

Basic Principle Application and Technology of Boron Neutron Capture Cancer Therapy (BNCT) Utilizing Monte Carlo N Particle 5'S Software (MCNP 5) with Compact Neutron Generator (CNG)

Aniti Payudan¹, Abdullah Nur Aziz¹, Yohannes Sardjono²

¹Jendral Soedirman University, *Jl. Prof. Dr. H.R. Boenyamin No.708 Grendeng, Purwokerto and 53122, Indonesia*

²Center for Accelerator Science and Technology, National Nuclear Energy Agency, *Jl .Babarsari, Yogyakarta and 61011, Indonesia*

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Abstract The purpose are to know basic principle, needed component, types of compact neutron generator, plus and minus CNG, identify materials can use as collimator, know physics parameters as input software MCNP 5, knowing step simulation with software MCNP 5, dose in BNCT, knowing boron compound that use in BNCT, getting collimator design for BNCT'S application with source is compact neutron generator and count physics parameter of collimator output and compares it with standard IAEA. Method are reading reference and simulation with MCNP 5. The result are BNCT use high linear energy transfer from alpha and lithium as a result of $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction. BNCT method is effective for cancer therapy. It is not dangerous to normal tissues. To work perfectly, BNCT needs neutron, boron (BSH and BPA as boron compound) Indonesia have study turmeric as boron compound, neutron source, collimator and dose. Dose component in BNCT that important are dose of recoil proton, dose of gamma, dose alfa and dose radiation to environmentally. CNG produce neutron with fussion reaction of deuterium-deuterium (2,45 MeV), deuterium-tritium (14 MeV), tritium-tritium(11,31 MeV) can used as neutron source BNCT. Many kinds of CNG are axial, coaxial, toroidal, plasma design, accelerator design, and CNG with diameter 2,5 cm. CNG have more benefit than another neutron source, make CNG compatible as BNCT application. Neutron from CNG need collimator to get neutron as IAEA's parameter. Material for collimator are wall and aperture (material: Ni, Pb, Bi), moderator (Al, Al_2O_3 , S, AlF_3), filter (^6Li , ^{10}B , LiF, Al, Cd-nat, Ni-60, BiF_3 , ^{157}Gd , ^{151}Eu), gamma shield (Bi, Pb). Simulation using MCNP 5 has severally steps, the first is sketching problem, the second is making listing program with notepad, the third open program on visual editor, and the last is running program. Acquired result is design tube collimator with radius 71 cm and high 139, 5 cm. Design contained on lead wall as thick as 19, 5 cm; moderate: heavy water as thick as 4 cm, AlF_3 girdle a half of part CNG, MgF_2 (19 cm + 10 cm), Al (6,5 cm + 5 cm);Gamma shield: bismuth, and aperture with diameter 6 cm by steps aside nickel. The result collimator output cross three of five IAEA'S defaults. They are the ratio among dosed gamma with flux epithermal is $5,738 \times 10^{-24} \text{Gy} \cdot \text{cm}^2 \cdot \text{n}^{-1}$, the value of ratio among thermal's neutron flux with epithermal neutron is 0, 02567, and ratio among current with flux neutron completely is 1, 2. Need considerable effort of all part to realize BNCT in Indonesia.

Keywords: cancer, BNCT, CNG, collimator, neutron

INTRODUCTION

Cancer is one of the troublesome non communicable diseases in the world. It is caused by abnormal cells divide without control. This diseases spread quickly to other parts of the body through the blood and lymph systems (NCI, 2009; NCI, no year). Most types of cancer cells eventually form a lump or mass called a tumor, and are named after

the part of the body where the tumor originates (American Cancer Society, 2013). Things that trigger cancer are smoking (Kristina, S.A., *et al* 2014), the wrong diet and poor reproductive factors (Arnold, M. *et al* 2013). There are several kind of cancer are brain cancer, breast cancer, stomach cancer, liver cancer, lung cancer, leukemia, cancer serviks, rectal cancer, pancreatic cancer, prostate cancer. According

