

area with the highest radiation dose was the PET/CT room, at 6.12 mSv/y. The areas exceeding the safety limit of 1 mSv/y to general individuals was the radiopharmaceutical injection waiting area, at 5.4 mSv/y, followed by the registration waiting area, at 4.4 mSv/y. This finding may be the result of incomplete isolation of patients after radiopharmaceutical injection, who still shared corridors with general individuals. However, the radiation dose would vary with the duration of the examination, radiopharmaceutical amount administered to patients, and average number of patients per day in the room, which varied each month.

However, our results differed from those of Al-Haj et al. (*7*), who explored the radiation dose at a PET/CT center using TLDs. They found that the patient injection room had the highest radiation dose because patients could seek advice and ask questions during and after the injection. In addition, nurses had to spend more time with patients here in order to insert new needles, and the patients had to remain in this area for a long time. This is different from our study, which used an automated injector to help administer radiopharmaceutical doses to patients, thus reducing the time spent near patients, increasing the distance from patients, and maintaining shielding of the machine. Thus, nurses did not receive radiation exceeding the safety limit.

In addition, comparison of survey results between studies may be inaccurate because of variations in such factors as the duration of services, number of patients, and type of dosimeter. We used the OSL nanoDot dosimeter. Wannawikorn et al. (*17*) studied the characteristics of this dosimeter for 6-MW x-ray power in radiotherapy. It was found to have a repeat dose measurement variation of ±2.5%, with a 0.05% loss of signal per reading. This dosimeter was associated with linear radiation doses and responded only to the direction of the radiation beam perpendicular to the dosimeter regardless of the dose rate—just the decrease in dosimeter response with increasing source-to-surface distance. Therefore, it is essential to calibrate the OSL nanoDot dosimeter and determine the correction factors specific to the type of radiation before its use.

Nupetch et al. (*11*) studied the radiation dose response of the OSL InLight dosimeter, which, when measuring γ-radiation from 662-keV ^{137}Cs at doses of 0.2, 2.0, and 5.0 mSv, had measurement errors of less than 5%, which is within the manufacturer's standard. Therefore, the measured radiation doses could be used as reference doses in each area of the National Cyclotron and PET Centre at Chulabhorn Hospital. The response of OSL dosimeters depends on the type, power, and amount of radiation.

A study by Sisai and Krisanachinda (*18*) was able to use personal OSL to estimate the amount of radiation received by operators through the eye lens and extremity. Hence, the radiation doses measured in our study might be initially applied for the estimation of radiation dose received by operators.

According to the radiation dose surveys and other studies, the highest radiation doses emitted from radioactive substances and the patient to the environment differed in each PET/CT center, depending on the management of patient service procedures, the division and design of the areas, the selection of radiation-shielding materials and equipment, the number of patients being served, the amount of radiopharmaceutical received by each patient, and the method of radiation dose measurement. Therefore, we concluded that the National Cyclotron and PET Centre at Chulabhorn Hospital maintained a good management system despite quite high radiation doses in some areas. According to personal reports, the radiation doses received by operators did not exceed safety limits. However, the as-low-as-reasonably-achievable principle should be followed for further radiation protection. We have provided reports on the radiation dose at our center, have recommended improvements to areas with excessive radiation levels, and recommend continuous monitoring of radiation levels.

TABLE 3
Number of Patients Receiving Services in Each Room During October to December 2022

Month	Number of patients			
	PET/CT 1	PET/CT 2	PET/MRI	Total
October	484	400	208	1,092
November	556	364	248	1,168
December	508	312	264	1,084
Mean ± SD	516.00 ± 36.66	358.67 ± 44.24	240.00 ± 28.84	1,114.67 ± 46.36

CONCLUSION

The evaluation of radiation dose in controlled and supervised areas indicated that the overall radiation level remains within the prescribed limits. However, the slight excess that was observed at the nursing counter indicates the need for improvement to ensure compliance with the as-low-as-reasonably-achievable principle. Continuous monitoring of radiation levels should be conducted annually to maintain safety standards and minimize the risk that workers and the general public will be exposed to radioactivity.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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KEY POINTS

QUESTION: What is the radiation dose emitted from radioactive substances and patients to the environment within the National Cyclotron and PET Centre at Chulabhorn Hospital?

PERTINENT FINDINGS: OSL nanoDot dosimeters were used to assess radiation within the National Cyclotron and PET Centre at Chulabhorn Hospital and found that the hospital maintained a good management system despite quite high radiation doses in some areas.

IMPLICATIONS FOR PATIENT CARE: This study emphasizes the importance of rigorous radiation monitoring and safety measures in medical facilities using radioactive substances to protect both health care workers and patients.

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