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Radiation measurement of boron neutron capture therapy research facility at Triga Mark-II research reactor Malaysia

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Abstract. Proper shielding ionizing radiations is a mandatory requirement in all nuclear facilities owing to the harmful effects of radiation on workers and general public. The present work is aimed to measure neutron fluxes and gamma fluxes around the Boron Neutron Capture Therapy (BNCT) research facility at the PUSPATI TRIGA Reactor. This measurement is needed in the subsequent safety assessment so as to ensure the research facility is safely operated

1. Introduction

Boron Neutron Capture Therapy (BNCT) is one of the promising methods in order to cure cancer by using neutron beam in which can be obtained commonly from research reactor or nuclear generator such as an accelerator. BNCT was the method used the combination of low energy of neutron (slow neutron) irradiation and the targeting of a tumour site with a proper boron containing compound. In general, most of the BNCT studies use neutron source from the research reactors [1]. It is upon this general observation that a BNCT facility was recently proposed to be installed at the PUSPATI TRIGA Reactor. The development of the BNCT facility in Malaysia required neutron source which only available at the thermal column of the Malaysia research reactor. The specification of neutron flux and the gamma dose rate must be considered for the development of the BNCT facility as a safety precaution for this research. Based on previous research, the thermal column is identified as a suitable place for BNCT facility. TRIGA MARK II was believed to supply a sufficient a quality neutron beam and as well to develop BNCT facility [2]. This research is thus aimed to ensure the newly developed BNCT research facility is safely operated with proper shielding design in light of this objective, a set of radiation measurements was taken during commissioning of the facility [3]. In addition, it is expected that this work provides a basic guideline on the neutron and gamma dose measurements for new nuclear research facility in Malaysia.

2. Methodology

Neutron and gamma dose measurement around the new BNCT research facility is conducted to ensure that the radiation dose around the research facility is in a safe range in both situations when the research facility is in operation as well as not in operation. This measurement used the Ludlum model 2363 survey meter and the model 42-42L PRESCILA neutron detector. This survey meter features lightweight neutron detection system, independent gamma, and neutron measurements, neutron detection range: 1 μSv/hr to 10000 μSv/hr, gamma detection range: 9 μSv/hr to 8770 μSv/hr, a scaler, and data logging capabilities. Figures 1 shows the neutron survey meter that was used in this research and Figure 2 show the portable gamma survey meter.

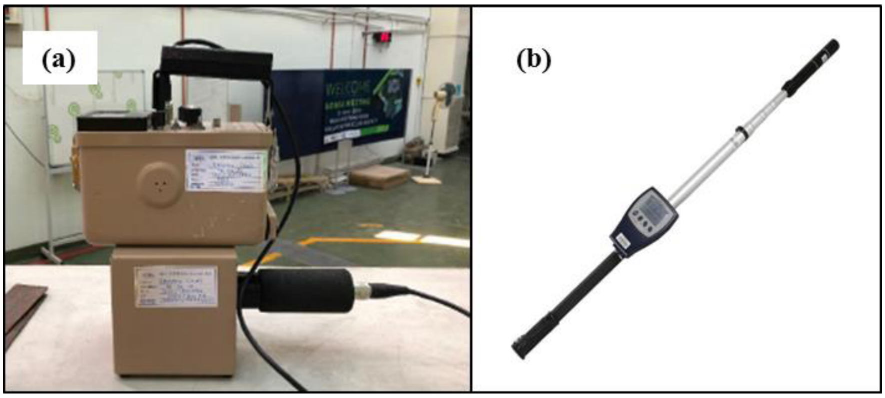

Figure 1.(a) Ludlum model 2363 survey meter with the model 42-42L PRESCILA neutron detector and (b) a portable gamma survey meter.

2.1. Dose measurement before, during and after installation of BNCT research facility

Before the measurements started, the selected locations will be marked using a tape. The survey meter battery and the calibration date are checked in order to ensure the data taken are reliable. Next, the surrounding of the measurement area is checked to make sure that it is safe from any danger. For these objectives, the dose measurement is carried out by measure the dose before, during and after the installation of collimator of BNCT research facility with 750kW reactor power without opening the beam shutter. There are two type of height for this dose measurement, first on the beamline height and another is 2-meter height from the beamline. Three measurements will be taken for each of the locations. The highest reading of the radiation dose will be selected.

