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Design Collimator and Dosimetry of in Vitro and in Vivo Test Using MCNP-X Code

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Abstract. Studies were carried out to collimator modelling and dosimetry BNCT of in vitro and in vivo test using MCNP-X code. Collimator modelling performed to obtain neutron beam as required by the International Atomic Energy Agency (IAEA). Dosimetry calculations performed to obtain the results of the dose calculation (dosimetry) in the application of BNCT. Collimator modelling and dosimetry simulations performed with MCNPX program. Neutron sources used for simulation, namely cyclotrons HM-30, energy 30 MeV, the current is 1.1 mA. Collimator modelling utilizes to program MCNPX covers cells target as beryllium, collimator wall (reflector), moderate, filter, gamma-ray shielding, and aperture. The simulation results of the modelling are Φ_{epi} 1.02241x10^{10} n/cm2 s, D_f/Φ_{epi} 2.36487x10^{-11} Gy-cm^2/n, D_γ/Φ_{epi} 4.68416x10^{-12} Gy-cm^2/n, Φ_{th}/Φ_{epi} 3.76285x10^{-01}, J/Φ_{epi} 8.37678x10^3. Based on the calculation of the dose rate that has been done, the result that the optimal dose rate at a depth of 1cm.

Keyword: *BNCT, MCNPX, collimator, dosimetry*

INTRODUCTION

Cancer is a group of diseases that cause the cells in the body to change and grow out of control. Most types of cancer cells eventually form a lump or mass called a tumour, and are named accordingly part of the body where the tumour originated [1]. Breast cancer is one type of cancer. Breast cancer cells either spread through the bloodstream or the lymphatic system or have a predilection to metastasize to certain parts of the body such as the lymph nodes, bones, liver, lungs, and brain [2]. Breast cancer is the most common cause of cancer death among women (522,000 deaths in 2012) and the most frequently diagnosed cancer among women in 140 of 184 countries worldwide [3]. Treatment of breast cancer, which until now often used are surgery and is often combined with other treatments, such as radiation therapy, chemotherapy, systemic therapy, hormone therapy, and / or targeted therapy [1]. Another treatment method for breast cancer is brachytherapy. Several methods of treatment turned out to have side effects for the patient.

Boron Neutron Capture Therapy (BNCT) has for many decades been advocated as an innovative form of radiotherapy, BNCT has the potential to be the ideal form of treatment for many types cancer [4]. BNCT is based on the nuclear capture and fission reactions that occur when the nuclide Boron-10 non-radioactive irradiated with thermal neutrons (0.025 eV) [5]. ^{10}B absorbs neutrons and produce two particles have the Linear Energy Transfer (LET) high, α particles (^{4}He) and lithium (^{7}Li) [6], [5] for particles of α ≈ 150 keVμm-1 and ^{7}Li ≈ 175keVμm- 1 [4]. Results of the reaction ^{10}B (n, α) ^{7}Li has a long-range 6-10μm [7]. Neutrons are used in BNCT treatment is thermal neutrons and epithermal neutrons. Neutron collimator is needed to collimate neutron beam [8]. Collimator in BNCT therapy is an important

part, because the collimator has a function to collimate neutrons that come out of the neutron source, so that the neutron beam to the patient in accordance with predetermined parameters. Besides collimator, dosimetry also important in BNCT. Dosimetry is the study of various magnitudes and unit dose [9]. In the BNCT treatment, the dose delivered to the healthy and tumour tissues depends on the interaction of neutrons with many different nuclei and the gamma ray back-ground [10]. Modelling collimator and dose calculation is very important to test the in vitro and in vivo BNCT therapy. Modelling collimator and dose calculations can be done using one of the methods of computing, namely Monte Carlo. Monte Carlo N-Particle (MCNP) code is developed and maintained by the Los Alamos National Laboratory [11].

MATERIALS AND METHODS

Collimator Modelling

Collimator modelling done by using MCNP-X. Figure 3.1 shows the geometry used in the simulation. Neutron sources used are 30 MeV cyclotron, which has a specification as in table 2.1. The modelling was conducted on the part of the target, moderator, filter, shield gamma, aperture, and a reflector.

