Neutron and Gamma Radiation Level Estimation and Biological Shielding Evaluation of a Medical Cyclotron Using a Monte Carlo Simulation Method

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Introduction

Medical cyclotrons are used extensively worldwide for the production of radionuclides, which are widely utilized in medical fields like nuclear medicine for the diagnostic imaging purposes. Cyclotrons **produce a high neutron and gamma field** during normal operation and its **accurate estimation** is necessary for the cyclotron **shielding design and radiation protection** of worker, public and the environment.

Objective

In this study, a medical cyclotron was simulated using a **Monte Carlo simulation code**. Then, an accurate estimation of neutron and gamma fluence and radiation levels was carried out. Furthermore, the biological shielding of the medical cyclotron was evaluated using the code as per the current international standard

Methods and materials

In this work, the simulation code used is the Monte Carlo N-Particle Transport Code, **MCNP6** version 1.

Simulation was carried out on the **non-self shielded cyclotron model PETtrace 800**, GE Medical system, capable of accelerating protons up to **16.5MeV**. The proton current used in the simulation was **40 μA**.

The simulation was carried out on an **Oxygen-18 enriched water target(95%)** used for the production of F-18 radionuclide by (p, n) reaction. The target system was simulated as per the manufacturer's specifications as shown in Fig 1 below.