¹Corresponding author. Email: anitipayudan42@gmail.com

International Agency for Research on Cancer (2013), the most commonly diagnosed cancers worldwide were those of the lung (1.8 million, 13.0% of the total), breast (1.7 million, 11.9%), and colon rectum (1.4 million, 9.7%). People that have lung cancer died in United States in 2013 are more than 159 thousand and the number of cancer sufferer increase every year (Saber, A., *et al* 2015). Cancer have not taken good and fast treatment will made bad effect there also be death. Death rate number because of cancer 2008 to 2030 is predicated increase from eight million to 12 million (Hosmane, N.S., *et al* 2012). According world health statistic (2014), cancer is in grade six to contribute caused death the years of life lost n 100.000 populations in the world on 2000-2012. Data from ministry of public health Indonesia (2013) said that chart of account cancer in Indonesia in 2013 1, 4 %. The number of sample is 1.027.763 (with male: 505.409 and female: 522.354), providable that amount of cancer serviks with female: 522.354; prostate cancer (m: 505.409); another cancer (all age: 1.027.763). The major cancer case is happen in Yogyakarta 4,1 %, central java 2,1 %, and Bali 2 %. Cancer not only came to old people but also children. In Indonesia, number cancer children increase more or less 6.700 every year (Gunawan, S., *et al* 2014).

Effective therapy to cancer still is analyzed and is looked for until currently. Expected therapy have tall success zoom criterion, don't wreck normal tissues, and is not impacted negative to human viability. Ordinary therapy type is done for cancer patient are Chemotherapy (NCI, 2009; Barth, R.F., *et al* 2005; Noble, S., *et al* 2014; Gorey *et al* 2014), radiotherapy (NCI, 2009; Barth, R.F., *et al* 2005; Stupp, R., *et al* 2005; Saurwein, W., *et al* 2012), and dissection (NCI, 2009; Wu, J., *et al* 2015; R. Gonza ´ lez Gonza ´ lez, *et al* 2012). That therapy not effective because just can increase

patient viability as big as 75% up to a two year and trouble other organ functions, as fall of hair and healthy tissue damage (NCI, 2009; Wahyuningsih, 2014). Operate is utilized on early phase therapy, where does tumor be still gets tame character (Abeloff and Martin, 2008). Surgical method or operate can't utterly lift cancer cell.

New threatment type for cancer one is being developed is Neutron Capture Therapy (NCT). Either one NCT what do be analyzed by Badan Tenaga Nuklir Nasional (BATAN) are Boron Neutron Capture Cancer Therapy (BNCT) with Compact Neutron Generator (CNG) as source of neutron. BNCT is looked on as therapy that really keeps faith to therapy cancer (Barth, R.F., *et al* 2005; Yu, Hui Ting., *et al* without year; Eskandari, M.R. and Kashian, S., 2009; Sauerwein, W.A.G., and Moss, R.L., 2009; Saurwein, W.A. G, *et al* 2012; Savolainen, S., *et al* 2012; Helsinki, 2014). Specifically for therapy raising hell cancer as head and neck cancer (R. Gonza ´ lez Gonza ´ lez, *et al* 2012; Yu, Hui Ting., *et al* without year; Helsinki, 2014), prostate cancer (Yasui, L., *et al* 2012), oral cancer (Yura, Y. And Fujita, Y., 2013; Heber, E.M., *et al* 2012; Trivellin, V. A, *et al* 2004), and breast cancer (Yanagie, H., 2012; Helsinki, 2014; Scorei, I.R., 2011). BNCT constitutes to be damped down radiation that reaction of boron 10 by thermal neutrons so results neglect particles(α), Lithium (Li) and gamma-rays scattering(γ), one that gets role in cancer cell desolation (Sauerwein, W.A.G., and Moss, R.L., 2009; Saurwein, W.A. G, *et al* 2012). Result of this reaction has characteristic Linear Energy Transfer (LET) one that tall (for particle α approaches $150 \text{ keV}\mu\text{m}^{-1}$ and for ^7Li approaches $175 \text{ keV}\mu\text{m}^{-1}$). Reach of this particle lies on distance 4, 5 μm until 10 μm , so the energy just in single cell (Sauerwein, W.A.G., and Moss, R.L., 2009). This therapy still can't

