Indonesian Journal of Physics and Nuclear Applications
Volume 3, Number 2, June 2018, p. 43-48
e-ISSN 2550-0570, © FSM UKSW Publication

Distribution of Water Phantom BNCT Kartini Research Reactor Based Using PHITS

Nunung Gupita Ratnasari [1*], Susilo [1], Yohannes Sardjono [2]

[1]*Department of Physics, Faculty of Mathematics and Sciences, State University of Semarang, Semarang 50229, Indonesia*
[2]*Pusat Sains dan Teknologi Akselerator Badan Tenaga Nuklir Nasional (PSTA-BATAN), Yoygakarta 55281, Indonesia*

Abstract The purpose of this research was to calculate the radiation dose on BNCT. Boron Neutron Capture Therapy (BNCT) is a cancer therapy which utilizes thermal neutron-capture reactions by boron-10 isotopes that produce alpha particles and lithium nuclei. The advantage of BNCT is that radiation effects can be limited to tumor cells. The dose of radiation on BNCT depends heavily on the distribution of boron and the neutron free region. The calculation method involves alpha and lithium particles of reactions having high Linear Energy Transfer (LET). By replacing the target of using water phantom that contains heavy water and covered by acrylic glass measuring 30 cm x 30 cm x 30 cm, the dose is calculated using PHITS-based applications. By comparing the simulation results between boron and phantom water or phantom without boron then the conclusion is the absorbed dose of phantom water containing boron is larger than phantom water without boron.

Keywords BNCT, Kartini Research Reactor, Dose, PHITS.

INTRODUCTION

In this modern era, more and more types of diseases are attacking humans, from infectious diseases to non-infectious. Cancer is one of the non-communicable diseases and is mostly found in developing countries (IAEA, 2014). According to WHO (2015), cancer or neoplasm is a disease characterized by rapid growth of abnormal cells which can then spread to other organs, also referred to as metastatic. Cancer is one of the leading causes of morbidity and mortality worldwide, with 14 million new cases by 2012 and being the second leading cause of death worldwide(American Cancer Society, 2016; National Cancer Institute, 2016; WHO, 2018).

There are several types of cancer treatment used by patients in general. Treatment of cancer with radiotherapy is a treatment technique of utilizing energy from radioactive sources (eg $_{137}$Cs, $_{60}$Co, and $_{131}$Ir) as well as high energy electromagnetic waves (eg energy from linear accelerator)(Triviño et al., 2016). The effects of radiation can kill cancer cells through ionization mechanisms in the local area of cells exposed to radiation(Sauerwein, 1993). The disadvantage of this therapy is the exposure to radiation of healthy tissue in line or parallel to the surface of cancer cells, especially those closer to the source of radiation(Akan, 2015) .

Based on the weakness of cancer treatment, a new cancer treatment with a selective targeting method was developed.

That method is Boron Neutron Cancer Capture Therapy (BNCT). BNCT utilizes ^{10}B nonradioactive nuclides irradiated with thermal neutrons through the reaction of ^{10}B (n, α) ^{7}Li(Miyatake et al., 2014; Park et al., 2015; Savolainen et al., 2013). The capture and fission of nuclear reactions occurring when boron-10, a non-radioactive constituent of boron natural elements, is irradiated with low-energy (0.025 eV) thermal neutrons. This leads to the production of high linear energy transfer (LET) on the alpha particle (^{4}He) and recoiling from the lithium-7 (^{7}Li) nucleus as shown in equation 1(Kageji et al., 2014; Kasesaz, Khalafi, & Rahmani, 2014).

$$
\begin{aligned}
&^{10}B + n_{th} \rightarrow {}^{11}B \rightarrow {}^{7}Li(1.01MeV) + {}^{4}He(1.78MeV)(6.3\%) \\
&\rightarrow {}^{7}Li(0.84MeV) + {}^{4}He(1.47MeV)(93.7\%) \\
&\rightarrow \gamma(0.48MeV)
\end{aligned}
$$

