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Evaluation of neutron spectra in the SK cyclotron room under different operation parameters

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A B S T R A C T

This work evaluated the neutron spectra induced by a medical used cyclotron. The neutrons were induced during the ^{18}F-radioisotope productions due to the 9.6 MeV proton beam hit ^{18}O-water target and induced (p, n) reactions in this SK Cyclotron. To evaluate the induced neutron doses in the cyclotron room, dual-TLD chips and gold foils with bare and ^{113}Cd covered were used separately to measure thermal neutron doses and fluence rates at positions outside the self-shielding of cyclotron, in the cases of using different targets. Besides, a ^{6}LiI (Eu) detector with Bonner spheres were used and were placed at the specific locations in the cyclotron room to estimate the neutron spectra of using different operation parameters. In the results, the thermal neutron doses at the locations outside the self-shielding of cyclotron in the case of using target 1 were less than that using target 2. However, thermal neutron doses inside the self-shielding in the case of using target 1 were higher than that using target 2. The evaluated neutron spectra inside and outside the self-shielding confirmed the dose results. The impact of the volume of ^{18}O-water target was discussed in this study. In conclusion, the large target volume (target 1) caused the higher production yield of ^{18}F-radioisotope and induced lower dose and softer spectra of neutrons than the small target, under the same operation parameters which were adopted for validation in this study.

1. Introduction

During the last decade, the Cyclotron Center in Shin Kong Wu Ho-Su Memorial Hospital (SK Cyclotron) has been operated 4124 times and produced ^{18}F-FDG (2-fluoro-2-[^{18}F]-fluoro-D-glucose) activities of 2015 Ci since 2002 to present. The ^{18}F isotope is obtained from the ^{18}O (p, n) ^{18}F reaction when ^{18}O-water (abundance 98%) is bombarded with a proton beam. This reaction produces the neutron field around the cyclotron. In the meantime, secondary radiation particles are generated by de-excitations of nuclides and other nuclear reactions during the operation of cyclotron, therefore, a mix radiation field is formed (Mendez et al., 2005). The workers need to enter the cyclotron room to make adjustment during the operation, if the cyclotron worked unsteadily due to the auxiliary system (cooling water system or the vacuum system or the radio-frequency system) losing efficacy. In these cases, the workers were exposed to the mix radiation (neutrons and γ-rays) in the cyclotron room (Kuo et al., 2010).

The intensity of mix radiation field depends on operation parameters and radiation interactions with the structures of cyclotron. Different operation parameters such as beam current and target volume affect the production yields of ^{18}F-FDG compound and also the doses and the spectra of induced neutrons in the cyclotron room. Several literatures were found to focus on estimating neutron spectra of different PET cyclotrons (such as IBA or Sumitomo cyclotron) and different sources (such as protons or deuterons) as the cyclotron was operated, but less discussed neutron spectra under the different parameters of operation in the medical cyclotron center (Mendez et al., 2005; Vega-Carrillo, 2001).Thereby, this study evaluated the thermal neutron doses at specific locations inside and outside the self-shielding of the SK Cyclotron, by means of the dual-thermoluminescent dosimeter, dual-TLD (TLD-600/700) chips and gold (^{197}Au) foils with bare and ^{113}Cd covered, in the cases of using targets with different volumes (2.4 cm^3 for target 1 and 1.5 cm^3 for target 2). Besides, a ^{6}LiI (Eu) detector with Bonner spheres in different diameters (“0–12”) was used and placed at the specific locations in the cyclotron room to

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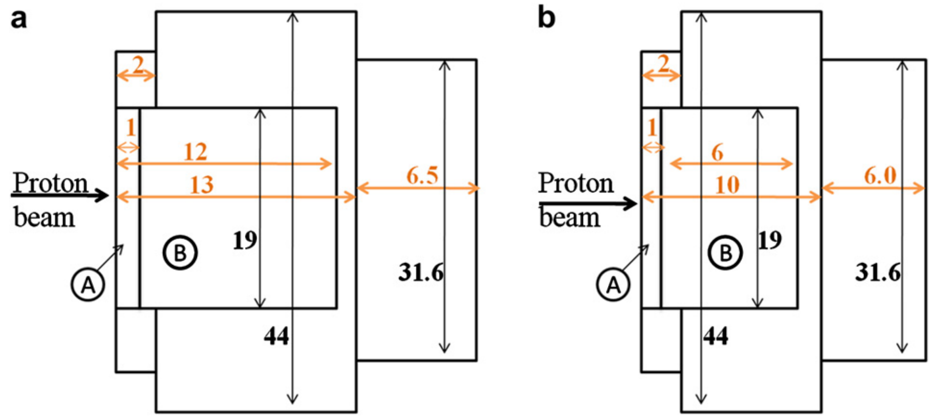

Fig. 1. The geometry of (a) target 1 and (b) target 2. The containers of targets are mainly consisted of silver (Ag) metals. The area A is filled with helium (He) gas and area B is ^{18}O-water (2.4 cm^3 for target 1 and 1.5 cm^3 for target 2). Size unit: mm.

estimate the neutron spectra. The relationship between neutron doses and spectra was analyzed and discussed in present work.

