Boron Neutron Capture Therapy (BNCT) using Compact Neutron generator

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Abstract-Boron Neutron Capture Therapy (BNCT) must be appropriate with five criteria from IAEA. These criteria in order to prevent neutron beam output harm the patient. It can be by using Collimator of neutron source Compact Neutron Generator (CNG) and Monte Carlo simulation method with N particles 5. CNG is developed by deuterium-tritium reaction (DT) and deuterium-deuterium (DD) reaction. The manufacture result of the collimator is obtained epithermal neutron flux value of $1,69 \times 10^9 \text{ n/cm}^2\text{s}$ for D-T reaction and $8,8 \times 10^6 \text{ n/cm}^2\text{s}$ for D-D reaction, ratio of epithermal and thermal is $2,45 \times 10^{-2}$ for D-T reaction and $1,89 \times 10^{-2}$ for D-D reaction, ratio of fast neutron component is $1,95 \times 10^{-13} \text{ Gycm}^2/\text{n}$ for D-T reaction and $8,97 \times 10^{-13} \text{ Gycm}^2/\text{n}$ for D-D reaction, ratio of gamma component is $1,69 \times 10^{-13} \text{ Gycm}^2/\text{n}$ for D-T reaction and $1,18 \times 10^{-13} \text{ Gycm}^2/\text{n}$ for D-D reaction. The Latest reaction is current ratio 0,649 for D-T reaction and 0,46 for D-D reaction.

Keywords : collimator, BNCT, CNG, MCNP 5

INTRODUCTION

BNCT is cancer therapy based on *cell targeting* that does not damage healthy cells. BNCT is very useful for cancer treatment among others *Glioblastoma Multiforme*. *Glioblastoma Multiforme* is one of the type of the tumor that comes from brain cells. These Tumors comes from the cell *glial* / cells *bricket*. Glioblastoma multiform have *worse prognosis* with the growth that most rapidly and it is difficult to be cured (Sun, 2013). Therapies used for cancer include surgery, *radiotherapy* and *kemoterapy*. Those Treatment is palliative care that is only prolongs life patients around 75 percent and patients will die after *prognosis*. So that developed research about BNCT to heal *Glioblastoma Multiforme* from the roots.

This cancer therapy with BNCT using neutron source of nuclear reactors. Regulations exploiting of natural resources neutron from nuclear reactors to BNCT very tight due to its relation with the salvation and physical protection. For the outlook source neutron

from nuclear reactors will be redirected to use neutron source that one of them is portable CNG. Excess CNG among other relatively small size at affordable prices, so that it can be used in the hospital and were a source neutron radiation that is free gamma (Alotib, 2012). In addition, CNG also can be enabled to and disabled so that it is more efficient in treatment BNCT.

First producers CNG by Electron, Sodern EADS and Schlumberger that is capable of producing neutron reaction from D-T around 10^8 to 10^{11} neutron/s. Producers Advanced CNG latest by Lawrence Berkeley who National Laboratory (LBNL) and commercially by Adelphi inc. USA with an neutron with reaction D-D of 10^{11} neutron/s and the reaction D-T of 10^{14} neutron/s.

BORON NEUTRON CAPTURE THERAPY

BNCT is cancer therapies that are able to send a compound boron selectively in cancer

cells and tissue damage caused by radiation can be avoided (Kobayashi, 2012). BNCT has been used in clinical tests designed to treatment *Glioblastoma Multiforme* which is cancer on the central nervous system that grows spread to healthy tissue quickly.