There are several elements that interact with thermal neutrons, such as nitrogen and hydrogen. Here are some doses to note in BNCT (Schmitz et al., 2014):

1. Boron Dose (D_B)

Boron dose is generated from the interaction of neutrons with boron that has been inserted into cancer tissue. Boron has a 3863.7 barn latitude, so it has a high chance of interacting. Boron-10 that interacts with thermal neutrons will turn into boron-11 which has a half-life of 10-12 seconds. Then boron-11 decays to produce lithium and alpha, the first of which produces 2.79 MeV (61% of total interaction) energy. The second generates 2.31 MeV (93.9% of the total reaction) energy. Then the second lithium decays back to its initial level with a gamma energy of 0.48 MeV. So that the average energy obtained from the interaction between neutron and boron-10 is 2.33 MeV.

2. Photon Dose (Dγ):

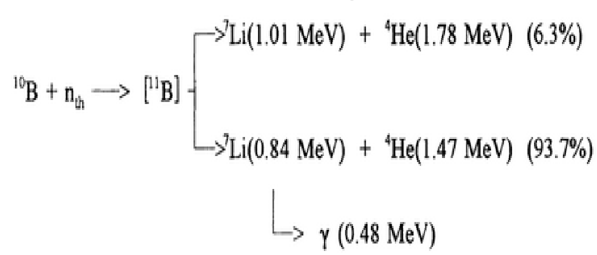
The resultant photon of the reaction- (n, γ), occurs mainly after the thermal neutrons capture the structure of the material, but also in the organic material. Photons of the 1H (n, γ) ^{2}H reaction with 2.2 MeV energy dominate [0.332 barn latitude (All cross-sections for thermal neutron energy 0.025 eV.)].

3. Proton Dose Dp:

The capture of thermal neutrons can also lead to the production of protons. In nitrogen-containing materials, the 14N (n, p) ^{14}C reaction with a 1.82-bar section (All sections that are for thermal neutron energy of 0.025 eV) are classified as separate dose components. Protons are emitted with kinetic energy of 560 keV on a micrometer scale.

4. Fast neutron dose Dn:

Fast epithermal or neutron doses are produced by scattering processes. Most important is the elastic scattering of hydrogen. Since the mass of neutrons and protons is large, so-called "recoiling protons" can result from 1H (n, n ') interactions 1H. The proton energy depends on the energy of the neutron reactions and the scattering process.



MATHERIALS AND METHODS

Time and Place

This research was conducted from February 2017 through March 2017. The process of making the code in the form of geometry specifications was implemented at National Nuclear Energy Agency (BATAN) Yogyakarta.

Instruments

One laptop, PHITS program, water phantom geometry shapes and a neutron source spectrum from the Kartini research reactor.

Research Flow

The procedure of research implementation is formulated in a flow chart shown by Fig 1.

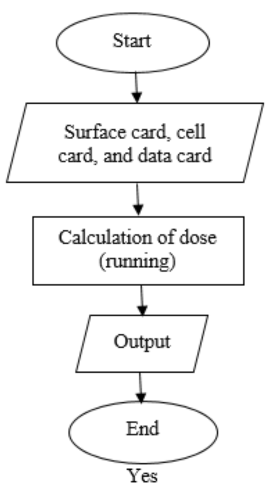


Fig 1. Dose calculation algorithm on PHITS program

Water Phantom Geometry

Shaping geometry of water phantom is a box containing D_2O (Deuterium Oxide) with dimension 30 cm x 30 cm x 30 cm. Water phantom wall is acrylic glass. In this study consists of two variations, namely water phantom containing boron and water phantom without boron.