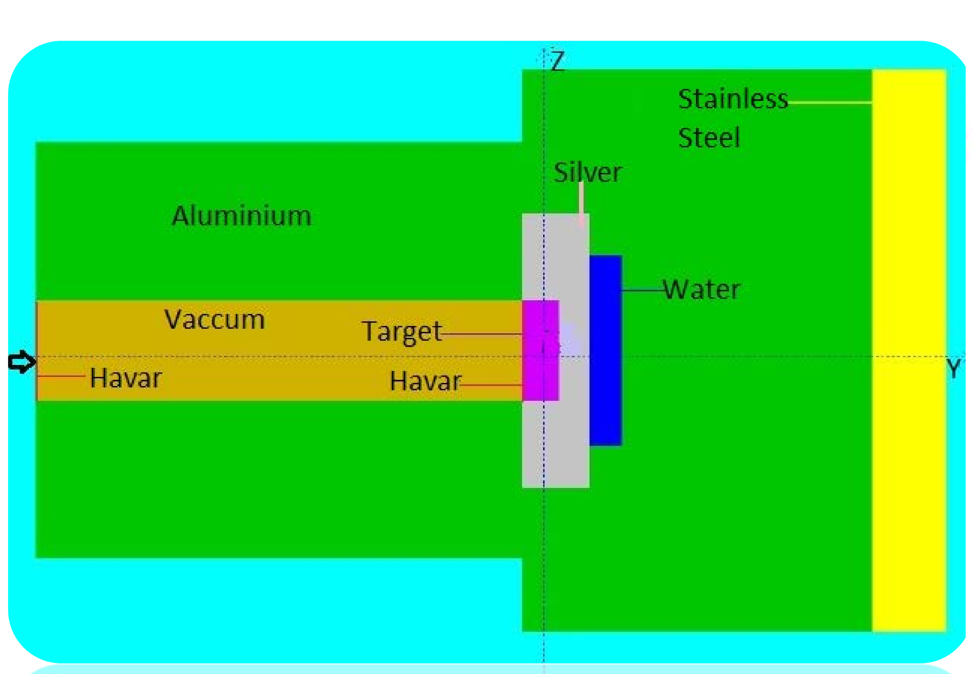

Fig. 1. Cross-sectional geometry of the target system

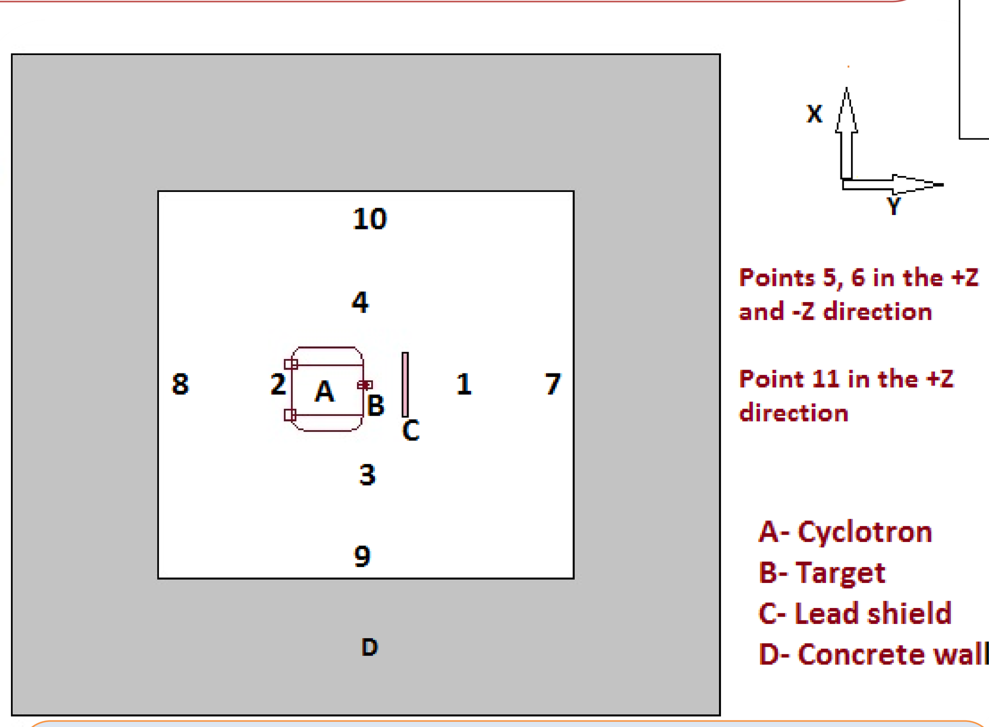

Fig. 2. Cyclotron and concrete bunker

The cyclotron simulated was placed in a concrete bunker wherein the inner **room dimension was 4.5m x 4.5 m in breadth and length and 3.5m in height**. **Regular concrete of density 2.3g/cc and a thickness of 160cm** were used in the simulation . The schematic diagram of the concrete bunker and the target system are shown in Figure 2.

Results

Fluence rate

As a result of proton interaction with the target, high levels of neutron and gamma radiation are generated.

The resultant neutron and gamma radiation fluence was estimated at various locations indicated in Figure 2 and is shown in Table 1.

Location	Distance from target	Neutron Fluence neutrons/cm^2 Sec	Gamma Fluence rate photons/cm^2 Sec
1	1m	8.23E+05	2.43E+06
2	1m	1.57E+06	2.15E+07
3	1m	1.32E+06	1.49E+07
4	1m	1.34E+06	1.51E+07
5	1m	1.34E+06	1.50E+07
6	1m	1.71E+06	2.03E+07
7	2m	5.93E+05	1.94E+06
8	2m	8.54E+05	8.48E+06
9	2m	7.36E+05	6.29E+06
10	2m	8.67E+05	6.65E+06
11	2m	7.62E+05	6.05E+06

Table 1. Neutron and gamma fluence at different locations

Dose rate

Neutron ambient dose equivalent rate and gamma effective dose equivalent rate was calculated at various locations as shown in Table 2.

Location	Distance from target	Neutron Ambient dose rate (mSv/hr)	Gamma Ambient dose rate (mSv/hr)
1	1m	449.00	33.22
2	1m	1520.49	590.43
3	1m	1219.63	390.89
4	1m	1165.98	398.26
5	1m	1180.93	391.88
6	1m	1429.64	442.05
7	2m	185.51	22.67
8	2m	544.45	179.20
9	2m	426.33	127.85
10	2m	439.43	127.20
11	2m	416.48	138.34

Table 2. Neutron and gamma dose rates at different locations

Shielding evaluation

In order to carry out the shielding evaluation, neutron and gamma dose rates in different axial directions as a function of the concrete shielding thickness were calculated and are depicted in Figures 4 and 5