The principle BNCT based on the reaction $^{10}\text{B}(n, \alpha)\text{Li}$ that occurs when isotope stable ^{10}B catch thermal neutron (n_{th}). Equation reaction can be written (Sauerwein, 2009)

Because ^{11}B above metastabil then split into

Particles α is at the core of ^4_2He with a Linear reach $7.1\mu\text{m}$ produce Linear Energy Transfer (LET) $150\text{ keV } \mu\text{m}^{-1}$, while ^7Li has reach $4.1\mu\text{m}$ produce LET $175\text{ keV } \mu\text{m}^{-1}$ would still be . traces LET was equivalent to diameter cells $< 10\mu\text{m}$ (single cell transplantation. Destructive effect particles α and ^7Li with high energy in a short distance depends on concentration boron attached to cancer cells. Optimum dosage will be fulfilled when ^{10}B to show off bars concentrated in 3835 barn to be able to cancer cells (Fantidis, 2013). Stock Exchange destructive events happened in a very short time because ^{10}B has a half- 10^{-12} s while ^7Li is 10^{-5} .

Therapy with BNCT has a number of advantages among others:

- [1] Kill cancer cells and minimize risks healthy cells.
- [2] The reaction ^{10}B with thermal neutron will be ^{11}B is unstable and produce gamma rays that energized 0.48 meV , atoms ^7Li and

particles α which has reach $5\mu\text{m}$ and $9\mu\text{m}$. Coverage particles ^7Li and α if compared with a diameter smallest cells $10\mu\text{m}$, will not be able to reach healthy cells about cancer.

- [3] Power Ionizing is very High and Very Large Residential almost does not have a print. Paper Timing the boron that only 10^{-12} seconds, there is no effects of radiation in the cell that is healthy.

- [4] Boron are more localised Only in Cancer cells

The Proportion Boron only deposited in cancer cells that reaction to catch neutron Boron that produce alpha particle (Helium and Lithium occurs only in cancer cells and not to take place in healthy cells and power and ionizing damaged what is happening is only in cancer cells, while healthy cells is still safe.

- [5] High Toxicity that is very low

Boron is the compound that contains toxic if in thoroughly juggled did not follow dosage that has already been determined. Boron would be a very useful if concentration that have been measured with a right dosage. Concentration throughput boron in cancer cells is 20 g/g . concentration is concentrating on HPAI boron is not toxic. In boron concentration that is more than 20 g/g , boron will be toxic (toxicity). But absorption if less than that of cancer cells that have been terboronisasi less absorption optimum conditions, and not fully carried out the neutronnya. Thus,limits optimum conditions that are used is $20\mu\text{ g/g}$.

COLLIMATOR FOR BNCT

Part of collimator that can be optimized for exodus neutron is the wall collimator, moderator, filters, shields gamma and aperture.

The wall collimator (Reflector)

The intensity sheaf neutron can be achieved by a wall collimator forms such as cone with a diameter early the width and *aperture* the narrow. Materials that are suitable for the wall collimator reflector is that have put on bars hardest issues (and the atom is relatively a great (Muslih,2013). Materials that are recommended for reflector is Pb, Bi, PbF_2 , Ni. CNG is capable of producing neutron fluks that is relatively high by using nickel and graphite as material reflector (Fantidis, 2013).

Reflector that is located close to the exodus, it is necessary to absorb neutron beam delimiter. This section ordered from B_4C or $^6\text{Li}_2\text{CO}_3$ that terdispersi in polyethylene. Neutron epitermal that batter this section will experience termalisasi and arrested gamma ray emissions with minimal (Fantidis, 2013).

Moderator

Moderator for quick neutron is materials that have the atom is low. Activation result neutron material from moderator must have a debt. Moderation from neutron fusion to energy neutron epitermal can be combined with material that is suitable and the thickness . Ten material that can be used polytetrafluoroethylene (CF_2), heavy water (D_2O), Flualental, B_2F_3 , B_2F_5 ,

mgf_2 , Al_2O_3 , alf_3 , tif_3 , and caf_2 (Fantidis, 2013).

Gamma ray shield

A shield gamma are raw materials that have bone density atoms. A shield gamma is good to be open and transparent neutron epitermal. Pb and Bi is a good material gamma rays that to reduce out of reactor.