yet be applied at Indonesia because still a lot of needed component. To get develops BNCT necessary science which adequately about BNCT and science about Monte Carlo N particle 5 software (MCNP 5), since in BNCT'S research there are many utilize software one of it MCNP 5. So writer chooses title "Basic Principle's Application And Technology Boron Neutron Capture Cancer Therapy (BNCT) Utilizing Monte Carlo N Particle 5's Software (MCNP 5) With Compact Generator Neutron (CNG) ".

MATERIALS AND METHODS

Materials

Writing tool as book and pulpen. A set of *Personal Computer*. Software that is utilized are *Microsoft Office Word 2007*, *Microsoft Office Excel 2007*, Search engine *Mozilla Firefox*, *Software MCNP 5*, *notepad*. Indonesian English dictionary. Material as journal and book that gets bearing with BNCT, CNG and MCNP 5.

Methods

Method those are used is reference and simulation by programs MCNP5.

RESULTS AND DISCUSSION

Basic principle BNCT

Boron neutron capture cancer therapy (BNCT) is a cancer therapy that works by neutron capture reaction $^{10}\text{B} (n, \alpha) ^7\text{Li}$. The reaction of 93.7% to He (alpha particles) with an energy of 1.47 MeV, Li with energy 0.84 MeV and 0.48 MeV gamma energy; and the rest is the decay of lithium (6.3%), which produces alpha with Li and each has an energy of 1.78 MeV and 1.01 MeV. BNCT utilizes ionization energy of alpha particles and lithium to damage the structure of DNA and RNA of cancer cells. A particles effective to kill cancer because actual α particles are helium nuclei, relatively heavier

than the other sub-atomic particles. A particle ionization proven as an effective agent, having high linear energy transfer (LET) in the range of $100 \text{ KeV} / \mu\text{m}$, and has a very high efficiency to keep on range short tissue (50 – 100) μm .

On BNCT first of all boron compound ^{10}B , can as BSH or BPA was sent to go to cancer cell by concentrates $20 \mu\text{g} / \text{g}$ or $\sim 10^9$ atom / cell. Hereafter cancer cell already contain boron ^{10}B at radiation with thermal neutron with energy 0,025 eV. On cancer cell that contain boron will happen reaction $^{10}\text{B} (n, \alpha) ^7\text{Li}$. Alpha and lithium 7 that ionizing cancer cells so cancer cells will wreck. Alpha particle and result lithium react BNCT to have transfer energy linear that tall with surrounding reach $10 \mu\text{m}$ (lie within range one cell diameter). So this therapy not wreck healthy tissues because just cancer cell that contain boron who will wreck and alpha particle ionization reach and lithium lies on reach one human cell diameter. At Asia, Country that applied BNCT as therapy cancer are Japan and Taiwan. Indonesia is developing BNCT as a treatment for cancer.

Components BNCT

BNCT has several components including a boron compound, neutron, neutron source, collimator and dosimetry. Boron compound that has been clinically tested and viable as boron agents there are two BSH (*Sodium borocapte*) and BPA (*p-boronophenylanine*). Both of these compounds have proven effective as an agent of boron. Currently in Indonesia are developing boron compounds using white turmeric. This is because the white turmeric can medicate cancer. The research still is developing. Expected white turmeric can be used as effective carrier of the boron compounds. Neutrons are used in BNCT is basically thermal neutrons with energies of 0.025 eV. Cancer that is located in the body with a depth of more than 8 cm can be treated

