Distribution of Water Phantom BNCT Cyclotron based Using PHITS

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ARTICLE INFO	ABSTRACT
	This research purpose is to estimate the dose distribution of BNCT in water phantom. Some common methods in the treatment of cancer such as brakhiterapi, surgery, chemotherapy, and radiotherapy still have the risk of damaging healthy tissue around cancer cells. BNCT is a selectively-designed technique by targeting high-loaded LET particles to tumors at the cellular level. BNCT proves to be a powerful method of killing cancer without damaging normal tissue. The source of the neutron used from the cyclotron dose in water phantom with the size of 30 cm x 30 cm x 30 cm was calculated using PHITS program. The result from the simulation is that boron water panthom has a dosimetri higher than phantom water without boron.

1. INTRODUCTION

WHO released data showing in 2015 as many as 8.8 million people died from cancer, with details of lung cancer (1.69 million deaths), liver (788,000 deaths), colorectal (774,000 deaths), stomach (754,000 deaths), and Breast cancer (571,000 deaths). That number makes cancer a major cause of both global deaths [1].

According to data from the Ministry of Health of Indonesia in 2013, the prevalence of cancer in the population of all ages in Indonesia is 1.4 ‰ or estimated to be around 347 792 people. Cervical cancer and breast cancer is the highest prevalence of cancer in Indonesia in 2013, which amounted to 0.8 ‰ of cervical cancer and breast cancer of 0.5 ‰. Province D.I. Yogyakarta has the highest prevalence for cancer, which is 4.1 ‰. Based on an estimated number of cancer patients of Central Java Province and East Java Province is province with estimation of cancer patient mostly, that is about 68.638 and 61.230 people[2].

Cancer is a group of diseases characterized by the growth and spread of abnormal cells that are not controlled. If the spread is uncontrolled, cancer can cause death. Cancer is caused by internal factors and external factors. Internal factors cause cancer such as inherited genetic mutations, hormones, and immune conditions. While external factors include smoking habits, infectious organisms, and unhealthy diets [3]. Based on previous statistical data it is known that the number of cases and deaths from cancer will continue to increase from year to year, for it needs an early diagnosis and appropriate treatment in order to suppress the increase in number.

Common methods of treating cancers such as brachytherapy, surgery, radiotherapy, and chemotherapy still have risks to be considered that can damage normal surrounding tissue [4] [5][9]. Therefore a method of treatment that can kill cancer without damaging normal tissue is required.

A promising method in the treatment of malignant tumors, especially incurable brain tumors, is Boron Neutron Capture Cancer

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Therapy (BNCT), which is particularly interesting because of the direct selective action on tumor cells [6]. BNCT is based on the ability of non-radioactive boron-10 isotopes to capture thermal neutrons with very high probability. This nuclear reaction produces two high-LET particles (He-4 and Li-7) with a limited network range on the diameter of a single cell. It is possible to target tumor cells and destroy them while maintaining other healthy tissues containing boron-10 lower than tumor cells. As radiotherapy at the cellular level, BNCT can provide very precise dose delivery which makes it possible to treat tumors and reduce side effects [7]. The BNCT treatment process was performed in two steps, first the patient was injected with drug-localized boron-containing tumor, then the target volume (cancer cell) was irradiated with thermal or epi-thermal neutrons [8][20]. This method was first used in 2001 in Pavia, Italy [6]. In order for cancer treatment with BNCT method to succeed and effectively kill tumor cells spread in healthy tissue, boron concentration sent to all tumor cells must be selective. The recommended amount of 10B is $\sim$ 20 µg/g tumor or $\sim$ 109 atom/cell[10].

During this time the neutron beam is obtained from the nuclear fission reactor due to the limitations of this technique it can not be applied in the hospital [11]. Therefore, to support the application of cancer treatment methods with BNCT at the hospital developed a source of accelerator-based neutron, that is, cyclotron. Cycllotron HM-30 MeV with file forming assembly has been made at KURRI in cooperation with Sumitomo Heavy Industries, Ltd. A proton beam with a current of 1.1 mA and an energy of 30 MeV obtained at a cyclotron weighing 60 t[6][12][19].