Filter

Filter function to hold neutron quickly and neutron thermal, and passed neutron epitermal without producing light γ (F antidis, 2013) . That can be used to *filter* thermal neutron is ^6Li and ^{10}B (have put on bars $1/\nu$) with ν was the neutron. Raw materials to show off bars $1/\nu$ can spend neutron with energy under a broad spectrum neutron epitermal. Pengkombinasian ^6Li to locally termed as waktu effectively catch thermal neutron at under 10 ev and reduce neutron with energy in over 10 kev would still be.

In-BNCT, the material is the first step in designing facilities BNCT. Generator neutron D-D transmits neutron quickly with energy price well as our own 2.5 mev that must be neutron epitermal with the time span 0.5 ev - 1 mev using moderator material is appropriate.

Table 1. parameter sheaf neutron suggested IAEA (Sauerwein, 2009).

Parameter	Notation	IAEA's recommendations
Fluks neutron epitermal	Φ_{epi} (neutron/cm ² s)	$> 1.0 \times 10^9$
The dosage neutron quickly / fluks neutron epitermal	$\frac{\dot{D}_f}{\Phi_{epi} \left(\frac{\text{Gy cm}^2}{\text{neutron}} \right)}$	$> 2.0 \times 10^{-13}$
The dosage gamma / fluks neutron epitermal	$\frac{\dot{D}_\gamma}{\Phi_{epi} \left(\frac{\text{Gy cm}^2}{\text{neutron}} \right)}$	$> 2.0 \times 10^{-13}$
The ratio between fluks thermal and epitermal	$\frac{\Phi_{th}}{\Phi_{epi}}$	< 0.05
The ratio between cash neutron and fluks neutron	$\frac{J}{\Phi_{epi}}$	> 0.7

Moderator is an ideal must have a parameter that must be fulfilled to exodus sheaf neutron at the ratio spectral energy, dosage neutron quickly and dosage sinar γ in facilities BNCT according to IAEA is served in the Table 1.

Aperture

Aperture function to determine put on bars sheaf neutron that out of collimator, generally is placed on the other end collimator. In his presentation which is served by Protti entitled *The efficacy of Boron Neutron Capture Therapy on Small Animal models*, he uses *aperture* 3-4 cm (Muslih, 2013).

NEUTRON GENERATOR

Some types of generators neutron in development and testing in *Lawrence Berkeley National Laboratory Plasma (LBNL)*, one of them is *Compact Neutron generator (CNG)*. CNG can be used for the development Analysis of Activating Neutron (AAN), *Prompt Gamma Activation Analysis (PGAA)* for the identification material and *Boron Neutron Capture Therapy* (Anonymous 4, 2012).

Figure 1. A diagram block CNG (Anonymous 4, 2012)

Construction CNG can be seen in the Figure 1. *Gas reservoir* used to store deuterium gas that is used as a material source plasma ion in CNG. *Gas Pressure Control* to maintain the pressure of gas deuterium 0.1 Pascal. Antenna System RF that developed in CNG solenoid antenna is a useful radio frequency to distribute to the source ion RF. Radio frequency

range with 100 Hz - 100 kHz strengthened by magnetic field to produce 13.56 MHz frequency. Induction magnetic field and induction radio frequency was formed the conductor siphon electricity mengionisasi deuterium gas. Gas Ionizing deuterium resulting in an electron together in *source anode* (anode source ion RF). Ion D^+ interested in the direction *source cathode* (cathode source ion RF) which is passed by *focus lens*. *Ion source pulser* to calculate many ion that produced in a certain period of time. Ion D^+ boosted by *accelerator* toward target titanium. A reaction between ion D^+ and target titanium formed titanium hidrit (håndfull tid). Titanium hidrit reactions D-D and emits neutron 2.5 mev such as in the Figure 2.

Figure 2. Principle CNG by using a reaction D-D

There are 2 types generator design neutron type aksial and koaksial. In a more complete explanation of generators aksial and koaksial can be seen as follows

Generator Neutron Aksial

CNG aksial use antenna RF that are useful for radio frequency in channeling resources ions. These ionised gases are what give passing through *plasma chamber* toward the target such as in the Figure 3. Water cooler is useful to cool target so that there will be experienced voltage by the heat from excessive. Insulator high voltage function to isolate the voltage) and that is not voltage.

