BEAM OPTIMIZATION FOR BORON NEUTRON CAPTURE THERAPY AT THERMAL COLUMN OF TRIGA MARK-II RESEARCH REACTOR

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"In the name of Allah, the most Gracious and the most Merciful"

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ABSTRACT

The thermal column at TRIGA PUSPATI research reactor has an ability to produce thermal neutron. However, the optimization on the thermal neutron flux produced should be performed in order to gain a sufficient thermal neutron for boron neutron capture therapy purpose. Thus, the objective of this study is to optimize the thermal neutron flux by designing the collimator with different materials at the thermal column. In order to fulfil the requirement, set by the IAEA standard, the collimator was designed using Monte Carlo N-Particle simulation. Initially, the measurement of the thermal neutron flux was conducted along the thermal column at 250 kW. The thermal column was divided into 3 phases (Phase 1, Phase 2 and Phase 3) so that an accurate measurement can be obtained by using gold foil activation method and thermoluminescent dosimeter detector. This value was used as a benchmark for the neutron flux produced from the thermal column. The collimator was designed using different types of materials and their characteristic towards gamma and neutron flux was investigated. The results demonstrated that the final thermal neutron flux produced was significantly depends on the shielding thickness, aperture size and collimator conditions (uncovered or fully covered). The collimator design using thickness shielding of 5+10 cm of lead, aperture size of 3 cm and operated using uncovered condition has produced the optimum thermal neutron flux. The sufficient amount of thermal neutron flux of 3.28 x 10^8 neutron.cm^{-2}s^{-1} at 250 kW of TRIGA PUSPATI research reactor power produced from the designated collimator was achieved.

ABSTRAK

Turus terma di reaktor penyelidikan TRIGA PUSPATI mempunyai keupayaan untuk menghasilkan neutron terma. Walaubagaimanapun, penghasilan neutron fluks terma yang optima perlu untuk memperolehi neutron terma yang cukup untuk tujuan terapi penangkapan neutron boron. Oleh itu, objektif kajian ini adalah untuk mengoptimumkan fluks neutron terma di turus terma dengan merekabentuk kolimator dengan menggunapakai bahan yang berbeza. Bagi memenuhi kriteria yang ditetapkan oleh piawaian IAEA, kolimator direka menggunakan simulasi Monte Carlo N-Particle. Kajian ini dimulakan dengan mengukur fluks neutron di turus terma pada kadar kuasa reaktor 250 kW. Bagi memudahkan pengukuran, turus terma telah dibahagikan kepada 3 fasa (Fasa 1, Fasa 2 dan Fasa 3) supaya pengukuran menggunakan keranjang emas dan pengesan meter dos pendarkilau haba lebih mudah dan tepat. Nilai fluks tersebut digunakan sebagai penanda aras bagi penyelidikan ini. Kolimator direkabentuk menggunakan bahan yang berbeza dan ciri-cirinya terhadap gama dan fluks neutron dikaji. Hasil penyelidikan ini mendapati fluks neutron terma yang terhasil sangat bergantung terhadap ketebalan perisai, saiz apertur dan jenis kolimator (jenis bertapis dan tidak bertapis). Rekabentuk kolimator yang menggunakan ketebalan pelindung 5 + 10 cm plumbum, saiz apertur 3 cm dan beroperasi menggunakan jenis tidak bertapis telah menghasilkan fluks neutron terma yang optimum. Jumlah neutron terma dihasilkan mencukupi iaitu 3.28 x 10^8 neutron.cm^{-2}s^{-1} pada 250 kW kuasa reaktor penyelidikan TRIGA PUSPATI daripada kolimator yang direkabentuk telah tercapai.

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LIST OF ABBREVIATIONS

Al	-	Aluminium
BNCT	-	Boron Neutron Capture Therapy
BTI	-	Bubble Technology Industries
BPE	-	Borated Polyethylene
Cd	-	Cadmium
CRANE	-	Centre for Application of Nuclear Energy
IAEA	-	International Atomic Energy Agency
LANL	-	Los Alamos Nuclear Laboratory
LET	-	Linear Energy Transfer
Li	-	Lithium
MCNP	-	Monte Carlo N-Particle
MINT	-	Malaysia Institute for Nuclear Technology Research
MOSTI	-	Ministry of Science, Technology and Environment
Pb	-	Lead
PUSPATI	-	Tun Ismail Atomic Research Centre
RTP	-	Reactor TRIGA Mark II PUSPATI
SANS	-	Small Angle Neutron Scattering
TLD	-	Thermoluminescence Detector

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Cancer is the most leading cause of death based on 172 countries in the world (Bray *et al.*, 2018). In fact, cancer had caused death over 8.2 million each year, which was roughly estimated about 13% around the world (Organization, World Health, 2003). There are more than 100 types of cancer exist and each requiring different techniques of diagnosis.