with BNCT using epithermal neutrons, will be moderated and when the cancer part into thermal neutron. This is done so that does not need surgery and neutrons can be emitted from outside the patient's body. The quality of neutron beam is used BNCT has five physical parameters, namely the intensity of neutron epithermal must be greater than 1×10^9 n/s cm^2 , the ratio between the dose rate of fast neutrons with a flux of epithermal neutrons value must be smaller than 2×10^{-13} Gy cm^2/n , the dose rate gamma / flux of epithermal neutrons smaller than 2×10^{-13} Gy cm^2/n , the ratio between the flux of thermal and epithermal smaller value of 0.05 and the ratio between the flow of neutrons with total neutron flux is greater than 0.07. All of which produce neutrons known as the neutron source. Neutron source that can be used there are many nuclear reactors, californium 252, nuclear reactions, accelerators, compact neutron generator, the photo-neutron source, and α -beryllium sources. So that the neutrons released by the neutron source can be used for BNCT treatment is needed collimator. Collimator consists of walls, filters, moderator, shielding gamma and aperture. The working principle collimator uses the interaction of radiation with matter. When a material is mashing neutron interaction will occur so that neutrons can be moderated and filtered so that its characteristics meet IAEA standards. Furthermore, dosimetry, dosimetry in BNCT is important to measure the components of boron, neutrons and radiation resulting

from the interaction with the material safely used for cancer patients and the surrounding environment.

Some countries use nuclear reactors as a neutron source BNCT. Countries that use nuclear reactors to the facility BNCT has existed in the United States with the reactor MIT (Cambridge, MS), in Japan with the reactor JAERI JRR-4, reactor KUR Kyoto, in Argentina using the reactor Bariloche RA-6 in Taiwan with reactor THOR TRIGA and in Italy by ENEA reactor. One reactor into the reactor Kartini BNCT testing, is the type research reactor TRIGA MARK II (Training, Research and Isotope Production by General Atomic), used for neutron irradiation services and training and research in the field of nuclear technology. Experimental analysis has been done on the physical parameters translucent beam port Kartini's reactor for the preparation of test in vivo and in vitro. The flux of neutrons from the reactor Kartini measured in ring B, ring C and ring D are respectively 1.27×10^{12} , $10^{12} \times 1.56$, 1.14×10^{12} n. $\text{cm}^{-2}.\text{s}^{-1}$. Collimator designing has been done in beam port translucent Kartini's reactor with the following output:

The types of compact neutron generator

Compact neutron generator (CNG) is producing neutrons by reacting ion source that has accelerated in the accelerator with a target of deuterium or tritium. After colliding, the fusion reaction occurs between the two

Table 1. Output collimator in beam port translucent Kartini's reactor

Name (year)	Φ_{epi}	$\frac{\dot{D}_f}{\Phi_{\text{epi}}}$	$\frac{\dot{D}_\gamma}{\Phi_{\text{epi}}}$	$\Phi_{\text{th}}/\Phi_{\text{epi}}$	$\frac{\Phi_{\text{th}}}{\Phi_{\text{ep}}}$	$\frac{J}{\Phi_{\text{total}}}$
M.I.M. Arrozaqi (2013)	$5,03 \times 10^8$ n/ cm^2s	$2,17 \times 10^{-13}$ Gy cm^2/n	$1,16 \times 10^{-13}$ Gy cm^2/n	0,120		0,835
Nina Fauziah (2013)	$7,65 \times 10^8$ n/ $\text{cm}^2 \text{ s}$	$1,76 \times 10^{-13}$ Gy cm^2/n	$1,32 \times 10^{-13}$ Gy cm^2/n	0,008		0,73
Dwi Wahyuningsih (2014)	1,2 n/ cm^2s	Gy cm^2/n	Gy cm^2/n	0,03		0,8