Figure 3. Diagram component block building blocks CNG type aksial (anonymous 4, 2012).

Fusion reactions that happen is D-D,T-T and D-T shows that equality follows (Ying, 2009)

$$E_n = 2.45 \text{ meV}, E_{He} = 0.82 \text{ meV} \quad (3.2)$$

$$E_T = 1.011 \text{ meV}, E_p = 3.022 \text{ meV} \quad (3.3)$$

$$E_n = 14.1 \text{ meV}, E_{He} = 3.5 \text{ meV} \quad (3.4)$$

$$E_n = 7.8 \text{ meV}, E_{He} = 3.5 \text{ meV} \quad (3.5)$$

Division of neutron energy range is: fast neutron $E > 1 \text{ meV}$, epithermal neutron $(0.5 \text{ eV} < E < 1 \text{ meV})$ and thermal neutron $E < 0.5 \text{ eV}$ (Anonymous 3, 2012). Using a result neutron D-D and D-T in CNG for BNCT can be known from great energy neutron produced by as shown on the common (3.2) and (3.4). These particles ^4He has the track AVRIL LAVIGNE that debt that is $9 \mu\text{m}$ until ^4He will be destroyed after the reaction D-D and D-T. Strong neutron source which is produced from the D-D is 10 neutron/s.

Generator Neutron Koaksial

CNG koaksial with strong source neutron 10^{11} neutron/s reactions (D-D) and 10^{14} neutron/s reactions (D-T) developed by LBNL for BNCT (Leung 2012).

CNG koaksial have 7 gap extraction such as in the Figure 4 up to 1.5 mm wide and long-term 75 mm. Source ion operated with 2.5 kw

Figure 4. Diagram component block building blocks CNG koaksial (Reijonen, 2005)

and cash sheaf ion 330 mA. Wrap electrons is useful to protect ions. Target as deuterium or tritium around source ions. Insulator Al_2O_3 function to protect them from the spark target. Generator plasma function to raise plasma deuterium and tritium. Vacuum pumps used to frustrating pool so that there will be collision between metal ions positive that produced by source ion with gas remains in CNG. Long-term CNG 80 cm and measuring 40 cm.

CHARACTERISTICS NEUTRON SOURCE

Fusion reactions CNG D-T produce neutron with energy 14 meV are isotropik. *Neutron yield* from this reaction is 1×10^{14} neutron/s. Running result simulation MCNP5, fluks neutron epithermal of 2.15081×10^6 neutron/cm² s and neutron quickly to 9.83040×10^{10} neutron/cm² s in home collimator. The reaction D-D with energy neutron 2.5 meV and *higher-yielding neutron* 1×10^{11} neutron/s, fluks neutron quickly $1,23228 \times 10^8$ neutron/cm² s in home collimator. A comparison fluks neutron reaction D-D and D-T between at home and in the end collimator can be seen in the Table 2.

It shows that fluks neutron at home collimator higher than fluks neutron at the collimator. The value is not in accordance with the criteria IAEA TECDOC-1223 that it needs to be made collimator by adding material in accordance with reflector, moderator, filters and shield so that by gamma fluks neutron that in accordance with the criteria IAEA TECDOC-1223.

Table 2. A comparison fluxes neutron on the reaction D-T and D-D

Reaction	Home collimator	The collimator
	Fast writes Φ Amino acid requirement (Neutron/cm2s)	Fast writes Φ Amino acid requirement (Neutron/cm2s)
D-T	9.83040 X1010 (industry standard)	4.86637 X105 (industry standard)
D-D	1.23228x 10 8	5.75799x10 3

COLLIMATOR CNG

Collimator CNG with reaction D-T and D-D can be described as follows

The reaction D-T

Design collimator using reaction D-T with energy 14 mev and *neutron higher-yielding assets* of 10^{14} neutron/s easier to meet the criteria IAEA TECDOC-1223 for BNCT. In the making simulation collimator, these criteria IAEA TECDOC-1223 have been fulfilled unless the ratio cash neutron to fluks neutron

total value was 0.656. Form a full design can be seen in the Figure .5.