BNCT is one of the promising methods in order to cure cancer by using neutron source either from nuclear research reactor or neutron generator such as an accelerator. BNCT method used the combination of low energy of neutron (slow neutron) irradiation and the targeting of a tumour site injected with a proper boron containing compound. Basically, the tumour cell was not directly destructed by neutron, but indirectly destroyed by the results of nuclear reaction between neutron and boron. In theory, the BNCT also is one of the forms of radiotherapy which is selectively kills the cancer cells and less effect on other normal cell that used photon that will selectively deposited in tumour cell of boron carriers such as BPA and BSH. The standard boron carries compound must be enriched by Boron-10 about 20% natural abundance. The patient will be irradiated with slow energy of neutron to reach the ratio of high concentration of boron in the tumour cell (Durisi, 2007). The irradiation with slow neutron points out of nuclear reaction that form the products of Boron-10 capture the thermal neutron and as a result of production Boron-10 convert into Boron-11 which decay from the emission of an alpha particle (Faião-Flores *et al*., 2011).

Initially in BNCT, thermal neutron is captured by Boron-10 and becomes unstable because of its properties towards neutron. Neutron, especially thermal neutron was well known for its neutral properties (no electrical charge) and could be absorbed by atomic nuclei which collide with it to create heavier isotope. The unstable reaction of Boron-10 and thermal neutron results of emitting both high LET (Linear Energy Transfer) α and γ before it changes to Lithium-7. The LET is a term that used to measure the force acting on a charged particle travelling through matter (Solleh, 2016). There are three factors affecting LET which is charge, velocity and the mass of the particle. (Kraft, 2000). BNCT emitted both high LET α and γ which have deeper penetration in the range of ~10µm which is approximately to the diameter of mammalian cell and promptly attenuating the radiation (Valda *et al.*, 2005). Hence, the BNCT give a highly localized treatment to the tumour cell compare to other treatment. The basic nuclear reaction is illustrated in Figure 1.1:

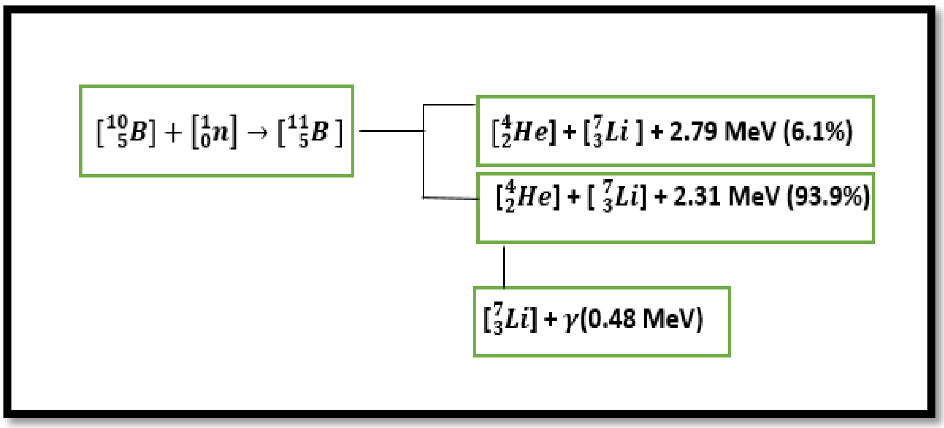

Figure 1.1 Neutron capture by the boron and subsequent nuclear reaction and nuclear fission (Gohil *et al*., 2015)

The neutron produce from the research reactor was mostly use in the studies of BNCT around the world (Gohil *et al.*, 2015). This kind of research are aim to develop a BNCT facility for the cancer treatment studies with safe and controlled from radiation and practically using slow neutron emitted from the Malaysia TRIGA MARK II research reactor (RTP). Thus, the first steps to achieve the long-term goal is to establish the suitability neutron fluxes produce from the research reactor. Commonly, most of the TRIGA reactor has a thermal column, which is the special place design to produce thermal neutron which can be utilized in BNCT facility. Therefore, the thermal column of RTP was identified to produce thermal neutron source in the investigation. In contemplation of developing the facility at the thermal column of RTP, the thermal neutron beam needs to be optimized by designing suitable ideal neutron collimator.