Table 2.1. Main Specification of Cyclotron HM-30 at KURRI (12)

Extraction ion	Proton
Energy	30 MeV
Current	1,1 mA
Number of extraction port	1
Magnet size	3,0 m (L) x 1,6 m (W) x 1,7 m (H)
Weight	60 Ons

Cells Target

Cyclotron is one of neutron source as accelerator. Cyclotron change proton particle into neutron. Proton into a neutron particle changes occur on the target. Materials that can be used to cells target that Beryllium (^{9}Be) and lithium (^{7}Li). Materials are selected in collimator design under which Beryllium with 5 cm thick. Beryllium has the advantage of high melting point, high thermal conductivity and the ability to directly cool the water.

Moderator

Moderator required in BNCT therapy should have a high scattering cross section for fast neutrons and a low absorption cross section for epithermal neutrons. The material used as a moderator, Al, Al_2O_3, AlF_3, MgF_2, PbF_2, alloy of Al / AlF_3 (30% Al, 70% AlF_3) and fluent (30% Al, 69% AlF_3, 1% LiF) (Kasesaz, et al., 2014). The material used in the collimator, under which Al (Aluminium) and Al_2O_3 (Aluminium Oxide) with a thickness of 2 cm each.

Filter

Filter the collimator serves to reduce the fast neutron component. Cadmium (Cd) is a material used as a filter on the design of the collimator below 2 cm thick.

Gamma-ray Shielding

Gamma-ray shielding serves to reduce the intensity of the gamma rays produced in the collimator. Materials such as Pb, Bi and Ni can be used as a shield gamma. Nickel (Ni) thickness of 5 cm is used in the collimator design below.

Aperture

Aperture is the tip of a conical collimator shaped to focus the radiation beam. The size of the aperture in the collimator design under that thick 5 cm and 6 cm radius.

Wall Collimator (Reflector)

Materials suitable for the reflector are a material that has a high scattering cross section and has a higher atomic mass. The material used

as a reflector in collimator design is graphite with a thickness below 20 cm.

Dosimetry

The first stage is define the geometry dosimetry calculations used for simulation. Geometry used is spherical with a mathematical equation as follows:

$$(x-x)^2 + y^2 + z^2 - R^2 = 0 \quad (1)$$

Geometry as the sphere approaches the cancerous lump form. Lump is assumed to have a shape like a sphere.

The next stage is to determine the material making up the tissues, such as H, C, N, O, P, Na, P, S, Cl, and K. Tally used to calculate the dose is tally f4 by adding a coefficient of Kerma. Thus, obtained dose calculation results. The final stage in the dosimetry calculations is to calculate the total dose rate on each tissue. The equation used as follows:

$$\dot{D}_{Total} = w_B \dot{D}_B + w_p \dot{D}_p + w_n \dot{D}_n + w_g \dot{D}_g \quad (2)$$

Where:

$\dot{D}_B$: Dose rate of Boron (Gy/s)

$\dot{D}_p$: Dose rate of recoil proton (Gy/s)

$\dot{D}_n$: Dose rate of recoil proton (Gy/s)

$\dot{D}_g$: Dose rate of gamma (Gy/s)

w_B : radiation weighting factor of alpha, 3.8 for the tumour tissue and 1.35 for normal tissue

w_p : weighting factor of the proton radiation is 3.2

w_n : weighting factor of neutron scattering radiation is 3.2

w_γ : .

RESULTS AND DISCUSSION

Collimator Design

Collimator design simulation results using MCNPX program as shown below:

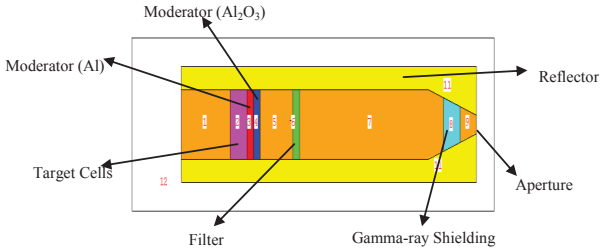

Figure 3.1 Modeling Simulation Results Collimator with MCNPX Program

Neutron beam obtained as simulation results using MCNPX program are presented in Table 3.1.