fusion's reaction, that occurs between hydrogen isotopes to produce neutrons. In principle there are three types of CNG is using reaction Deuterium-Deuterium (DD) resulting in neutrons with energies 2, 45 MeV, the reaction Deuterium-Tritium (DT) generating neutrons with energy of 14.1 MeV and Tritium-Tritium (TT) produce neutrons with energy 11.31 MeV. Compact neutron generator (CNG), which is based on the fusion reaction DD / DT was designed and developed by Lawrence Berkeley National Laboratory (LBNL) (Berkeley, USA). Some types of compact neutron generator developed are axial generator, coaxial, toroidal, neutron generator plasma design, the design of accelerator neutron generator and the neutron generator with a diameter of 2.5 cm. Generator types of axial diameter of 15 cm and a length of 40 cm produce neutrons at 108 n/s is being developed by a group of science Plasma and Ion Source Technology. DD reaction coaxial generator operates with a power of 120 kV and a current of 1 A and can produce a neutron yield greater than 10^{11} n / s sent to Turin at the end of 2004. Furthermore this applied at the University of Turin in March 2005. Planning to update the generator EUROSEA DD reaction order produce neutron yield greater than 10^{12} n/s has been investigated. Compact neutron generator is still investigation.

Advantages and disadvantages of different types of neutron sources

Nuclear reactors as neutron source in BNCT have some advantages and disadvantages. The advantages of the reactor which reactors are already available in many countries, especially Indonesia has three reactors, so there is no cost for the purchase or procurement of nuclear reactors, the reactor produces high flux allowing use as a source of neutrons BNCT, there are neighboring countries that use the reactor in Japan and Taiwan

so as to enable the sharing of knowledge and can be quickly realized in Indonesia. The drawback of nuclear reactors do not have a single energy need to be moderated, nuclear reactor is too large that can not be put in the hospital, Indonesia has a rule that does not allow the therapy is done in a nuclear reactor, it is not possible, the thought of cancer patients on the reactor was creepy when people are ill-treated and should be treated involving the reactor, it can lead to depression and excessive fear. Indonesia will not use nuclear reactor for BNCT therapy in humans, nuclear reactors will only be used to test the in vivo and in vitro.

Californium 252 as a neutron source BNCT has several advantages are have small size, the range of neutron production is 2.3×10^{12} neutrons/s for each gram ^{252}Cf , already available in Russia, USA, Germany, Japan, and France. Weakness 2.645 ^{252}Cf short half-life of 2.5 years so every year should change isotopes.

Photo-neutron is a reaction between a photon with an element to produce neutrons. The half-life is usually lower depending on the type of elements. Flux generated is also small, for the reaction $\gamma + {}^9\text{Be} = {}^8\text{Be} + \text{n}$ produces 2×10^6 neutrons per second per Ci of ^{24}Na . Photo-neutron source is less suitable for BNCT therapy.

Accelerator is ion accelerating so while interacting with other elements will produce high-energy neutrons. One of the newest accelerators are currently attracting attention for BNCT treatment is cyclotron 30 MeV. Cyclotron with particles that are accelerated protons in 30 MeV available at Kyoto University. The advantages of the cyclotron of this type is capable of producing neutrons with high flux, energy is single, focusing neutrons is easier than nuclear reactors for energy is single, neutron yield more, compared with the nuclear reactor it can be put in the hospital, do not pose a radiation hazard to environment, permit the use easier,

the installation easier, the cost of maintenance is easier, cheaper than having to build a nuclear reactor near the hospital, drawback cyclotron requires material or elements of a target to produce neutrons, because the energy it big to be neutron epithermal needed moderation that great anyway, Cyclotron has dimensions greater than ^{252}Cf and compact neutron generator.

Advantages of *compact neutron generator* compared to the neutron source other has a smaller size, does not need to be converted into a neutron because the output of CNG are neutrons, permit easier than the nuclear reactor, can be placed in a hospital, the room size is smaller than the accelerators and nuclear reactors energy neutrons produced by a single character, the energy generated is small so designing collimator CNG will not be so complicated to produce epithermal neutron appropriate IAEA standards. Shortage of CNG neutron yield produced CNG is still too small, so when moderated and filtered neutron yield at the end of the collimator does not meet the standards of the IAEA, CNG with neutron yield of 10^{12} n/s is still in the research, isotopes of hydrogen form ion source and the target must always be replaced and it will troublesome.

Characteristics of Material Collimator

Based on data obtained and a search through the literature, the material can be used as collimators are:

1. Walls collimator

The materials required for the collimator wall is a material that can reflect neutrons back, and make stable neutron energy. The material must have the characteristics: the abundance of existing and readily available, high elastic scattering cross section, high total scattering cross section, absorption cross-section of small, relatively large atomic mass, density of large

atoms. Materials are as wall collimator are Pb, Bi, PbF₂, BeO, Ni.