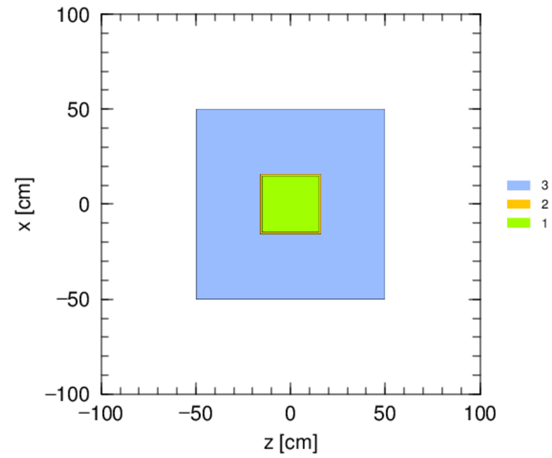


Fig 2. Water phantom Geometry Shape without Boron

Table 1. Material of Water Phantom

No Cell	Material Type	Density (g/cm^3)
1	D_2O	0.017
2	$CO_{16}H$	1.18
3	Air	0.0012

Shoot the Neutron Spectrum

The neutron spectrum is fired into the phantom water from the left and interacts with the boron inside. Then we get the value of flux which is observed according to depth. Part 1 is at a depth of 1-5 cm, part 2 at a depth of 6-10 cm, part 3 at a depth of 11-15 cm, part 4 is at a depth of 16-20 cm, part 5 is at a depth of 21-25 cm, and 6 is at a depth of 26-30 cm. Next was calculated the spread of absorbed dose (photons, gamma, protons, and neutrons) using PHITS program.

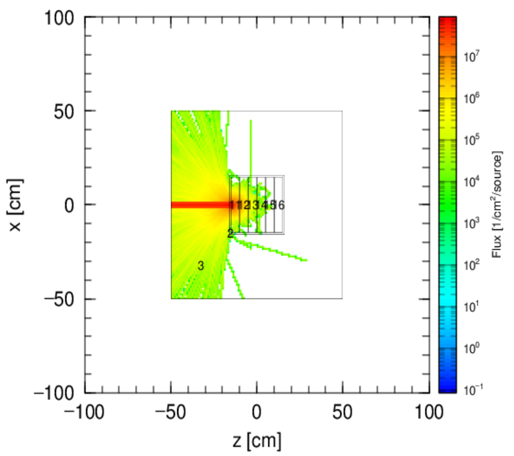


Fig 3. Neutron Spectrum Shooting on Water Phantom containing Boron

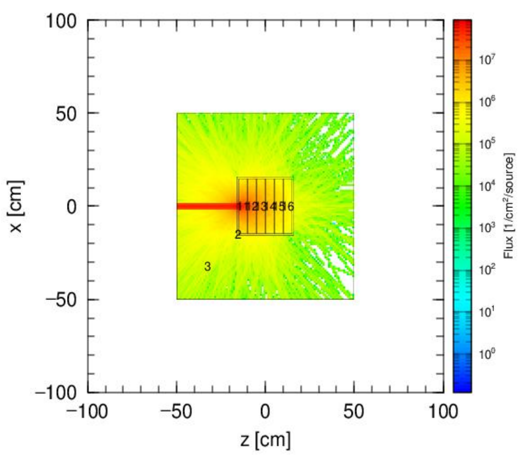


Fig 4. Neutron Spectrum Shooting on Water Phantom without Boron

Calculation of Dose

The calculation of the absorbed dosage in water phantom used one tally on PHITS software that is [T-deposit].

RESULT AND DISCUSSION

Water Phantom contains Boron

Boron-10 that interacts with thermal neutrons will turn into boron-11. Then boron-11 decays to produce lithium and alpha. This results in the largest alpha and lithium absorption dose called D_B boron dose (Fig 5).