1.2 Problem Statement

The development of the BNCT facility in Malaysia can be performed at the thermal column of the Malaysia research reactor. TRIGA MARK II is one of the facilities that can provide neutron souce for BNCT facility. The specification of neutron flux and the gamma dose rate must be considered for the development of the BNCT facility as a safety precaution for this research. Based on previous research, the thermal column is identified as a suitable place for BNCT facility.

RTP was believed to supply a proportionate of neutron beam in developing the BNCT facility (Munem, 2007). The thermal neutron flux measurement at inside the thermal column show that the thermal neutron flux inside the thermal column was 1.17 x 10^{10} neutron.$cm^{-2}s^{-1}$ which is higher than the IAEA requirement for BNCT (1.0 x 10^{9} neutron.$cm^{-2}s^{-1}$) at 1000 kW based on research by Solleh (2016).

Unfortunately, those thermal neutron fluxes were decreased into 8.58 x 10^8 neutron.cm^{-2}s^{-1} as measurement at the thermal column door (Solleh, 2016). Thus, the optimization on the thermal neutron flux at outside of the thermal column to get the equivalent result as thermal neutron flux inside the thermal column for BNCT facility by designing neutron collimator was carried out.

In order to design the neutron collimator for BNCT purpose, the characterization of material towards thermal neutron flux and gamma was explored and the optimization of collimator was performed in terms of shielding thickness, aperture size of collimator and types of collimator design in order to produce high thermal neutron flux.

1.3 Objectives

The main aims of this study are:

1. To measure the neutron flux at thermal column using two technique (gold foil activation analysis and TLD detector).
2. To design the collimator for BNCT research facility at the thermal column of TRIGA MARK II.
3. To simulate the desired neutron flux for the BNCT purpose by using MCNPX.

1.4 Scopes of Study

In order to achieve the objectives of this study, the following scopes of study have been carried out:

a) Collecting data of thermal neutron flux and gamma flux from experimental work at thermal column using TLD detectors and gold foil activation method analysis.
b) Characterizing material behaviour towards neutron and gamma using TLD detector and Microspec-6 N-probe for designing collimator.
c) Designing collimator, the BNCT research facility and simulate from the reactor core using MCNPX software.
d) Estimating the thermal neutron flux and gamma flux produce through the BNCT facility design using MCNPX.
e) Maximizing the production of thermal neutron passing and minimize the unnecessary gamma and fast neutron by optimizing the aperture size, shielding thickness and collimator conditions.
f) Comparing the data obtained from simulation and experimental work.
g) Fabricating process for the BNCT collimator as the result of thermal neutron flux and gamma flux produce from the MCNPX was sufficient for BNCT.

1.5 Significance of Research

There is one and only research reactor in Malaysia that was identified as an available neutron source for BNCT. The thermal column of RTP are determine to be a suitable place for BNCT purpose based on the early studied of BNCT. The measurement with the verification by MCNP for the thermal neutron at the thermal column was clear that the availability of the thermal column of Malaysia RTP was sufficient enough for the development of BNCT as the quality and intensity of the neutron beam produced was well within standard requirement for BNCT facility. Research of BNCT at thermal column are being continued by Solleh (2016) in order to produce the data of gamma and neutron outside of the thermal column and as well to develop basic neutron collimator for these purposes. The result produce by Solleh (2016) show that the neutron flux at the end of thermal column door was 8.58 x 10^8 neutron.$cm^{-2}s^{-1}$ which is lower than IAEA standard (was 1.00 x 10^9 neutron.$cm^{-2}s^{-1}$) for BNCT facility. Thus, aim of this research is to optimize the thermal neutron beam by designing the neutron collimator for the BNCT purpose so that the neutron flux obtained is within the range that set by the IAEA standard. Furthermore, in the previous research done by Solleh (2016), only single phase was considered which is refer to the Phase 1 (in this work). In this study, three phases were involved in collimator design.

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