During the BNCT treatment, the absorbed dose is sent to normal tissues and tumors. The results of irradiation depends on the spatial, spectral and characteristic angles of the neutron beam as well as on the geometry and composition of the target [13]. When neutrons are about tissue, they not only react with boron neutrons but also react with other nuclei. An effective biological dose will depend on the relative biological effectiveness (RBE) and biological effectiveness of the compound (CBE) for different components in each case [14]. There are four dose components that include[15][16][17][18]:

1. Photon Dose

Photon yield of the reaction (n, γ), mainly occur after thermal neutrons on the structure of the material, but also in organic materials dominated by photons with energy of 2.2 MeV from the reaction of 1H (n, γ) 2H (0.332 barn cross section; all sections for 0.025 eV thermal energy neutrons).

2. Neutron Dose

Dose fast neutron storage or epithermal neutrons by elastic scattering process in hydrogen. Due to almost the same mass of neutron and protons, so-called recoiling proton' can be obtained from the interaction of 1H (n, n ') 1H. The proton energy depends on the incident neutron energy and the scattering process.

3. Proton Dose

The thermal neutron capture may also lead to the production of protons. In a nitrogen-containing material, the reaction is 14N (n, p) 14C with a cross section of 1.82 barn (V). Classified as a separate dose component. Protons are emitted with 560 kV kinetic energy and range on a micrometer scale.

4. Boron Dose

Dose of capture 10B due to reaction 10B (n, α) 7Li.

The purpose of this research is to estimate the spread of the dose of proton, nitrogen, boron and photon in water phantom with source of neutron from cyclotron where the distribution of dose in water phantom is known and simulated using tally program Particle and Heavy Ion Transport Simulation (PHITS). PHITS is software development from Monte Carlo Particle and Heavy Ion Transport code System. Several new tallyes were included to estimate the relative biological effects (RBE) that support the determination of the dose of BNCT distribution.

2.   MATERIALS AND METHODS

2.1 Water Phantom Geometry

The first step of the research is to make water phantom geometry. Water phantom used contains D_2O (Deutirium Oxide) with a size of 30 cm x 30 cm x 30 cm, wrapped by acrylic glass with 1 cm thick around. This study used two varian, that is, water phantom without boron and water phantom that has been given boron.

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Fig.1 Water panthom geometry without boron

Figure 1 showed geometry where part 1 is a water phantom, part 2 is acrylic glass, while part 3 is air.

2.2 Shooting Spectrum Neutron

The neutrons spectrum emerging from the collimator are shot at the water phantom from the left. The water phantom was created or divided into 6 slices from the direction of the neutron shooting, so dose distribution of each specified depth can be seen.
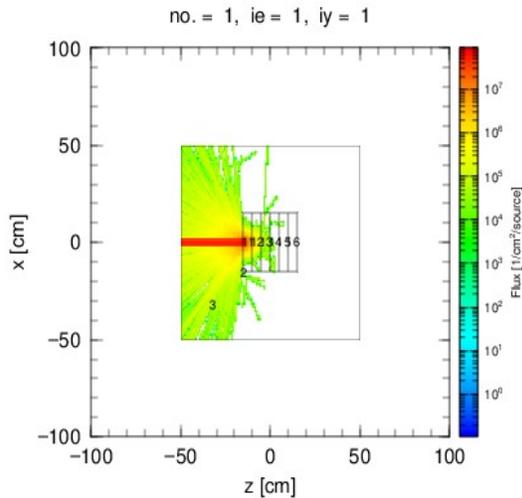
Fig 2. Shooting spectrum neutron at water phantom

2.3 Calculation of Dose

Calculation of dose distribution using [T-Deposit] tally of PHITS program.

3.   RESULTS AND DISCUSSION

3.1. Water Phantom With Boron

When neutrons pound the water phantom, neutrons will interact with the material contained therein. In phantom water with boron, neutrons will interact with boron and produce alpha particles and lithium nuclei. In addition to these two particles also emit gamma (photon).
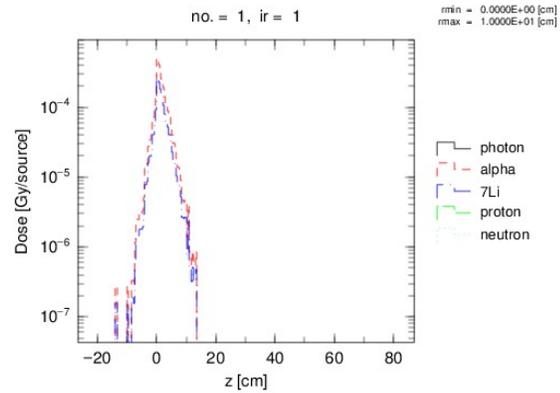
Fig 3. Dose distribution in water phantom with boron

In Figure 3 doses visible are only doses of alpha and lithium which are both a boron dose while the doses of photons, neutrons and protons do not exist. Large doses are described in Table 1.

