บทความวิจัย

Estimation of Radiation Dose to Workers in Siriraj Cyclotron Center

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Abstract

Siriraj cyclotron is a self-shielded medical cyclotron for production of PET radionuclides. It accommodates with radiochemistry laboratory and hot cells for radiopharmaceutical synthesis. During operation, induced radioactivity may accumulate in various cyclotron components, radioactive gases may escape into the atmosphere results in exposure of workers. Individual and workplace monitoring are required for maximum safety to all personnel in and around the facility. Deep dose and shallow dose equivalent and neutron doses to 3 groups of workers, medical physicist, radiochemist, and housekeeper were measured on monthly basis using OSL and a 1-year result was analyzed. Seven areas, cyclotron, QC rooms, hot cell, electric room, preparation room, control and the staff rooms were monitored by gamma and neutron detectors to determine dose rate when the ^{18}F has been produced for 61 times.

The mean ± SD of Hp(10) and Hp(0.07) of the finger (averaged from 3 radiochemists) were 0.13 ± 0.02 mSv/year and 8.81 ± 2.18 mSv/year, respectively. For 2 medical physicists in operating the cyclotron, the mean ± SD of Hp(10) and Hp(0.07) of the finger were 0.05 ± 0.06 mSv/year and 4.94 ± 2.89 mSv/year, respectively. Dose to housekeepers was not detected. The neutron dose to workers was undetected. The dose rate from neutrons was found to be negligible and the mean dose rate from gamma photons of less than 6.43 μSv/h was well within the limits. The occupational dose received by cyclotron workers did not exceed the international recommended annual dose limits.

The gamma and neutron dose rate were analyzed as part of a workplace-monitoring program in controlled and supervised areas. It was found that the maximum dose rate is below the dose limit (6.43 vs 20 μSv/hr). The maximum effective doses and finger dose to workers were 0.15 vs 20 mSv/year and 11.32 vs 500 mSv/year that below the dose limit, respectively. Radiation dose to workers and dose rate from area monitors are in accordance with international radiation safety regulations. This demonstrated that the level of protection provided to the worker is satisfactory and the workplace condition is adequate for environmental protection.

Keywords: Effective dose, radiation area, optically stimulated luminescence (OSL), area monitoring, cyclotron

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Introduction

PET imaging represents one of the most effective diagnostic tools in nuclear medicine. It employs mainly short-lived positron emitting radiopharmaceuticals. The cyclotron is the most widely used particle accelerator for producing PET radionuclides. The four basic cyclotron produced radionuclides most widely employed are: 18F (t½ = 110 min), 13N (t½ = 10 min), 15O (t½ = 2 min) and 11C (t½ = 20 min). Siriraj Hospital has installed compact medical cyclotrons for on-site production of short-lived PET radionuclides. This is a self-shielded medical cyclotron, can accelerate protons to energies of 20 MeV and 10 MeV for deuteron. This cyclotron is one of the Medical Research and Development Centers of the Faculty of Medicine Siriraj Hospital. At present, 3 PET radionuclides ^{18}F, ^{11}C and ^{15}O are produced [1].

The cyclotron is equipped with chemical processing modules in separate neighboring areas. During routine cyclotron operation and target bombardment, high levels of prompt neutrons and gamma rays are produced. During radiopharmaceutical processing, a substantial fraction of the volatile PET radiopharmaceuticals are released into the atmosphere. The radiation exposure to workers arises mainly from cyclotron operation, the maintenance of radio-activated components, handling and moving of activated items as well as radioactive waste handling. Based on the principles of the radiation protection, it is necessary to establish a monitoring program that allows the dose control of the workers against possible unwanted health effects and also to protect the environment [2].

The implementation of area monitoring and the use of individual dosimeters are essential measures of this program, for allowing preliminary assessment of the dose rates in areas to be occupied by workers and also to confirm of accumulated radiation dose to workers.

This study aims to evaluate external exposure to gamma and neutron radiation through the analysis of the effective dose received by workers and the dose rates obtained by the area monitoring when ^{18}F is being produced. The effective dose equivalent can be obtained from OSLD body and ring OSLRD badges. These dosimeters have been read on a monthly basis by Thailand Institute of Nuclear Technology (TINT) personal dosimeter services. The dose rate can be collected from area radiation monitors; gamma detector (GM-41, GM-42 Ludlum) and neutron detector (12-4 Ludlum), every time a cyclotron is operated and a radiopharmaceutical is produced. These survey results will be collected for 1 year to assess whether the workers and workplace are safe in accordance with the requirements of international standards.

