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The Neutron Radiation Analysis of in Vitro/in Vivo Testing Facility Boron Neutron Capture Therapy

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ABSTRACT

Boron Neutron Capture Therapy (BNCT) is a radiotherapy method that utilizes the interaction of boron-10 and thermal neutrons that produce lithium particles and alpha particles to kill cancer cells. Before treatment is done to humans, clinical and non-clinical testing is carried out. Non-clinical testing included in Vivo and in Vitro tests. This in Vivo and in Vitro test involves the Kartini reactor as a source and guarantees that the workers and the environment are safe when the reactor is operated. This research is aimed to analyze the neutron radiation after it has passed shielding made from paraffin with aluminum casing in an in vivo/ in vitro testing facility for BNCT. The shielding should withstand neutron radiation so that the radiation dose does not exceed the dose constraint set by PSTA-BATAN at 10 μSv/ hour. In this research, the initial shielding design was in the form of a 2D beam arrangement. For this reason, optimization of each shielding beam form into 3D can be identified. After that, the shieldings were produced and arranged in the radial piercing beam port of Kartini Reactor. The measurement results showed that neutron radiation exposure in the working area around shielding at all measurement points is 0 μSv/ hour, so the results of shielding design calculations can be validated. Neutron radiation exposure was found at 3.78 μSv/ hour and 2.36 μSv/ hour in measurements that were taken between the shielding gaps on the left and right side of the reactor's wall. These measurement results were below the prescribed dose constraint, so the working environment is safe.

1. INTRODUCTION

Cancer or malignant tumors are the rapid formation of abnormal cells that grow faster than and attack the normal cells. Based on the official website of the World Health Organization (WHO), in 2018 there were 9.6 million deaths of cancer. The most common cancers were lung cancer with 1.76 million deaths, liver cancer with 782,000 deaths, colorectal cancer with 862,000 deaths, stomach cancer with 783,000 deaths, and breast cancer with 627,000 deaths [1].

The cancer treatment methods that are currently developing are chemotherapy, radiation, and surgery. Along with the development of science and technology, a new treatment method has been developed. It is called Boron Neutron Capture Therapy (BNCT) [2]. BNCT has a high level of selectivity in destroying cancer, so that the effect on the healthy tissue is very little or none at all [3]. The advantage of BNCT is that it can reduce radiation exposure to normal tissue, so it does not damage normal tissue.

BNCT has attracted the attention of scientists who desire to study and apply this technique in the field of cancer treatment, especially brain and skin cancer. BNCT can be operated at facilities equipped with nuclear reactors or at hospitals that have built alternative neutron sources. Countries that have modified reactors for BNCT include Japan, the United States, Finland, Argentina and Taiwan [6]. In addition to the reactor, neutron sources for BNCT can also be produced from cyclotrons or neutron generators [7].

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BNCT research in Indonesia was conducted at the Kartini Reactor located in Yogyakarta, with in vitro and in vivo test methods

Basic Principles of BNCT

The Boron Neutron Capture Therapy (BNCT) method is one of the alternative cancer therapy methods which are being developed for cancer therapy in Indonesia. To support this program, the Kartini Research Reactor is used for basic research and in vitro in vivo testing. The Kartini Research Reactor is TRIGA type (Training Research Isotope Production by General Atomic) and has an operating license from the regulatory body (BAPETEN) for a 100 kW thermal operating maximum power level. This reactor is included in the small reactor category, and for 100 kW thermal, the neutron flux is around 10^{11}-10^{12} n/cm^{2}s. As usual, the purpose of the TRIGA reactor laboratory activity is especially for neutron irradiation, education, training, research, and development in the field of nuclear technology.

At this time the Kartini Reactor is licensed by the Nuclear Energy Supervisory Agency of Indonesia (BAPETEN) to operate at the power 100 kW thermal. The Kartini research reactor has 4 (four) neutron beamports as irradiation facilities and one of them is called radial piercing beamport. This beamport is radial-through the reactor core [Widarto et all 2014]. This means that the radial piercing beamport has higher neutron flux than the other beamports.

