THE EFFECT OF THICKNESS VARIATION OF BERYLLIUM TARGET TOWARD CHARACTERISTICS OF NEUTRON ENERGY SPECTRUM ON CYCLOTRONS HM-30 USING MCNP-X

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Abstract The research about the characterization of neutron energy spectrum as the effect of thickness variation of beryllium (Be) target on HM-30 cyclotron using Monte Carlo N-Particle eXtended (MCNP-X) has been conducted. This research aims to know the characteristics of neutron energy spectrum which are the result of the reaction of Be(p,n) with HM-30 cyclotron as one of BNCT facilities. Modelling and simulation have been done by using MCNP-X software, then the data obtained is arranged on a graph by using Origin 8+. The result of the simulation shows that the characteristics of neutron energy spectrum of each thickness are in the range of fast neutron energy. The thicker the Beryllium target, the more diminishing the neutron energy will be.

Keywords Neutron Energy Spectrum, BNCT, Neutron, Beryllium, MCNP-X

INTRODUCTION

Cyclotrons are one type of ion accelerator-based neutron source (Mitsumoto, et al., 2013). The accelerator is widely used as a medical facility, one of Boron Neutron Capture Therapy (BNCT). BNCT was first described by Gordon J. Locher in 1936 (Zarma, et al., 2014). BNCT is an innovation in cancer therapy based on core capture reactions and fission reactions that occur when non-radioactive Boron-10 nuclides are irradiated with thermal neutrons for nuclear reactions $^{10}\text{B}(n,\alpha)^7\text{Li}$ (Barth, et al., 2012; Sauerwein, et al., 2012). One type of cyclotron being developed as a BNCT application is HM-30 Cyclotrons. Cyclotron HM-30 accelerates negative hydrogen ions (H^-) with a 1 mA current resulting in a 30 MeV (Mitsumoto, et al., 2010). Cell targets for neutron production are an important part of the cyclotron. Beryllium (Be) is used as the target

material on the cyclotron because it has the highest thermal conductivity, which is equal to 201 W/m/K compared to other target materials such as Lithium (Li), Wolfram/Tungsten (W), and Tantalum (Ta) (Tanaka, et al., 2009).

The energy spectrum of neutron flux $\phi(E)$ is a quantity that states the number of neutrons (per unit of energy) that have an energy range of about E and $E+dE$ (Yazid, 2013). The characteristic of energy spectrum can provide information related to neutron energy (Spear, 2005; Harvey, 2010). Classification of energy-based neutrons as in **Table 2.1**

Table 1. Type of Neutron Based on Energy Level (Yura and Fujita, 2013; Engenhardt-Cabillie and Wambersie 1998)

Type of Neutron	Energy
Fast Neutron	$E_n > 10 \text{ keV}$
Intermediate Neutron (Epithermal Neutron)	$0,5 \text{ eV} < E_n < 10 \text{ keV}$
Thermal Neutron	$E_n < 0,5 \text{ eV}$; at room temperature $0,025 \text{ eV}$
Cold Neutron	$E_n < 0,025 \text{ eV}$

The interaction of protons in Be has a random property that requires a method that can model the transport phenomenon, an effective method is Monte Carlo. Monte Carlo is packaged in a Monte Carlo N-Particle eXtended software (MCNP-X). MCNP-X can be used to calculate secondary particle flux densities, reaction rates of elastic/ inelastic scattering and other nuclear reactions, distribution of residual ions, deposited energy and energy distribution of pulses (Sedlačková, et al., 2013). Therefore, MCNP-X was used in this study to obtain neutron energy spectrum characteristics as the effect of Be target thickness variation.

MATERIALS AND METHODS

This research method is divided into three stages namely

1. PREPARATION STAGE

This stage consists of literature study and installation of *MCNP-X* program, *visedX22S.exe*, *Origin 8+*

2. STAGE GEOMETRY MODELLING

At this stage the first is to model the source geometry simply in the form of a tubular beam transport with length 50 mm and diameter 120 mm. After which it modelled the target geometry of a tube with a diameter of 190 mm and its thickness varied from 5.0 mm to 6.0 mm. The entire listing is written with Notepad.

3. STAGE OF CHARACTERIZATION OF NEUTRON ENERGY SPERCTRUM

At this stage, the listing program is complete, then simulated and obtained the distribution of neutron energy for each thickness. Furthermore, the simulated results obtained are arranged into graphs

using Origin 8+, and the last one analyzes the energy spectrum of neutrons.

RESULTS AND DISCUSSION

1. GEOMETRY MODELLING OF BERYLLIUM TARGET

Modelling the system has been done as in the following figure, which consists of the beam transport, target cells, air space, and voids. Beam transport is modelled tube diameter 120 mm and length 50 mm. The target cell portion of a cylinder having a diameter of 190 mm and its thickness varied from 5.0 mm to 6.0 mm. In addition to beam transport and target cells, the system also consists of air space and voids. The air space serves as a boundary space for the system with the outside environment of the system. While the void is a space where MCNP-X does not simulate any interaction of particles. System geometry modelling in MCNP-X is presented in **Figure 1**.

