Shielding Assessment of the INMP Cyclotron Facility in BAEC, Bangladesh

Mahiuddin Ahmed [a, c, *], Jun-Ho Lee [b], and Dong Myung Lee [b]
[a] *Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, 34141, Republic of Korea*
[b] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong, Daejeon, 34142, Republic of Korea*
[c] *Institute of Nuclear Science and Technology, Bangladesh Atomic Energy Commission, Savar, Dhaka, Bangladesh*
[*] *Corresponding author: mahiuddin.baec@gmail.com*

1. Introduction

A cyclotron facility for the research and production of medical isotopes is being constructed at the Institute of Nuclear Medical Physics (INMP), Bangladesh Atomic Energy Commission (BAEC). This construction project is planned to install the cyclotron of proton beam energy 16.5 MeV mainly for producing ^{18}F by proton irradiation of ^{18}O for positron emission tomography (PET) scans. The reactions for the production of ^{18}F are as the following equations:

$$^{18}_{8}O \, + \, ^{1}_{1}H \, \rightarrow \, ^{18}_{9}F \, + \, ^{1}_{0}n$$
$$^{18}_{9}F \rightarrow \, ^{18}_{8}O \, + \, ^{0}_{+1}\beta(positron)$$

Therefore, the cyclotron facility must be operated with significant shielding to keep dose rates to operators and visitors as low as reasonably achievable (ALARA).

This study aims to support the radiation shielding design of the INMP cyclotron vault, by assessing the shielding effectiveness for maze entrance walls as wedge and rectangular shapes. Therefore, the estimation of the dose equivalent rates at the entrance door location of the cyclotron vault for two different maze shapes was performed using the Monte Carlo code MCNPX [1].

2. Methods and materials

2.1. Design of the vault and source term

The vault to install a GE PETtracer 800 series cyclotron is designed as shown in Figure 1.

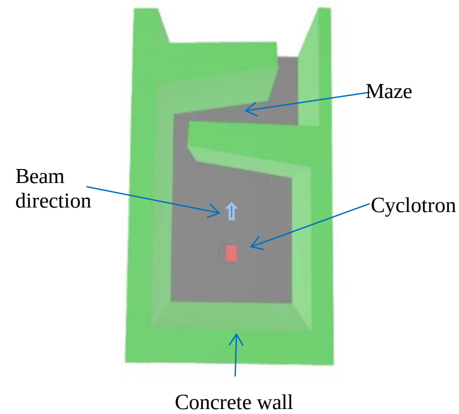


Figure 1. Cutaway view of the cyclotron vault in 3D shade

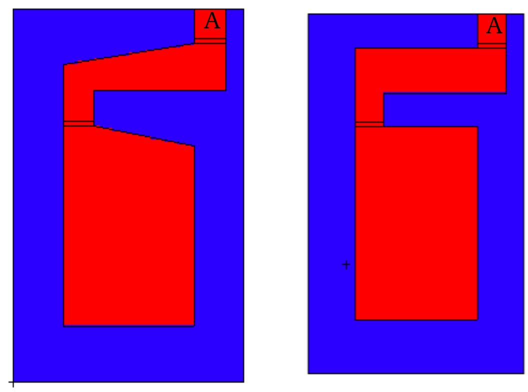
The surrounding vertical walls, floor, and roof are made of ordinary concrete. The inner dimension of the vault is 792cm(26ft) in length and 640cm(21ft) in width with a 731.5cm(24ft) ceiling height. The side walls all around are 243.8cm(8ft) thick and the entrance maze walls have a wedge shape with thickness starting from 152.4cm(5ft) to 243.8cm(8ft).

The design included the base frame position of the cyclotron, which is 122cm above the ground floor, and 198cm(6ft6in) horizontal distance from the back, left, and right walls. The plan also mentioned that the location of the collimator and target are on the side of the entrance maze with a plug-in-the-wall type door made of lead, placed at the end of the maze.

The desired particle accelerator will produce 16.5 MeV proton beams which will eventually impinge on the target material, placed at the end of the collimator, at a maximum beam current of 60µA. According to the data provided by the vendor, it is expected to get 240GBq of 0.511 MeV annihilation photons emitted by ^{18}F at the end of bombardment (EOB) after 2hrs of continuous run.

2.2. Maze modeling

Two models with accurate descriptions of vault and maze geometry, shielding materials property, and details of a typical target system were developed using MCNPX visual editor.



(a) (b)

Figure 2. Maze entrance model (a) wedge wall and (b) rectangular wall

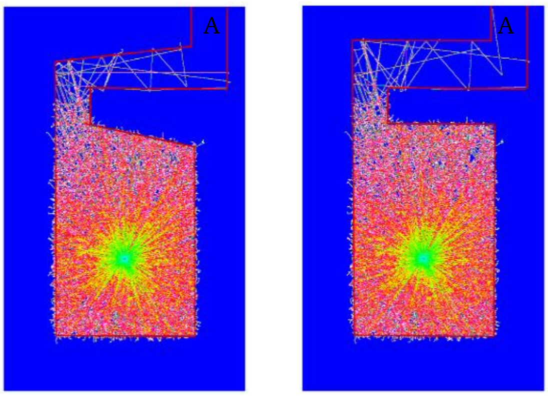
The XY plane views of the cyclotron vault and maze models, shown in Figure 2, are the visual representation of the wedge and rectangular shape entrance maze.

2.3. Monte Carlo simulation

The transport of photons was calculated with the Monte Carlo code MCNPX version 2.5.0. Dose-response functions are used to convert the photon flux to a dose equivalent rate in Sv/hr. The photon response function is taken from ICRP-74 1977 for ambient dose equivalent. The dose rate due to the 0.511MeV annihilation photons at the door position (point A in Figure 2(a) and 2(b)) of two designed models were calculated.

3. Results and discussions

The trajectory of the produced photons in the target water for 10^3 times of iteration run of the MCNP was visualized in MCNP visual editor. Figure 3(a) and 3(b) are presentations of the course of emitted photons.



(a) (b)

Figure 3. 0.511MeV photon trajectory in maze entrance. (a) wedge model (b) rectangular model

The simulated dose rates and errors for two designed models are presented in Table I. This outcome shows that, at the door location, the dose rates are 1.96, 2.18, and 0.94μSv/hr for wedge wall, rectangular thin wall, and rectangular thick wall, respectively.

Table I. Comparison of dose rates due to photons at the maze entrance door.

	Wedge wall	Rectangular wall	
		Thin (5ft)	Thick (8ft)
Dose rate (μSv/hr)	1.96	2.18	0.94
Error (%)	3.07	2.94	5.50

From the table above, it can be seen that there is no significant difference in dose rate between the wedge shape and the thin(5ft) rectangular wall, while the thick(8ft) rectangular wall is more effective than the wedge shape in case of photons only. Thus, estimation of dose rate at the same door location for neutron flux is needed for a better assessment of the shielding efficacy, as neutrons can travel appreciable distances in matter without interacting and they can be scattered in passing through matter.

4. Conclusions

We have calculated the dose equivalent rates at the door location. The dose rate arising from photon flux is adequately lower than the regulatory limits. Further study will be conducted to estimate the total dose rates from protons, neutrons, and photons throughout and outside the INMP cyclotron facility.

REFERENCE

[1] D. B. Pelowitz, Ed., "MCNPX User's Manual," Version 2.5.0," Los Alamos National Laboratory report, Los Alamos, New Mexico, LA-CP-05 0369 (April 2005).