In order to improve the utilization of the Kartini research reactor, the radial piercing beamport is used for test facility in the in vitro/in vivo methods of Boron Neutron Capture Therapy (BNCT). The neutron collimator is inserted in the radial piercing beamport especially for optimizing and focusing the neutron flux in order fulfill the requirements of the in vitro in vivo test facility. The neutron collimator which has been installed is made of pure nickel with 95% purity [Arrozaqi.MI 2013].

The BNCT cancer therapy method is based on neutrons catching and reacting with the nuclide ^{10}B. The boron, which is non-radioactive (stable), is irradiated using thermal neutrons with energies of 0.025 eV. This produces alpha particles with high Linear Energy Transfer (LET). The decay of lithium expressed by equation for the nuclear reaction 10B (n, α) 7Li is as follows,

$$[^{10}_{5}\mathrm{B}] + [^{1}_{0}\mathrm{n}] \rightarrow [^{11}_{5}\mathrm{B}]^{*}.$$

The mechanism of cancer therapy by the method of BNCT can simply be stated in this way: the nuclide Boron (^{10}B), which is stable, is injected into cancer cells and then illuminated with a beam of thermal neutrons ($_0n^1$) which produces boron isotope metastable (^{11}B*) that emits a beam of alpha (α) , and will damage the surrounding cancer cells. Actually, ^{10}B is not the only nuclide which has a tendency to absorb thermal neutrons. There is another nuclide in addition to ^{10}B for Neutron Capture Therapy (NCT) which has a cross-section that has a higher uptake of gadolinium isotope ^{157}Gd. However, the weakness of the ^{157}Gd reaction (n, γ) in Gadolinium Neutron Capture Therapy (GdNCT) is that a product of the reaction is not emitted selectively at the level of cancer cells so it can cause damage healthy cells as well [3].

The BNCT facility is similar to other nuclear facilities in that the radiation exposure must be controlled. BAPETEN (Nuclear Energy Supervisory Agency) rules (PERKA Number 4 of 2013), states that the effective dose limit value for the worker, including skin, is 20 mSv per year in a five-year period, so the accumulated dose of more than five years should not exceed 100 mSv, and in a given year no more than 50 mSv [10]. In order to minimize radiation exposure in accordance with the provisions of BAPETEN radiation protection system is needed at the BNCT facility. One step that can be taken to reduce radiation exposure is to add shielding material [11]. The protective material which is used to protect against neutron radiation is paraffin, with aluminum is added as a cover. The protective strength must be considered when applied to real conditions. Paraffin used from protection easily changes shape even at room temperature [12]. Previous research has been carried out on paraffin and aluminum modeling for the Boron Neutron Capture Therapy facility using the MCNP simulator. To validate the results of this study, it is necessary to conduct a Neutron Radiation Analysis study in the In Vitro Neutron Capture Therapy Facility by directly measuring with a neutron detector in maximum reactor power.

2. METHOD

The method for this research can be seen on Figure 1.

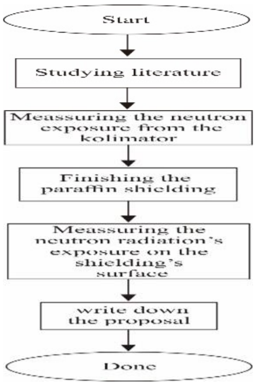


Fig 1. Research Plan

The first step was to identify the shape and size (length, width, height) of each uniquely sized paraffin beam. Material data collection was also conducted to find out the number of paraffin beams available and the number of deficiencies of paraffin beams that were still needed to improve paraffin shielding designs. Shielding design optimization was performed using AutoCAD 2014 software to create a 3D model so that the production process could be carried out without shielding beams from 2D models. The 3D model was created using the modeling tool 'Line' to create a wireframe scheme and then adjust it to the shape that would be created.