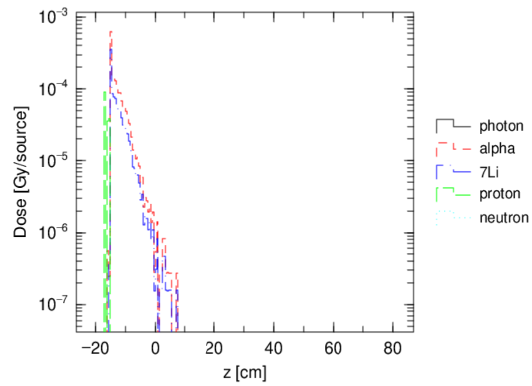


Fig 5. Dose on Water Phantom contains Boron

Table 2. Dose on Water Phantom

Dose Types	(Gy/source)
Photon ($D\gamma$)	0
Boron (D_B)	27,5743757
Proton (Dp)	1,6541
Neutron (Dn)	0

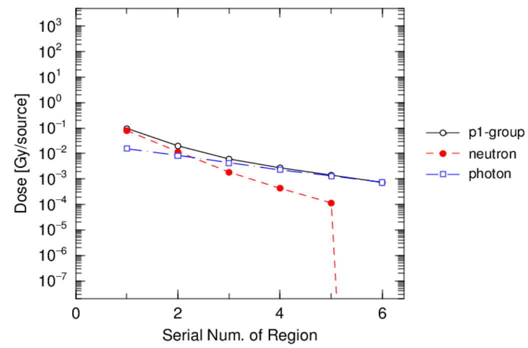


Fig 6. Dose multiplier on Water Phantom without Boron

The following values of absorption doses of neutrons and photons are scattered in the water phantom.

Table 3. Dose on Water Phantom

Region	Doses	
	Dn	Dγ
1	7.9357E-02	1.5765E-02
2	1.1524E-02	8.3822E-03
3	1.8304E-03	4.2397E-03
4	4.3687E-04	2.3250E-03
5	1.1349E-04	1.3053E-03
6	0.0000E+00	7.2942E-04

Water Phantom without Boron

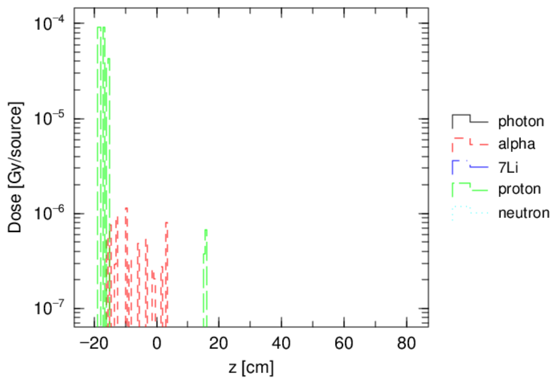


Fig 7. Dose on Water Phantom without Boron

Fig 7 shows the absorbed dose of water phantom without boron in it. On the graph shows that there is only absorption dose of proton and alpha. The absorbed doses of proton become the highest absorption dose. Since there is no interaction between the neutrons and boron, the absorbed dose of Li and the photon is not visible.

Table 4. Dose on Water Phantom without Boron

Dose Types	(Gy/source)
Photon (Dγ)	0
Boron (D_B)	0,0689
Proton (Dp)	3,54
Neutron (Dn)	0

The absorbed dose is divided into several sections based on the depth of water phantom as shown in fig 8.

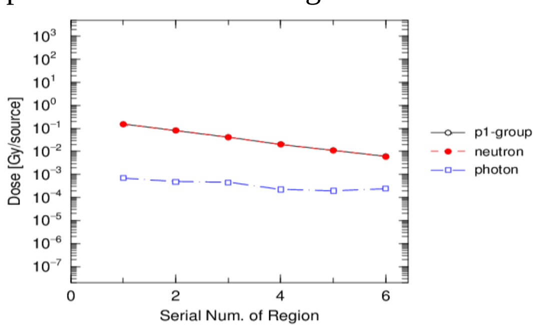


Fig 8. Dosemultiplier on Water Phantom without Boron

Table 5. Dose on Water Phantom

Region	Doses	
	Dn	Dγ
1	1.5231E-01	6.9466E-04
2	8.2022E-02	4.8363E-04
3	4.1453E-02	4.4620E-04
4	2.0328E-02	2.2215E-04
5	1.1036E-02	1.9497E-04
6	5.8941E-03	2.4372E-04

CONCLUSION

The absorbed dose in water phantom with boron compound is higher than absorbed dose in water phantom without boron.