Table 1. Dose distribution of water phantom with boron

Dose Type	Gy/source
Photon	0
Alpha	27,6795277
Lithium	15,7941626
Proton	0
Neutron	0
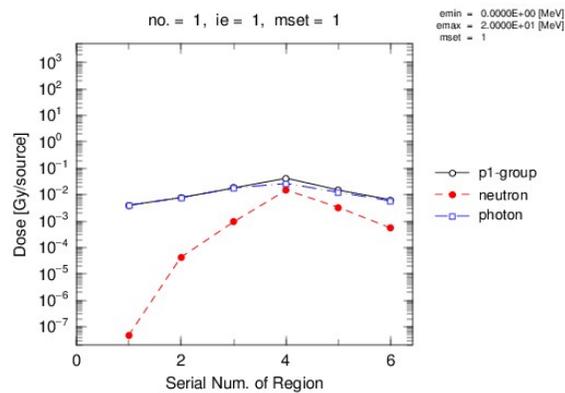
Fig 4. Dose multiplier each region in water phantom   with boron

Figure 4 shows that the photon dose is much higher than the neutron dose. Neutron dose and photon dose in each region are different where the highest dose in region 4 and the lowest in region 1 with dose details are found in Table 2.

Table 2. Dose of neutron and gamma (photon) in each region of water phantom with boron

Region	Dn(Gy/source)	Dγ(Gy/source)
1	4,72E-04	3,91E+01
2	4,22E-01	7,68E+01
3	9,64E+00	1,78E+02
4	1,51E+02	2,57E+02
5	3,20E+01	1,18E+02
6	5,58E+00	5,56E+01

3.1 Water Phantom Without Boron

In water phantom without boron, pure water phantom contains only D_2O.
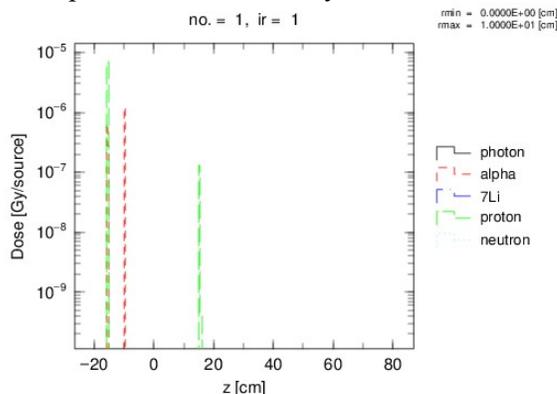
Fig 5. Dose distribution in water phantom without boron

Figure 5 shows that the visible dose distributions are alpha dose and proton dose, while for doses of photons, lithium, and neutrons does not exist. The dose of proton is higher than the alpha dose. Large doses are described in Table 3.

Table 3. Dose distribution of water phantom without boron

Dose Type	Gy/source
Photon	0
Alpha	0,0210285
Lithium	0
Proton	0,12711041
Neutron	0
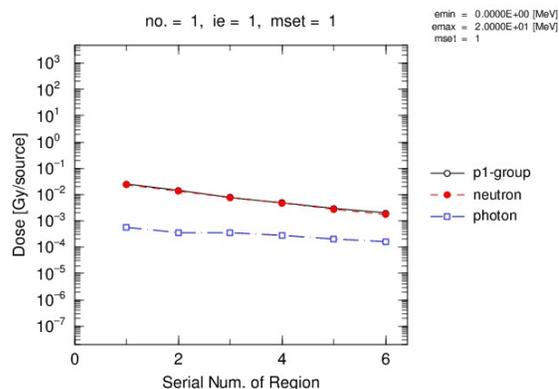
Fig 6. Dose multiplier each region in water phantom with boron

Unlike the water phantom containing boron, Figure 6 shows that the water phantom without the boron dose of neutrons values higher than the dose of photons. The dose of each region is also different but not too conspicuous. The dose decreases with increasing depth. Large doses of each region are described in Table 4.

Table 4. Dose of neutron and gamma (photon) in each region of water phantom without boron

Region	Dn(Gy/source)	Dγ(Gy/source)
1	2,44E+02	5,61E+00
2	1,40E+02	3,52E+00
3	7,70E+01	3,51E+00
4	4,75E+01	2,84E+00
5	2,76E+01	2,01E+00
6	1,80E+01	1,67E+00

4. CONCLUSION AND REMARKS

From that research can be concluded that water phantom boron-containing has dosimetri higher than in water phantom without boron.

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