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Double Layer Collimator for BNCT Neutron Source Based on 30 MeV Cyclotron

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Abstract A research of design of double layer collimator using $^{9}Be(p,n)$ neutron source has been conducted. The research objective is to design a double layer collimator to obtain neutron sources that are compliant with the IAEA standards. The approach to the design of double layer collimator used the MCNPX code. From the research, it was found that the optimum dimensions of a beryllium target are 0.01 mm in length and 9.5 cm in radius. Collimator consists of a D_2O and Al moderator, Pb and Ni as a reflector, and Cd and Fe as a thermal and fast neutron filter. The gamma filter used Bi and Pb. The quality neutron beams emitted from the double layer collimator is specified by five parameters: epithermal neutron flux 1×10^{9} n/cm^{2}s; fast neutron dose per epithermal neutron flux 5×10^{13} Gy cm^{2}s; gamma dose per epithermal neutron flux 1×10^{13} Gy cm^{2}s; ratio of the thermal neutron flux of epithermal neutron flux 0; and the ratio of epithermal neutron current to total epithermal neutron 0.54.

Keywords double layer collimator, MCNPX, 30 MeV cyclotron, BNCT

INTRODUCTION

Boron Neutron Capture Therapy (BNCT) is a method in cancer therapy that causes minimal damage to normal tissues. This method utilizes the ability of Boron to capture neutron beam, subsequently killing cancer cells (Sauerwein, 2012.)

One of the neutron beams used in BNCT comes from a cyclotron (Hasimoto at al., 2014). The resulting neutrons from the cyclotron are regulated to comply with the requirement set by the International Atomic Energy Agency (IAEA). Part of a cyclotron that is capable to process neutron beam is a collimator.

Until now, most efforts for cyclotron-based BNCT have been focused on the design of the collimator to investigate the feasibility of clinical neutron beams having the desired characteristics for patient irradiation. To achieve this, many types of collimators have been designed using MCNP code (Pelowitz, 2008). The design is expected to produce neutrons that meet the IAEA standard of quality.

In this paper, I propose a double layer collimator model. The goal of the design is to provide an appropriate epithermal neutron beam suitable for BNCT.

2. MATERIALS AND METHODS

2.1 Apparatus

This research uses a Personal Computer (PC) installed with MCNPX and MCPNX Visual Editor Software, under Windows 8 operating system.

2.2 Research Procedure

The procedure started with initialization, which is the installation of MCNPX software and MCNPX Visual Editor. The next step was to choose the materials for the various components of the neutron collimator. Each material was chosen for its characteristic that is suitable for every component of the collimator. The reflector of the collimator was made of Ni and Pb, moderator of D_2O and aluminum material, and filter of cadmium and iron material (Sato, 2014).

The simulation procedure commenced by modeling the interaction between ^{9}Be and 30 MeV proton beams (Mitsumoto, 2010). The radius and length of the target was varied to gain maximum neutron flux. The second step was to model all components of the collimator, which are the moderater, reflector, and filter such that the thickness and length of each component produces neutron beams that comply with the IAEA standards.

3. RESULTS AND DISCUSSION

3.1 Interaction of Proton with ^{9}Be Target

The ^{9}Be target was made in a cylindrical shape. The simulation result shows that the optimum interaction between protons and the ^{9}Be target is gained when the size of the target is 0.01 mm in length and 9.5 cm in diameter. The results obtained matched the research done by Takata et al. (2010). The calculation of neutron generation in target with various thicknesses is presented in Figure 1.

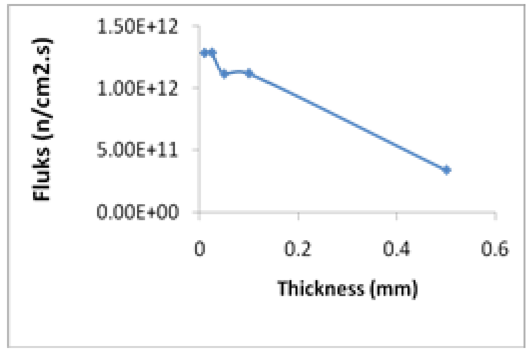

Fig. 1. Total neutron flux –thickness of a beryllium target of at 30 MeV proton energy.

3.2 Reflector

Based on the simulation result protons interacting with neutron target, which results from ^{9}Be(p,n) reaction, not only go through the axial surface but the radial surface as well. In order to optimize the number of neutrons penetrating the radial surface, a wall surrounding the target is required. The wall will reflect the neutrons going in the radial direction, allowing more neutrons to penetrate the axial surface. A simulation result using nickel and lead as reflecting walls provides maximum neutron reflections. The ability to reflect both materials is possible with a high elastic scattering cross section and low absorption cross section (Rasouli etal., 2012).