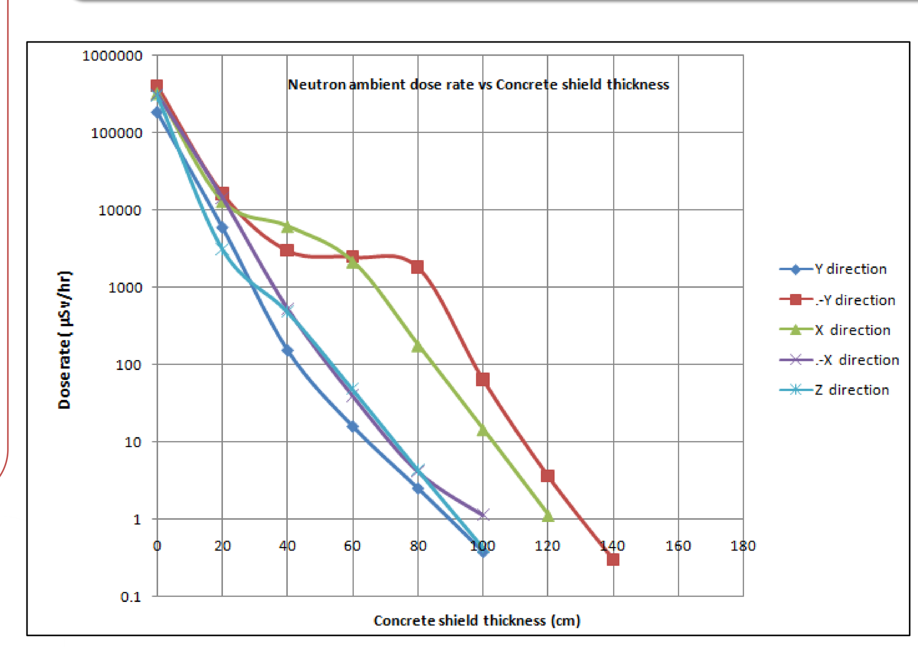

Fig. 4. Neutron dose rate Vs concrete thickness

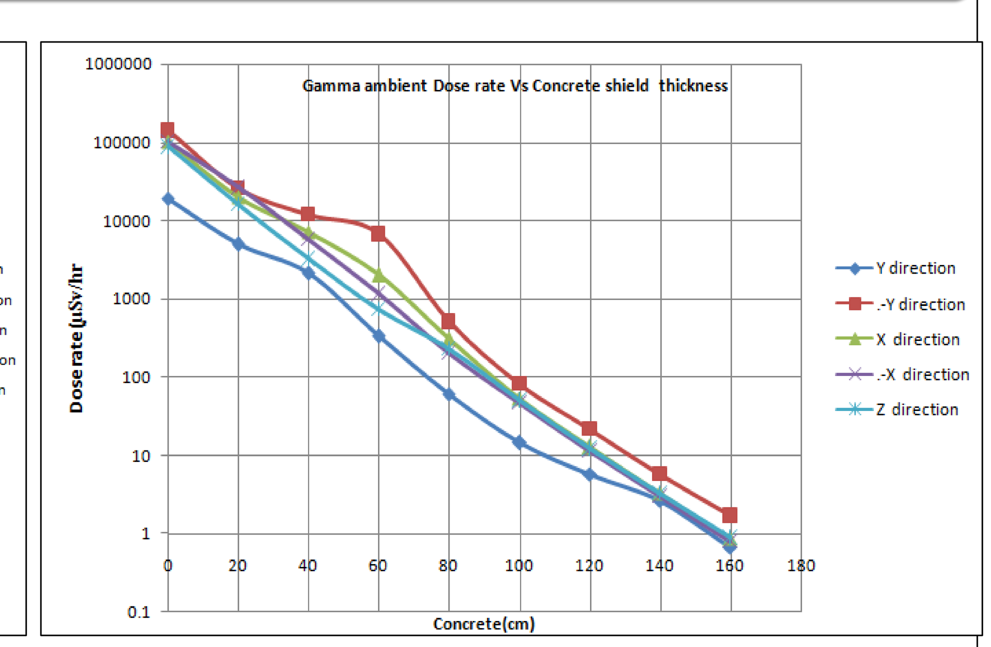

Fig. 5. Gamma dose rate Vs concrete thickness

Conclusion

It was evident from this study that high levels of neutron and gamma radiation are generated during the operation of medical cyclotrons and an accurate estimation of those levels are vital from radiation safety view point.

Using a Monte Carlo simulation code, an accurate estimation of neutron and gamma fluence and dose rate can be arrived at.

*From the biological shielding evaluation performed it was found that **160cm of concrete** is **adequate** to achieve the acceptable radiation level for the specific machine and site characteristics used in this study.*