Based on the results obtained, the value of epithermal flux for 1.02241×10^{10} n/cm^2-s IAEA has fulfilled recommendation that $>1.0 \times 10^9$ n/cm^2-s. Meanwhile, the simulation result for fast neutron dose per epithermal flux (Df/Φepi) still exceeds the limit recommended values. This is possible because the number of fast neutrons in the collimator many passes or the number

Table 3.1 Neutron Beam Collimator Modelling Results with MCNPX Program

Notation	Simulation Results	IAEA Recommendations	Compliance with the IAEA recommendations
Φ_{epi} (n/cm^2 s)	1.02241×10^{10}	$>1.0 \times 10^{9}$	Yes
D_f/Φ_{epi} (Gy-cm^2/n)	2.36487×10^{-11}	$<2.0 \times 10^{-8}$	No
D_γ/Φ_{epi} (Gy-cm^2/n)	4.68416×10^{-12}	$<2.0 \times 10^{-8}$	No
Φ_{th}/Φ_{epi}	3.76285×10^{-01}	<0.6	No
J/Φ_{epi}	8.37678×10^{3}	>0.7	No (because maximum 1)

of fast neutrons in the collimator is still high. The simulation results for gamma dose per epithermal flux (D_γ/Φ_{epi}) still exceeding the standards because of the possible amount of radiation in a gamma ray collimator is still quite high. The possible numbers of gamma rays that pass from gamma shield quite a lot, so it is necessary election material and thickness settings in the appropriate gamma shield. The amount of thermal flux per flux epithermal (Φ_{th}/Φ_{epi}) still exceeding the standards for the amount of thermal neutrons released by collimator fewer than epithermal neutron. Simulation results for current ratio per epithermal flux (J/Φ_{epi}) are very far from the value recommended by IAEA, possibilities for the direction of the neutrons in the collimator is random or not mono direction.

Dosimetry

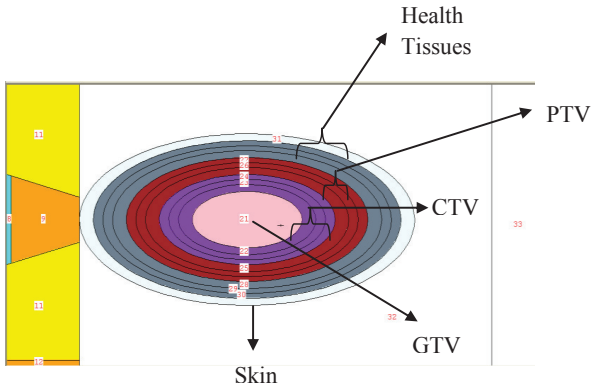

Figure 3.2 Modelling Phantom Breast Cancer

Modelling phantom breast cancer using spherical geometry, assuming that the lumps (cancer cells) spherical. Phantom is divided into several parts, the GTV, CTV, PTV, healthy tissue, and skin. Gross tumour volume (GTV)