Reflector is ^{208}Pb with 20 cm. Moderator For the first was ^{12}C pages 9 cm, producing the fluks neutron epitermal $1,43 \times 10^9 \text{ neutron/cm}^2\text{s}$. This value has fulfilled criteria IAEA TECDOC-1223 so for further consideration is to reduce the rate of gamma dose fluks epitermal and neutron quickly. ^{27}Al is 25 cm is material for moderator that is used to conditions quality are met. ^{27}Al would be able to reduce the rate of gamma dose fluks epitermal and neutron quickly to $8,31 \times 10^{-13} \text{ Gycm}^2/\text{neutron}$ and $8,81 \times 10^{-13} \text{ Gycm}^2/\text{neutron}$

Next step will be done an additional 40% Al + 60 percent alf_3 with 23 cm. Additional was able to reduce the rate of gamma dose fluks epidermal to $2.12 \times 10^{-14} \text{ Gy cm}^2/\text{neutron}$ and the dosage neutron quickly to fluks epidermal to $8,69 \times 10^{-13} \text{ Gy cm}^2/\text{neutron}$. An additional 40% Al + 60 percent alf_3 get dosage neutron quickly to fluks epidermal not meet the criteria IAEA TECDOC-1223 so added again material ^7Li pages 7 cm. Additional was able to reduce dosage neutron quickly to fluks epidermal to $1.27 \times 10^{-13} \text{ Gy cm}^2/\text{neutron}$

The next step is a shield gamma using material ^{208}Pb with 12 cm, the radius *aperture* 7.5 cm. Overall distance from the source of the *aperture* is 80.9 cm and toes collimator is 55

Figure 5. Design Collimator for a reaction D-T.

Φ_{th} (neutron / cm ² s ⁻¹)	Φ_{epi} (neutron / cm ² s ⁻¹)	Φ_{fast} (neutron / cm ² s ⁻¹)	$\frac{\Phi_{th}}{\Phi_{epi}}$	$\frac{J}{\Phi_{epi}}$	$\frac{D_f}{\Phi_{epi}^2}$ (Gy cm ² / neutron)	$\frac{D_y}{\Phi_{epi}^2}$ (Gy cm ² / neutron)
4,72 $\times 10^7$	1,34 $\times 10^9$	6,6 $\times 10^6$	3,52 $\times 10^{-11}$	0.656	1,62 $\times 10^{-13}$	9,81 $\times 10^{-14}$

Table 3. Optimization result of collimator

Figure 6. Collimator design for a reaction D-D

cm. Optimization result collimator can be seen in the Table 3.

The reaction D-D

Collimator reaction to D-D more difficult is designed to suit the criteria IAEA TECDOC-1223 for BNCT. Deuterium is hydrogen isotopes that many available in nature and non-radioactive so safe enough developed for BNCT. Strong source CNG reaction D-D low so long source to *aperture* which will be shortened that reaction D-T. Distance source to *aperture* is 35.9 cm with an elaboration ¹²C pages 7 cm and ²⁷Al is 10 cm and 40% Al + 60 percent alf₃ layer 9 cm, ⁷Li is 10 cm and design collimator as shown in the Figure 6. Finger collimator finger to the reaction D-D is 45 cm and 10 cm is reflector nickel.

The radius *aperture* is 7.5 cm on the assumption that will be made to clinical tests so diameter *aperture* adjusted with the size cancer.

As a whole minutes from collimator D-D not meet the criteria IAEA TECDOC-1223 in terms of quality and quantity. This was due to strong source fluks neutron and energy on the reaction D-D is low.

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