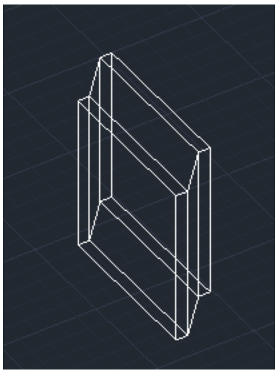


Fig 2. Schematic shielding

Then, after all forms were made and identified, it could be seen which casings must be produced. The aluminum casing to be produced would follow a paraffin beam design whose shape varies with an aluminum plate thickness of 3mm.

The beam casting process began with the insertion of paraffin liquid into the aluminum casing and the cooling of it. After the cooling process, the paraffin liquid shrank according to the nature of the material which easily shrinks at cold temperatures. After the cooling process, the aluminum casing was refilled with paraffin until it was confirmed to be completely full.

Fig 3. Fulfilling the shielding

The Paraffin beams were then numbered to make it easier to identify the shapes through the process of preparation. Beam numbering was done using an engraver pen and according to the following format.

- Numbers (1,2,3 etc) → Rows
- Letters (A, B, C etc.) → Column
- Roman numerals (I, II, III etc.) → Layers

Example: 1A.I, 4D.III, 9E.V.

Fig 4. Numbering the shielding

After all shielding beams were ready, the next step was the preparation of the Kartini

Reactor. The preparation stage began with the installation of the collimator on the radial beamport. Then, the paraffin shielding beams were arranged according to their location, sequence and design. When shielding had been completed, the instrumentation system to carry the sample was installed on the sample inlet on the left side of the shielding.

After the shielding refinement process, the measurement of the exposure rate was carried out using a neutron surface survey meter. The steps taken to measure exposure to the shielding surface are as follows.

1. Use a pocket dosimeter and read the appointment of the initial dosimeter.
2. Check the survey meter that will be used (battery, calibration certificate, response and scale).
3. Determine the measurement location by varying the angle by 15˚ (from 0˚- 180˚)

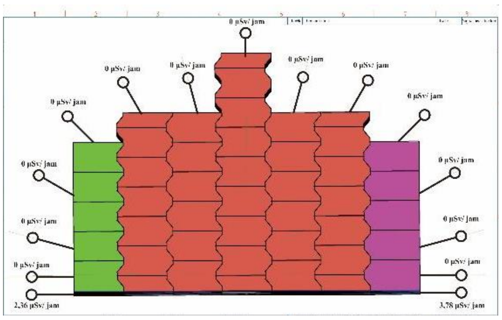


Fig 5. Shielding

4. Take measurements from the farthest point that the detector can read.
5. Estimate the measurement time using calculations.
6. Record the measurement results and the dose received in the pose.
7. Perform analysis

3. RESULTS AND DISCUSSION

After the production of shielding beams was finished, paraffin casting / filling was done to Aluminium beams for further arrangement according to the design that was made. Then the shielding beam was arranged at the output of the radial tube.

The measurement of neutron radiation exposure outside shielding was done by measuring directly using the NSN3 neutron detector so that the radiation exposure pattern in the environment around shielding could be known. Based on the procedures compiled in the previous chapter, the radiation exposure pattern around shielding can be seen through Figure below.

From the results of research by Atikah Maysaroh (2018), it was shown that neutron radiation exposure outside shielding at most points was 0 μSv / hour, except for code cell 401 and code cell 406 which had neutron radiation exposure of 3.56 μSv / hour and 0.45 μSv / hour.

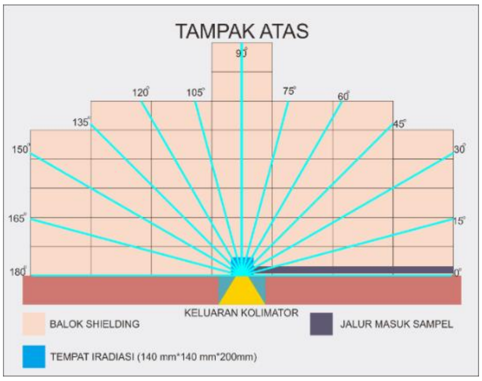


Fig 6. Top view of the shielding, sample entrance and radiation place.