Materials and methods

A. Instruments and materials

1. Area monitoring: Gamma detector, Model GM-42 and GM-41 (Figure 1A), ROTEM INDUSTRIES LTD. Arava, Israel [3, 4].

2. Area monitoring: Neutron detector, Model 12-4 (Figure 1B), Ludlum MEASUREMENTS, INC. TEXAS, US: [5].

3. Personnel OSLD body and ring badges (Figure 2), serviced by Thailand Institute of Nuclear Technology (TINT) (Figure 2).

4. ^{137}Cs standard source (9 kBq), Eckert & Ziegler.

B. Workers groups and Monitoring areas groups

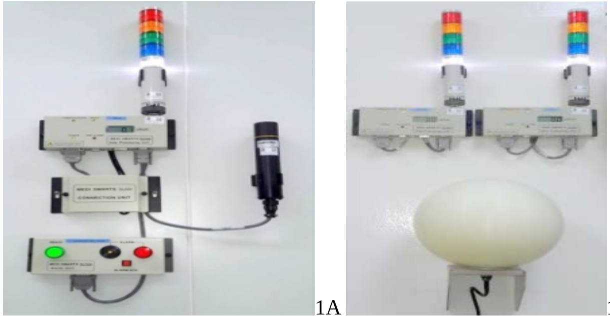
1. Categorization of workers groups

Six cyclotron workers were categorized into 3 groups based on working conditions, amount of radionuclides being handled and risk associated with everyday activities of external radiation is likely to occur. These include 2 physicists, 3 radiochemists and 1 housekeeper.

2. Categorization of monitoring areas

Seven controlled and supervised areas were categorized into: A. Control room, B. Cyclotron room, C. Electric room, D. Hot Cell room, E. Preparation room, F. Quality control room and G. Staff room.

A to F are controlled areas and G is supervised areas.



1A 1B

Fig. 1 Area monitoring: 1A Gamma detector &; 1B Neutron detector

Fig. 2 Personnel OSLD and ring OSLRD

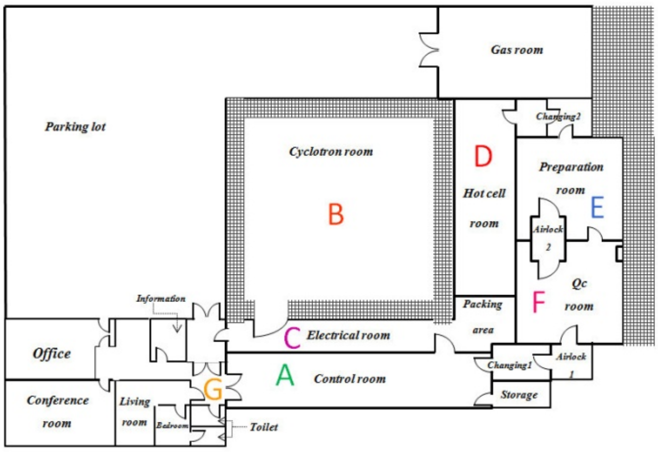


Fig. 3 The location A-G of installed radiation detectors

C. Methodology

The study was based on individual monitoring using OSLD and OSLRD, and, area monitoring using gamma and neutron detectors.

1. The occupational exposure involved the external dose; personal dose equivalents Hp(10) whole body , Hp(3) eye lens and Hp(0.07) skin received by workers during the year 2017 was analyzed. The extremity effective dose Hp (0.07) was measured using finger techniques. The results were read and evaluated on monthly basis by Thailand Institute of Nuclear Technology; TINT. Radiation dose received by three group of cyclotron workers; 2 physicists, 3 radiochemists and 1 housekeeper are compared according their tasks, and compared with the values established in international recommendations.

2. The dose rate collected from gamma and neutron detectors reported in 2017 during the production of about 2 hours per batch of ^{18}F-FDG. The total 61 measurements performed at 7 predetermined spots identified as A to G in Figure 3. Position A to G have gamma detectors, only position C; electronic room, has both gamma and neutron detectors [2].