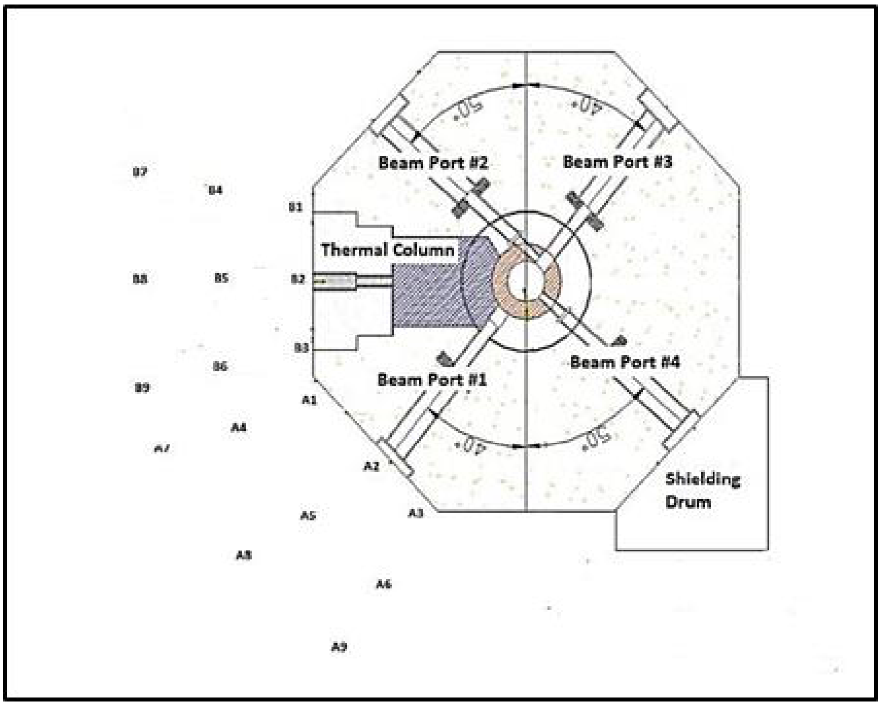

Figure 2. The position for dose measurement at BNCT research facility.

2.2. Neutron and gamma measurement at BNCT research facility during standard operation power

Once the BNCT installation in the RTP thermal column is carried out, testing and commissioning should be done to ensure that the collimator and shielding of BNCT used meets the standards. Therefore, a test was performed on the RTP thermal column to see the capability of the BNCT shielding and collimator. In addition, this test also aims to ensure that the radiation produce from the collimator in accordance with the prescribed rules and does not endanger the safety of workers in the reactor itself. This test is done by increasing the reactor power from 0 kW to a 250 kW. When the power of the reactor reaches 10 kW,50kW, 100kW and 250kW the measurements of the neutron dose, gamma dose starts to be taken at each of the marked locations the measurements will be taken for each of the locations. The highest reading of the radiation dose will be selected. After the measurements of all the doses are completed at the selected locations, the measurements are repeated for three times for average reading. Survey meters are the main instruments in this research to ensure no excess neutron radiation or gamma beam can endanger the safety of workers. Figure 3 display the position for the neutron and dose mapping for BNCT research facility.