2. Materials and methods

The SK Cyclotron (GE MINItrace) is a self-shielding cyclotron which was installed inside the vault (consists of concretes, leads and PE plates). It triggered for the 9.6 MeV proton bombardment of ^{18}O-water liquid target. The SK Cyclotron has been performing over 500 operations per year in average and 80 min per operation since 2002. Therefore, information regarding the radiation dose of mix radiation fields in the cyclotron room is important for the workers when the cyclotron operates. In this study, the impact on operation parameters of beam current (30–35 μA) and target volume (geometry of targets are shown in Fig. 1) were investigated to evaluate fluctuations of neutron doses during the operation of cyclotron. In the routine conditions, the beam current was set as 30–35 μA for target 1 and 30 μA for target 2 when the operation time is greater than or equal to 60 min.

2.1. Thermal neutron doses and fluence rates

To estimate the dose contribution of mix radiation inside the cyclotron room, dual-TLD (TLD-600/700) chips were used to measure and to distinguish the doses contributed by photons and thermal neutrons (Kuo et al., 2010; Rogus et al., 1994). TLD chips were positioned at 60 points in the cyclotron room. TLD-600 and TLD-700 chips (each with the size of 3 × 3 × 1 mm^3) were both

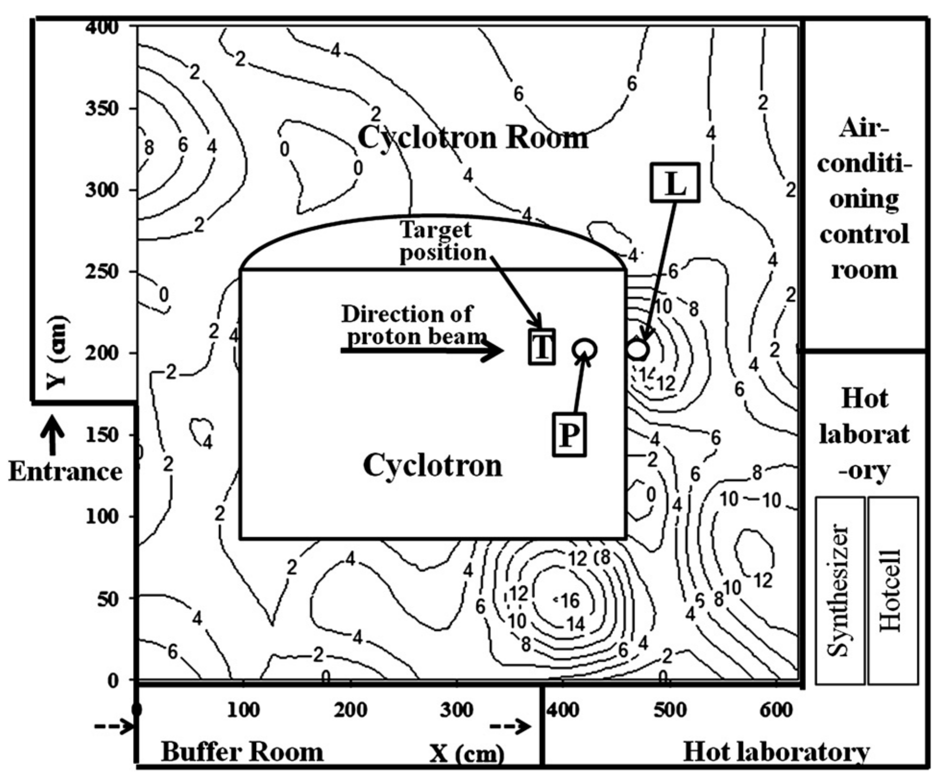

Fig. 2. Dose rate distribution of thermal neutron during the operation in Cyclotron Room using target 2 (volume of 1.5 cm^3). Maximum dose contribution of thermal neutron is at location L. The dose rate distribution was determined by means of dual-TLD method (Kuo et al., 2010). Dose rate unit: nGy min^{-1}.