2. Moderator

Material moderator can reduce the energy of fast neutrons into thermal neutrons. The material characteristics are: its abundance in nature a lot, is not readily biodegradable material in high radiation fields, low atomic mass, neutron activation results from the moderator material must have a short life, do not give rise to gamma rays when reacting with neutrons. Recommended materials for these properties are Al, Al₂O₃, S, and AlF₃.

3. Filter

Material Filter is material that can filter fast neutron and thermal neutron but can liberate epithermal neutrons. The material characteristics are: thermal neutron absorption cross section of high, fast neutron absorption cross section is high, inelastic scattering cross section of large, abundant in nature a lot, not give rise gamma rays.

Materials recommended for the filter material is ^6Li ^{10}B , LiF, Al, Cd-nat, Ni-60, BiF₃. ^{157}Gd possibility, ^{151}Eu can be used as thermal neutron filter because it has a thermal neutron absorption cross section which is great.

4. Shield gamma

Materials that can be used as a shield gamma is a material with the following characteristics: abundant in any natural, large gamma attenuation, while interacting with neutrons do not emit gamma. Materials that can use are Pb, Ti, Li, and Bi.

5. Aperture

Materials that can be used as an aperture equal to the material which can be used for reflectors are Pb, Bi, PbF₂, BeO, Ni. Diameter smaller is better.

Physical Quantities and Units Used in MCNP 5

MCNP 5 software is the principle method of monte carlo. This software is required for simulating the manufacture of a collimator, dosimetry calculation, modeling cancer, etc. Quantities and standard units used in MCNP 5 are as follows:

- Length (cm),
- Energy (MeV),
- When shaking (10-8 s),
- Temperature, with units of MeV (kT); $k = 1.3807 \cdot 10^{23} \text{ J / K}$,
- The density of the atoms, the atomic unit / b cm,
- Mass density, with units of g/cm^3 ,
- Looks latitude, with units of barns; 1barns = 10^{-24}cm^2 .

Phase Simulation with MCNP 5

Step simulation using MCNP 5 software are

- 1) Creating a design sketch problem.
- 2) Creating a coding or program listing with notepad, stored in format i.

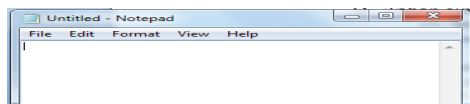


Figure 1. Notepad

- 3) Run the program in visual editor (vised). Open the file in vised and click update. Figure 2 gives display visual editor (vised).

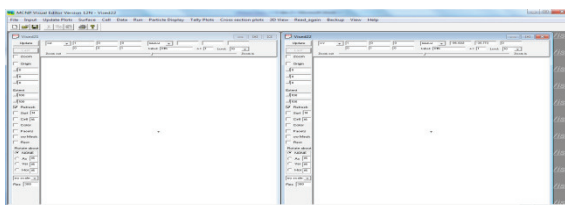


Figure 2. Figure visuals editor (vised).

- 4) Select taksbar RUN on the top, so it will appear as follows:

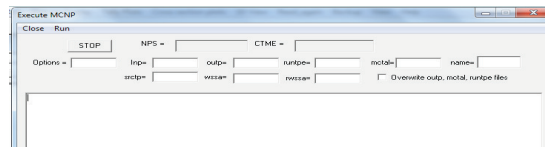


Figure 3. Vised preparation for running

- 5) Fill Inp column with the input file.
- 6) Click RUN at the top of the taskbar, the output file will appear in the folder where the input files are located. If the output file will be given another name can be a way to fill out column of the file name ends with a dot o (.o) before running.