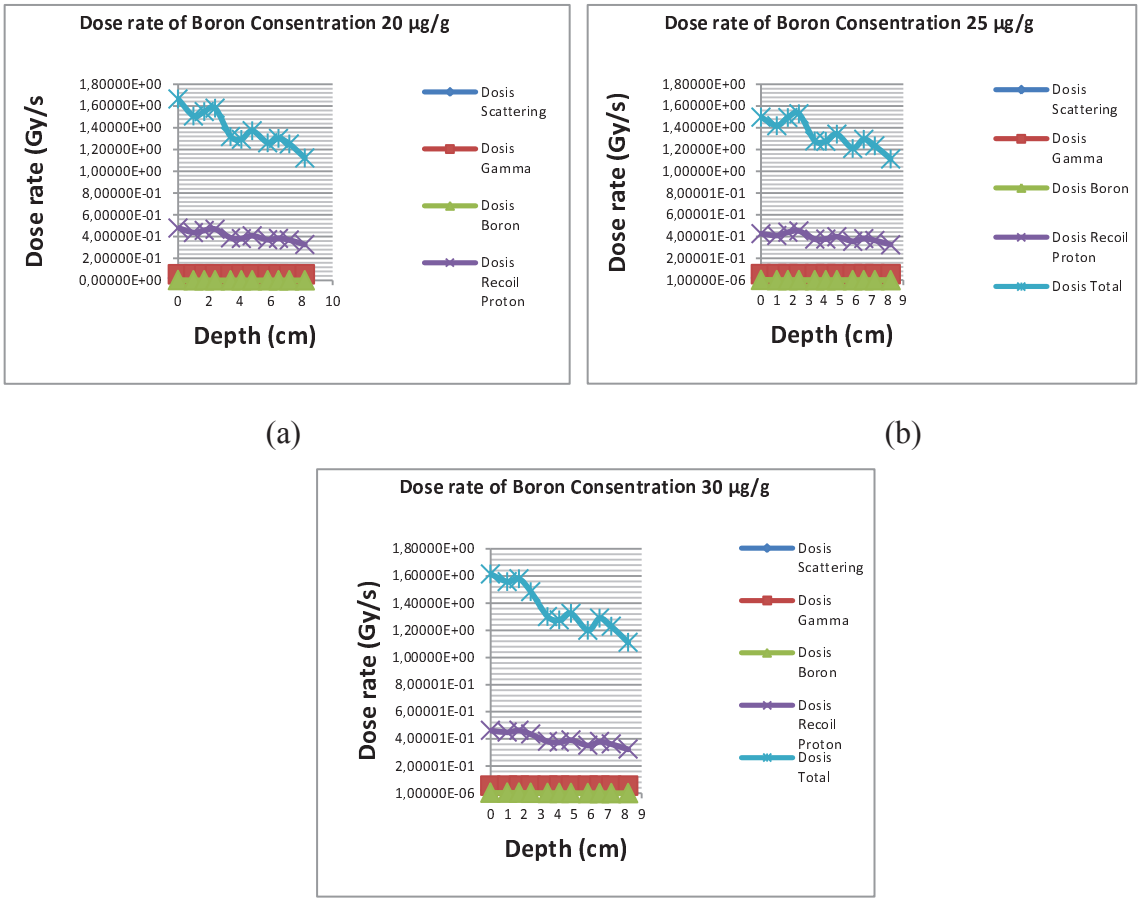

Figure 3.3 Dose rate chart with Boron Concentration (a) 20 µg/g, (b) 25 µg/g, (c) 30 µg/**g**

is a measure of how much the cancer visible or provable extent or location of the cancer growth. Clinical Target Volume (CTV) is a tissue that contains GTV has proven malignant disease microscopic or sub-clinical to be eliminated. Planning Target Volume (PTV) is defined as the geometric concepts to radiating volume appropriate cancer, in order to ensure that the prescribed dose to kill the cancer is absorbed.

Phantom modelling is used to perform the calculation of the dose rate. Components of the dose in BNCT therapy is dose of neutrons scattering, gamma dose, Boron dose (interaction of ^{10}B with thermal neutrons), and recoil proton dose. Dose of neutrons scattering and gamma dose as a result of output collimator can be obtained through simulations on MCNPX program. While, for the gamma dose, boron dose, and the recoil proton dose as results of interactions thermal neutron with hydrogen in the tissues is done by manual calculation. Dose calculation results are presented in Figure 3.3

The third chart above shows the relationship between the depth of the dose rate (dose scattering of neutrons, gamma dose, dose boron, and the recoil proton dose). Based on the results presented in the figure above, all components of the dose fluctuation. All the components of the dose began to decline when it reaches a depth of 1cm of skin. The optimal dose rate only at a depth of 1 cm, after it experienced a significant decline. This is possible because the probability of the number of neutrons reaction with the boron in tissues is less than optimal. Thus, the dose rate is only optimal when it reaches the organ PTV, not yet to the cancer cells. The amount of boron concentration and irradiation time is very important in BNCT treatment, it is necessary to optimize between them. Absorbed dose recommended for BNCT therapy was 50 Gy. The result of dosimetry calculations can not be used for in vitro and in vivo in application of BNCT.

CONCLUSION AND REMARKS

CONCLUSION

Modelling collimator using cyclotron 30 MeV neutron source. The modelling includes parts of the target cell, a moderator, filter, shield gamma, reflectors, and aperture. MCNPX simulation results show that the epithermal neutron flux issued by the collimator has met standard IAEA is equal 1.02241×10^{10} n/cm^2-s. Dose rate calculation performed on the four components of the therapeutic dose BNCT. Boron concentrations used in the simulation are 20 μg/g, 25 μg/g, and 30 μg/g. Based on calculations, the optimal dose rate at a depth of 1 cm.

Remarks

Need to do further research relate to modelling collimator and dosimetry calculations, in order to obtain results in accordance with the parameters.

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