Fig.1 Modelling of system geometry withH MCNP-X

Protons as source particles are fired with 30 MeV of energy, operating current of 1.1 mA, and fired radials from the tip of the 120 mm diameter beam transport. The scheme of firing is as shown in **Figure 2**. The total number of simulated particle history of 500.000.000

particles. The tally used is f4, which gives the output in the form of counters in each bin of energy.

Fig.2 Schematic of collision of proton particles on Beryllium target.

2. CHARACTERIZATION OF THE NEUTRON ENERGY SPECTRUM

This spectrum is obtained after simulating the created program. In this simulation the neutron energy bin is divided into 300 bin (range) energy. The energy range of neutrons used in the simulation is 10^{-10} MeV to 100 MeV. The neutron energy spectrum for each target thickness has the same tendency of having distributed characteristics in fast neutron energy. The spectrum also shows that no neutrons are distributed in thermal and epithermal neutrons. Fast neutrons are neutrons that have an energy greater than 10 keV. These characteristics are suitable for BNCT therapy.

Fig.3 The neutron energy spectrum with a target thickness of 5.0 mm beryllium.

Fig.4 The neutron energy spectrum with a target thickness of 5.1 mm beryllium.

Fig.5 The neutron energy spectrum with a target thickness of 5.2 mm beryllium.

Fig.6 The neutron energy spectrum with a target thickness of 5.3 mm beryllium.

Fig.9 The neutron energy spectrum with a target thickness of 5.6 mm beryllium.

Fig.7 The neutron energy spectrum with a target thickness of 5.4 mm beryllium.

Fig.10 The neutron energy spectrum with a target thickness of 5.7 mm beryllium.

Fig. 8 The neutron energy spectrum with a target thickness of 5.5 mm beryllium

Fig.13 The neutron energy spectrum with a target thickness of 6.0 mm beryllium.

As shown in **Figure 3** to **Figure 13**, it can be seen that the change in the shape of the neutron energy spectrum is not significant. The apparent change in the thickness of 5.2 mm is that two peaks appear the same. At a thickness of 5.0 mm and 5.1 mm having the same tendency of peaks that are on a larger neutron energy they have a higher neutron flux count than the peak at a smaller neutron energy. While at a thickness of 5.3 mm to 6.0 mm, the peak that is at greater neutron energy has a lower number of neutron fluxes than the peak at smaller neutron energy. Thus, the thicker the target of beryllium, the resulting neutron flux dominance moves to smaller neutron energies. So the longer the reaction, the neutron energy will go down. The decrease can be seen in **Table 2**

Fig.11 The neutron energy spectrum with a target thickness of 5.8 mm beryllium.

Fig.1 The neutron energy spectrum with a target thickness of 5.9 mm beryllium.

Table 2. The peak change of the neutron energy spectrum.

Target Be Thickness (mm)	Spectrum Peak Right		Spectrum Peak Left	
	Neutron Flux (n. cm ⁻² . s ⁻¹)	Neutron Energy (MeV)	Neutron Flux (n. cm ⁻² . s ⁻¹)	Neutron Energy (MeV)
5,0	2,72062×10 ¹⁰	6,9800	2,61884×10 ¹⁰	2,1163
5,1	2,72873×10 ¹⁰	6,3678	2,67196×10 ¹⁰	2,1163
5,2	2,72491×10 ¹⁰	6,3678	2,72308×10 ¹⁰	1,9307
5,3	2,68841×10 ¹⁰	6,3678	2,75603×10 ¹⁰	1,9307
5,4	2,66192×10 ¹⁰	6,3678	2,78423×10 ¹⁰	1,9307
5,5	2,64023×10 ¹⁰	6,3678	2,77963×10 ¹⁰	1,9307
5,6	2,59647×10 ¹⁰	6,3678	2,76061×10 ¹⁰	1,9307
5,7	2,57266×10 ¹⁰	6,3678	2,74281×10 ¹⁰	1,9307
5,8	2,53806×10 ¹⁰	6,3678	2,71556×10 ¹⁰	1,9307
5,9	2,51471×10 ¹⁰	6,3678	2,68188×10 ¹⁰	1,9307
6,0	2,48843×10 ¹⁰	6,3678	2,65900×10 ¹⁰	1,9307

The peak in the energy spectrum is a neutron energy that has a higher flux than other energies. That is because the neutron of the proton reaction with Be reacts back to the Beryllium core through the reaction of ${}^9\text{Be}(n,2n+\alpha){}^4\text{He}$. Thus the number of neutrons in a given energy increases or the resulting flux value is higher than that of other neutron energies.

In the spectrum, neutron energy also has a slightly lower neutron flux. That's because the number of Helium as the end result of the reaction between neutrons with Be more than

the neutrons produced. As stated by Kuntjoro (2010), that Be reaction with fast neutrons continuously generates significant helium gas.

CONCLUSION

The conclusions obtained from the research are

- a. The energy spectrum of each thickness has a distributed characteristic in the fast neutron energy range;
- b. The resulting neutron energy increases to a certain thickness, and at the subsequent thickness of the neutron energy generated decreased;

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