ACKNOWLEDGMENT

The authors would like to thank Pusat Sains dan Teknologi Akselerasi Badan Tenaga Nuklir Yogyakarta for providing a place to conduct research.

REFERENCES

Akan, Z. (2015). Boron Neutron Capture Therapy for Breast Cancer. https://doi.org/10.1016/j

American Cancer Society, I. (2016). *Cancer Facts & Figures 2016*.

IAEA. (2014). PACT :Together Against Cancer.

Kageji, T., Nagahiro, S., Mizobuchi, Y., Matsuzaki, K., Nakagawa, Y., & Kumada, H. (2014). Boron neutron capture therapy (BNCT) for newly-diagnosed glioblastoma: Comparison of clinical results obtained with BNCT and conventional treatment. *The Journal of Medical Investigation*, *61*(3.4), 254–263. https://doi.org/10.2152/jmi.61.254

Kasesaz, Y., Khalafi, H., & Rahmani, F. (2014). Design of an epithermal neutron beam for BNCT in thermal column of Tehran research reactor. *Annals of Nuclear Energy*, *68*, 234–

238. https://doi.org/10.1016/j.anucene.2014.01.014

Miyatake, S. I., Kawabata, S., Hiramatsu, R., Furuse, M., Kuroiwa, T., & Suzuki, M. (2014). Boron neutron capture therapy with bevacizumab may prolong the survival of recurrent malignant glioma patients: Four cases. *Radiation Oncology*, *9*(1), 1–6. https://doi.org/10.1186/1748-717X-9-6

National Cancer Institute. (2016). Types of Cancer Treatment. Retrieved November 30, 2018, from https://www.cancer.gov/about-cancer/treatment/types

Park, J.-M., Lee, H.-J., Yoo, J. H., Ko, W. J., Cho, J. Y., & Hahm, K. B. (2015). Overview of gastrointestinal cancer prevention in Asia. *Best Practice & Research Clinical Gastroenterology*, *29*(6), 855–867. https://doi.org/10.1016/J.BPG.2015.09.008

Sauerwein, W. (1993). Principles and history of neutron capture therapy. *Strahlentherapie Und Onkologie : Organ Der Deutschen Rontgengesellschaft ... [et Al]*, *169*(1), 1–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8434333

Savolainen, S., Kortesniemi, M., Timonen, M., Reijonen, V., Kuusela, L., Uusi-Simola, J., … Auterinen, I. (2013). Boron neutron capture therapy (BNCT) in Finland: Technological and physical prospects after 20 years of experiences. *Physica Medica*, *29*(3), 233–248. https://doi.org/10.1016/j.ejmp.2012.04.008

Schmitz, T., Bassler, N., Blaickner, M., Ziegner, M., Hsiao, M. C., Liu, Y. H., … Hampel, G. (2014). The alanine detector in BNCT dosimetry: Dose response in thermal and epithermal neutron fields. *Medical Physics*, *42*(1), 400–411. https://doi.org/10.1118/1.4901299

Triviño, S., Vedelago, J., Cantargi, F., Keil, W., Figueroa, R., Mattea, F., … Valente, M. (2016). Neutron dose estimation in a zero power nuclear reactor. *Radiation Physics and Chemistry*, *127*(127), 62–67. https://doi.org/10.1016/j.radphyschem.2016.06.011

WHO. (2018). Cancer. Retrieved November 30, 2018, from https://www.who.int/cancer/en/