Result and Discussion

A. Radiation dose

The mean Hp(10), Hp(3) and Hp(0.07) for each group of workers are shown in Table 1, 2 and 3. The measured results of Hp(3) and Hp(0.07) in all groups, were comparable to Hp(10). The highest levels was found in 3 radiochemists ranging between 0.11–0.15 mSv/year, followed by 0.01–0.09 mSv/year, and 0–0.01 mSv/year for 2 physicists and 1 housekeeper, respectively.

A higher dose received by radiochemist is from synthesizing radiopharmaceuticals labeled, dispensing and quality control testing of the products. Medical physicist is responsible for operation of cyclotron for radionuclide production, sample transfer, radiation safety of personnel and radiation surveillance in and around cyclotron facility. The amount of radiation received by the housekeeper is from carrying the products and room cleaning which is negligible. The mean levels of Hp(10) whole body, Hp(3) eye lens and Hp(0.07) skin doses in all groups were observed to be well within the established limits because all of workers are on rotation and do not constantly handle radioactive sources throughout the whole year (Figure 4) [6].

The Hp(0.07) finger doses in 3 radiochemists vary in the range between 7.38 and 11.32 mSv/year with the mean value of 8.81mSv/year. These results were observed to be higher than those received by the physicists by a factor of about 2 (8.81vs4.94), but still in consistent with international radiation protection regulations. Radiation dose received by the 2 physicists ranging between 2.89 – 6.98 mSv/year but not detected in housekeeper. Radiation dose from neutron cannot be detected in any group of workers.

Table 1 Dose to 2 medical physicists (mSv/year)

No.	Hp(10)	Hp(3)	Hp(0.07)	finger	neutron
1	0.01	0.01	0.01	2.89	0
2	0.09	0.09	0.09	6.98	0
Mean±SD	0.05±0.06	0.05±0.06	0.05±0.06	4.94±2.89	0

Table 2 Dose to 3 radiochemists (mSv/year)

No.	Hp(10)	Hp(3)	Hp(0.07)	finger	neutron
1	0.14	0.14	0.13	11.32	0
2	0.15	0.15	0.15	7.73	0
3	0.11	0.11	0.11	7.38	0
Mean±SD	0.13±0.02	0.13±0.02	0.13±0.02	8.81±2.18	0

Table 3 Dose to 1 housekeeper (mSv/year)

No.	Hp(10)	Hp(3)	Hp(0.07)	finger	neutron
1	0	0.01	0.01	0	0

Table 4 Dose rate from gamma and neutron in chosen areas (µSv/hr)

Room	Dose rate (µSv/h)			
	Gamma		Neutron	
	Max	Mean±SD	Max	Mean±SD
A. Staff office	0.3	0.07±0.03	-	-
B. Control	0.5	0.10±0.01	-	-
C. Electric	12.4	0.15±0.08	1	0.01
D. Cyclotron	75.2	6.43±1.37	-	-
E. QC	57.1	0.19±0.07	-	-
F. Preparation	2.3	0.12±0.02	-	-
G. Hot cell	41.8	0.24±0.11	-	-

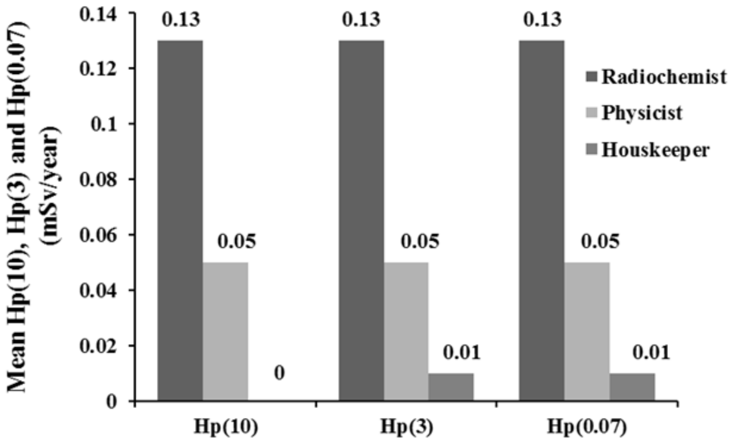


Fig. 4 Mean Hp(10), Hp(3) and Hp(0.07) (mSv/year)