3.7. Making Collimator using MCNP 5 software

1. The assumptions are:
 - Neutron source is a deuterium-deuterium fusion reaction, which produce fast neutrons with energies of 2.45 MeV and shaped point.
 - The material used is a material with ideal composition without impurities.
 - Neutron yield is $10^{11} \text{ n cm}^{-2} \text{ s}^{-1}$
 - Units and scale are used in accordance with MCNP 5 software
2. The material chosen for manufacture of a collimator:
 - a. Moderator, moderator material chosen D2O, Al, AlF_3 , MgF_2 .
 - b. Shield gamma, gamma shield used is Bismuth.
 - c. Reflector, reflector used is Pb, Ni 95%.
3. The shape and material composition of collimators

Design collimator is a collimator tube with radius 71 cm and high 139, 5 cm. Design contained on lead wall as thick as 19, 5 cm; moderate: heavy water as thick as 4 cm, AlF_3 girdle a half of part CNG, MgF_2 (19 cm + 10 cm), Al (6,5 cm + 5 cm); Gamma shield: bismuth,

and aperture with diameter 6 cm. Design is modified Durisi, *et al* (2007). With the addition of moderator D₂O, changes in dimensions of space confines of a compact neutron generator and replacement polyethylene with 95% Ni on neutron output aperture collimator makes characteristics better.

CONCLUSION AND REMARKS

1. Boron neutron capture therapy (BNCT) works by neutron capture reaction ¹⁰B (n, α) ⁷Li. The reaction of 93.7% to He (alpha particles) with an energy of 1.47 MeV, Li with energy 0.84 MeV and 0.48 MeV gamma energy; and the rest is the decay of lithium (6.3%), which produces alpha with Li and each has an energy of 1.78 MeV

and 1.01 MeV. BNCT utilizes ionization energy of alpha particles and lithium to damage cancer cells by broke DNA, RNA and protein.

- Components needed in BNCT are neutron, boron compound, neutron source, collimator and dosimetry.
- Compact neutron generator used in a fusion reaction that there are three, namely CNG using reaction Deuterium-Deuterium (DD) resulting in neutrons with energies 2, 45 MeV, the reaction Deuterium-Tritium (DT) generating neutrons with an energy of 14.1 MeV and Tritium-Tritium (TT) produces neutrons with an energy of 11.31 MeV. Some types of compact neutron generator developed ie axial generator, coaxial,