These two cell codes are on the right and left side of the shielding front which is adjacent to the reactor wall. The measurement results show that at all predetermined measurement points, the neutron radiation exposure is 0 μSv/hour. However, there is a backscatter of 3.78 μSv / hour and 2.36 μSv / hour in the gap between the reactor wall and the front shielding surface.

Based on Fig 6. and Fig. 7, it can be concluded that the results of the MCNPX running program validated the measurement results directly in the field because at each measurement point the results compared with the MCNPX results were the same, except on the right and left side of the front shielding.

In the measurement results there is a backscatter. The authors suspect that this is caused, among other reasons, by:

1) Conditions in the field, so that there is a gap between the shielding and the reactor wall.

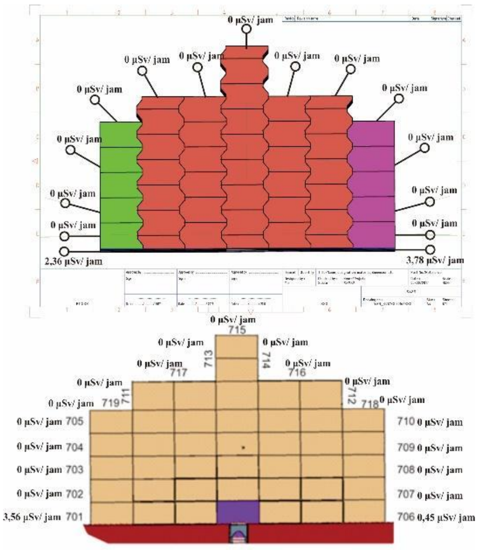


Fig 6. Condition in the field

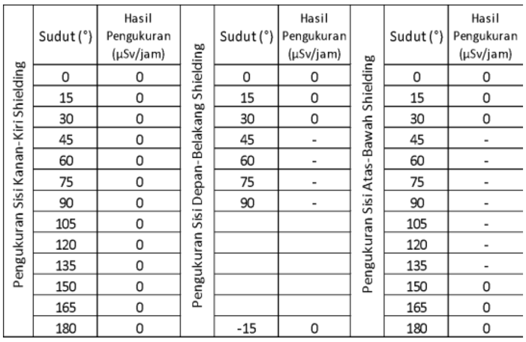
2) There is an irradiation entrance on the right side of the shielding so that the backscatter value is greater.

After the results of the design were validated, the measurement results were compared with the dose constraint value. In the LAK PSTA-BATAN in 2012 set the dose constraint value for neutron radiation exposure to be no greater than 10 µSv/hour when the reactor operates. By comparing the measurement results in the field to the prescribed dose constraint, it can be seen that the workers around the shielding will be safe from the danger of neutron radiation because the measured value is smaller than the dose constraint value.

4. CONCLUSION

According to the BAPETEN Decree number 4, 2013, the maximum radiation dose rate is 20 mSv/year and the Analysis Safety Report (LAK) PSTA BATAN maximum neutron radiation exposure is 10 µSv/hour. The result of measurement of neutron radiation mapping using NSN3 detector is 0 µSv/hour except in the gap between the reactor wall and the shielding. Neutron backscattering is 3,78 µSv/hour and 2.36 µSv/hour .

Therefore, this in vivo/in vitro testing facility at Kartini Research Reactor is safe.



	Sudut (°)	Hasil Pengukuran (µSv/jam)		Sudut (°)	Hasil Pengukuran (µSv/jam)		Sudut (°)	Hasil Pengukuran (µSv/jam)
Pengukuran Sisi Kanan-Kiri Shielding	0	0	Pengukuran Sisi Depan-Belakang Shielding	0	0	Pengukuran Sisi Atas-Bawah Shielding	0	0
	15	0		15	0		15	0
	30	0		30	0		30	0
	45	0		45	-		45	-
	60	0		60	-		60	-
	75	0		75	-		75	-
	90	0		90	-		90	-
	105	0					105	-
	120	0					120	-
	135	0					135	-
	150	0					150	0
	165	0					165	0
	180	0		-15	0		180	0

Fig 7. The result of Measurement

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