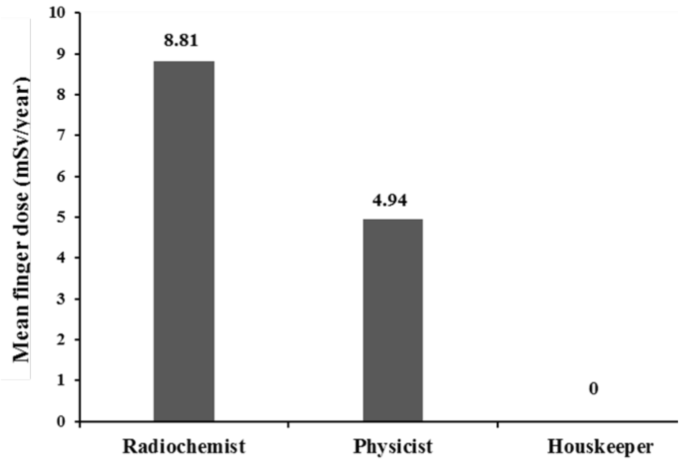


Fig. 5 Mean finger dose (mSv/year)

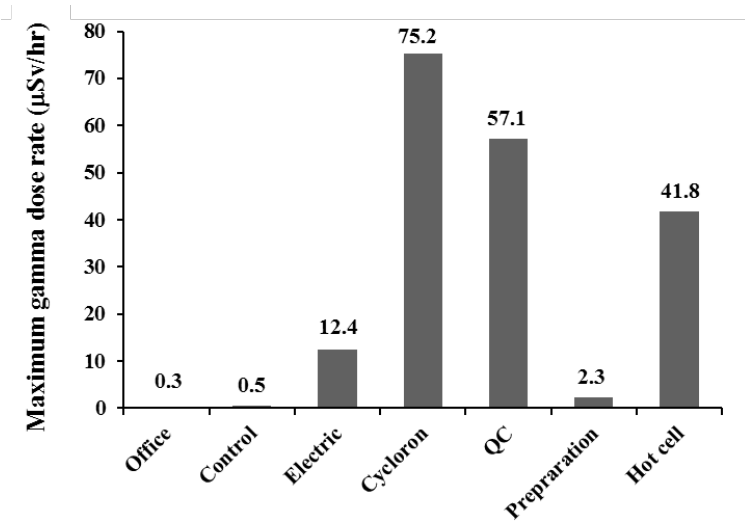


Fig. 6 Dose rate of maximum gamma radiation (µSv/hr).

B. Radiation exposure rate from area monitoring

The maximum and mean ± SD of the gamma and neutron dose rates in the different chosen areas as indicated in Figure 3 are presented in Table 4. The maximum values are shown in Figure 6.

The radiation levels measured inside the Siriraj Cyclotron Center was collected during 2 hours of 18F-FDG production for a total of 61 times in 6 months. The highest gamma radiation dose rate of 75 µSv/hr was detected in the cyclotron vault when bombarding 18O to 18F with an average operating current of 50 µA on the target. This value is below the limits for environmental protection; 20 mSv/hr for control area [7].

The maximum gamma dose rates in cyclotron vault from production of 18F-FDG, 75 µSv/hr is higher than those reported by Silva et al., 12 µSv/hr [8, 9]. However, this value is higher than our mean value (6.43 µSv/hr) by a factor of 2. Kaushik et al. [10] showed very high dose rate of gamma radiation, 10 mSv/hr which is higher than this study for approximately 133 times.

High gamma dose rates of 57 µSv/hr and 41.8 µSv/hr were also observed in the QC room and hot cell room, respectively. Although these levels were below the limit, the lower dose rate, 31µSv/hr was reported by Silva et al. [8, 9] and only 0.5 µSv/hr reported by Kaushik et al. [10].

In this study, very low level of neutron radiation was detected. The maximum neutron dose rate was found to be only 1 µSv/hr in electric room. However, Kaushik et al. [10] reported no neutron radiation was detected by the neutron monitor located on the door of the cyclotron vault during bombardment and at the end of bombardment (EOB).

Conclusion

Surveillance of the gamma and neutron radiation is performed as part of a personnel and workplace-monitoring program in controlled and supervised areas of the cyclotron facility. It was found that the maximum dose rate is below the dose limit (6.43 vs 20 µSv/hr). The maximum effective doses and finger dose to workers were 0.15 vs 20 mSv/year and 11.32 vs 500 mSv/year that below the dose limit, respectively. These demonstrated that the released of gamma and neutron radiation into the general environment in and around the cyclotron are well below the allowable limits, and could be concluded that the workplace condition is satisfactory. The levels of protection provided to the workers are in compliance with the international radiation protection regulations.

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