3.3 Moderator

Fast neutrons from ^{9}Be(p,n) reactions was moderated to transform them into epithermal neutrons. Two materials are available for use as a moderator i.e. deuterium (D_2O) and aluminum. According to (Ra et al., 2011), the requirement for a moderating material is that it has to be able to change fast neutrons into epithermal neutrons. One of its characteristics is its low mass density. Deuterium has a higher density than aluminum and consequently has to be set in front of aluminum in the design of a collimator.

The simulation result shows that the combination of deuterium and aluminum can produce the flux of epithermal neutron 1×10^9 neutron $cm^{-2}\ s^{-1}$.

3.4 Filter

Although the two moderators decrease the fast neutron flux, the output neutron beam still produces thermal and fast neutrons. Therefore, a filter is essential to absorb thermal and fast neutrons so as to maintain compliance with the IAEA criteria for the ratio.

An adequate material that serves the objective is cadmium to absorb thermal neutron (Volev et al., 2013) and iron to absorb fast neutron (Musolino et al., 1991). Simulation results suggest that the optimum thickness of the neutron thermal filter 10 and fast filters is 20 cm.

Bi and Pb to filter gamma were used. The result of simulation shows the optimal thickness of Bi was 10 cm and of Pb was 10 cm.

3.5 Aperture

The collimation level of neutron beams is exceptionally important to guarantee that the size and quality of beams a patient is exposed to does not significantly vary. The level is quantified by a ratio of collimated neutron flux and total neutron flux. This particular investigation finds that the value is 0.54. Such a value does not meet the IAEA standard, which is 0.7 or larger. It is possible to increase the collimation level by installing an aperture having a certain length. The material used for the aperture is equal to that for the reflector, i.e. lead

The values of IAEA parameters corresponding to the final design of double layer collimator are shown in **Table 1.** Epithermal neutron flux, gamma dose, ratio of thermal neutron to ephitermal component meets the IAEA standard. The collimation level of beams and fast neutron dose were not within the range acceptable by the IAEA but fast neutron dose is still within the tolerable limit.

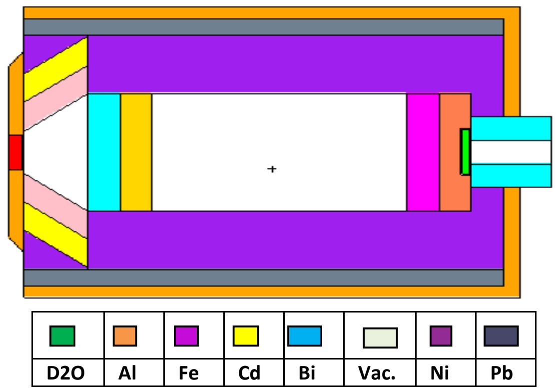

Fig. 2. Final design of double layer collimator

Table 1. Output parameters of simulation corresponding to double layer collimator design

Parameter	Result	IAEA* Criteria	Tolerance	Unit
φ_e	1.0×10^9	$\geq 1 \times 10^9$	$\geq 5 \times 10^8$	Neutron $cm^{-2}s^{-2}$
$\frac{D_f}{\varphi_e}$	5×10^{-13}	$\leq 2 \times 10^{-13}$	$\leq 13 \times 10^{-13}$	Gy cm^2 s $neutron^{-1}$
$\frac{D_\gamma}{\varphi_e}$	1×10^{-13}	$\leq 2 \times 10^{-13}$	$\leq 13 \times 10^{-13}$	Gy cm^2 s $neutron^{-1}$
$\frac{\varphi_t}{\varphi_e}$	0	≤ 0.05		
$\frac{J_e}{\varphi_e}$	0.54	≥ 0.7		

***(IAEA 2011)**

4. CONCLUSION AND REMARKS

It is concluded, based on the conducted research that the optimum dimensions of neutron collimator from ^{9}Be(p,n) source are as follows: Beryllium target is 0.01 mm in length and 9.5 cm in radius. Collimator consists of D_2O and Al moderator, Pb and Ni as a reflector, and Cd and Fe as a thermal and fast neutron filter. The gamma filter used Bi and Pb.

The quality of the neutron beams emitted from the collimator is specified by five parameters: epithermal neutron flux 1×10^9 n/cm^{2}s; fast neutron dose per epithermal neutron flux 1×10^{13} Gy cm^{2}s; gamma dose per epithermal neutron flux 5×10^{13} Gy cm^{2}s; ratio of thermal neutron flux to epithermal neutron flux 0; and ratio of epithermal neutron current to total epithermal neutron 0.54. These parameters of neutron beam quality are not entirely in agreement with the IAEA criteria.

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