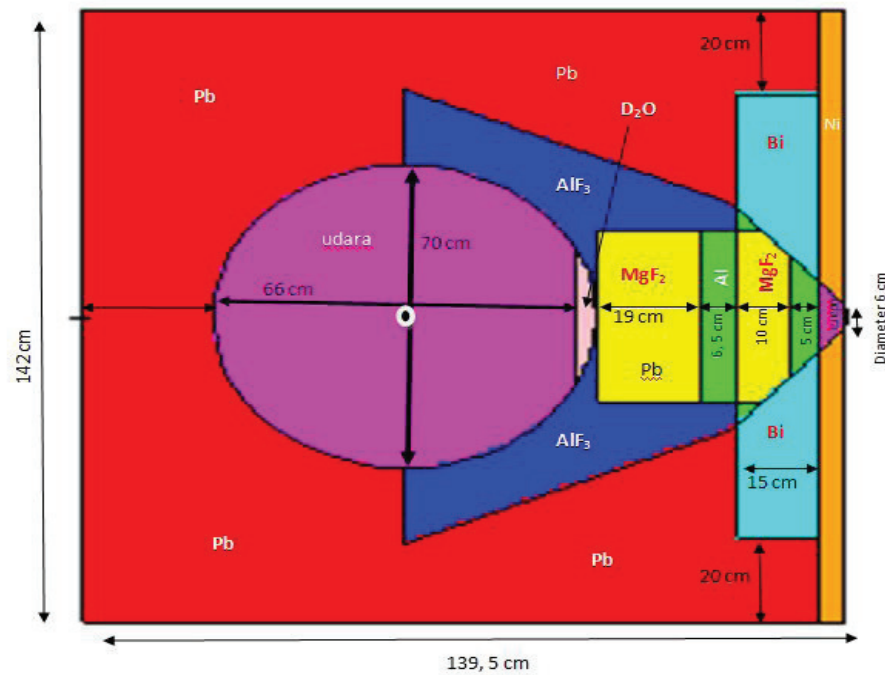


Figure 4. Design collimator proposed

Desain	Φ_{epi} (n/cm ² s)	J/ Φ_{total}	Φ_{th}/Φ_{epi}	D_f/Φ_{epi} (Gy cm ² /n)	D_γ/Φ_{epi} (Gy cm ² /n)
Standar IAEA	$> 1 \times 10^9$	$> 0,7$	$< 0,05$	$< 2 \times 10^{-13}$	$< 2 \times 10^{-13}$
Durisi et al, 2007	$1,87 \times 10^6$	0,61	-	$18,2 \times 10^{-13}$	$2,98 \times 10^{-13}$
Desain	$2,6 \times 10^7$	1,2	0,027	$22,2 \times 10^{-13}$	$5,499 \times 10^{-24}$

toroidal, neutron generator plasma design, the design of accelerator neutron generator and the neutron generator with a diameter of 2.5 cm.

4. CNG has advantages: smaller so easily be put in the hospital, do not need to be converted into a neutron because the output of CNG has been neutrons, permit easier than the nuclear reactor, the size of the room for a CNG smaller than the accelerators and nuclear reactors, energy neutrons produced is single, the energy generated is small so designing collimator CNG will not be so complicated to produce epithermal neutron appropriate IAEA standards, easier acceptance than the nuclear reactor. The drawback: CNG existing having neutron yield is too small so that when moderated and filtered neutron yield at the end of the collimator does not meet the standards of the IAEA, CNG with neutron yield of 10^{12} n/s is still in the research, isotopes of hydrogen form ion source and the target must always be replaced and the will be troublesome.
5. Materials that can be used as wall collimator are Pb, Bi, PbF₂, BeO, Ni. Materials that can be used as a moderator are Al, Al₂O₃, S, and AlF₃. A material recommended for the filter material is ⁶Li, ¹⁰B, LiF, Al, Cd-nat, Ni-60, BiF₃. Unsure ¹⁵⁷Gd and ¹⁵¹Eu can be used as thermal neutron filter because it has a thermal neutron absorption cross section which is great. Materials that can be used as a shield gamma are Pb, Ti, Li, and Bi. Materials aperture are Pb, Bi, PbF₂, BeO, Ni with smaller diameter is better.
6. Quantities and units used in MCNP 5 are: Length (cm), Energy (MeV), Time shuffle (10^{-8} s), Temperature, with units MeV (kT); $k = 1.3807 \cdot 10^{23}$ J / K,

The density of atoms, the atom units/b cm, Mass density, with units g/cm³,

Cross section, with units barns; 1barns = 10^{-24} cm²

7. Steps simulation using MCNP 5 software is sketched design, coding entries on the notepad, running on vised, select Run, fill the fields Inp with an input file and select RUN again.
8. The dose is considered in BNCT are recoil protons, gamma dose, dose rate and alpha radiation exposure to the environment.
9. Boron compounds already used in BNCT are BSH and BPA. Now Indonesia developing boron compounds with analog white turmeric.
10. Collimator design has been generated for the application of BNCT with compact neutron generator source DD reaction using MCNP program, design a collimator tube with a radius of 71 cm and 139.5 cm high. Design composed of a lead wall thickness of 19.5 cm; moderator: D₂O, covers half of the CNG AlF₃, MgF₂ (19 cm + 10 cm), Al (6.5 cm + 5 cm); Shield gamma: bismuth, and the aperture diameter of 6 cm at the edge of the nickel. Neutron output has exceeded three out of five IAEA standards.

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Policy Brief

Indonesia for cancer therapy used chemotherapy, surgery and radiotherapy. The therapy will have an impact on other parts of the

body healthy. According the studied conducted by the author, BNCT is a very effective method to cancer treatment and it should be realized in Indonesia. Therefore, the authors requested that the Indonesian republic government support this project until it is completely realized in Indonesia for the prosperity of the people of Indonesia, especially in health.

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