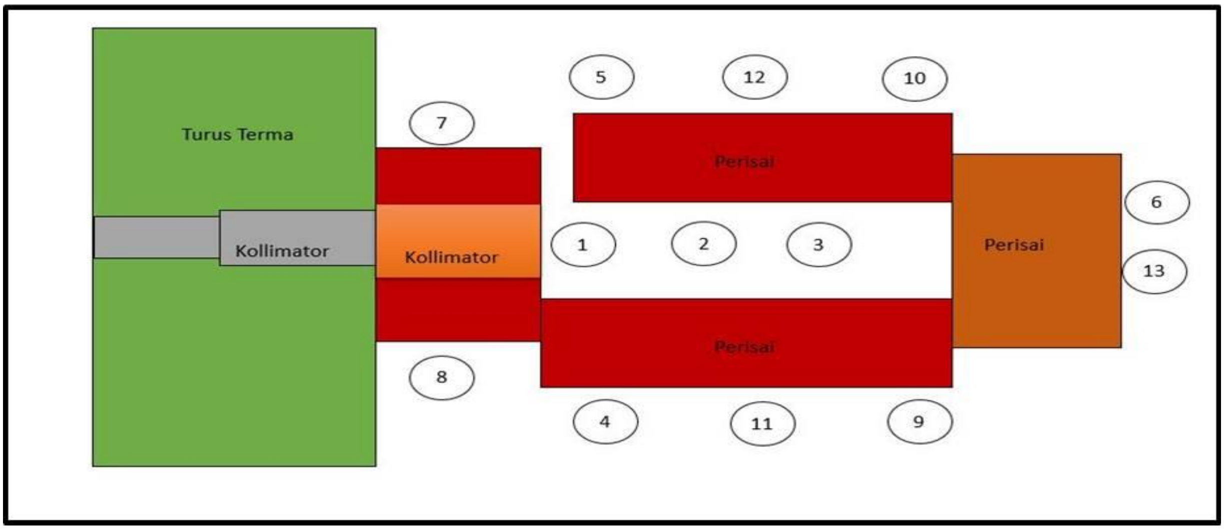

Figure 3. The position for neutron and gamma dose measurement at BNCT research facility

3. Results and discussion

3.1 Dose measurement before, during and after installation of BNCT research facility at RTP

Table 1 shows the dose measurement on beamline height before, during and after the installation of collimator at the different position around BNCT research facility and Table 2 display the dose measurement on 2-meter from the beamline high before, during and after the installation of collimator at the different position. Position B1 shows the highest beamline dose of 0.50 μSv due to a leak in the RTP thermal column door itself. For the 2-meter top position, the side door of the RTP thermal column door, namely B1, B2 and B3, also has a high dose reading due to the same leak. However, leaks that occur in the RTP thermal columns are still within the controlled radiation range set and do not endanger the safety of workers [6]. During installation in RTP thermal columns where the reactor does not operate (0 kW), dose mapping is very important because collimator installation involves the production of existing old collimators in RTP thermal columns.

When the installation of the new collimator is performed, there is a dose difference that occurs at positions B1, B2, B3, B4, B5 and B8. All of these positions indicate the dose reading increases as the beam plug is pulled out of the RTP thermal column. This is because the radioactivity of the beam plug itself is high even though this installation is done 3 days after the reactor is not operating (shutdown) [7]. Position B2 showed the highest increase from 0.05 μSv to 0.25 μSv. Dose mapping for reactors operating at full power was performed one week after collimator testing was performed at RTP thermal columns.

Upon 750 kW of reactor power, each position either A or B indicates an increase in beamline and also at the 2-meter height. At the beamline, positions B1 and B3 show the highest dose readings with 15.0 μSv while for dose records above 2-meters it shows B2 and B3 positions have the highest dose with 12.0 μSv. Through this research the maximum and minimum dose measurement can be identified and referenced to formulate and validate the irradiation parameters for BNCT in addition to being able to help regulate radiation safety in the research reactor itself. Positions B1, B2 and B3 received the highest reading points while B8 was the reading point receiving the minimum dose in this study. With this dose mapping, workers' safety against radiation will be more assured because it can plan the implementation of the way of working on BNCT research facility.

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Table 1. The dose measurement on beamline height before, during and after the installation of collimator at the different position around BNCT research facility.

	Before Installation(0kW)	During Installation(0kW)	After Installation (750kW)
Position	Beamline Dose, μSv		
A1	0.02 ± 0.02	0.02 ± 0.00	9.0 ± 0.03
A2	0.01 ± 0.02	0.01 ± 0.00	1.0 ± 0.00
A3	0.07 ± 0.02	0.07 ± 0.01	7.0 ± 0.02
A4	0.03 ± 0.06	0.03 ± 0.00	3.0 ± 0.04
A5	0.25 ± 0.00	0.25 ± 0.02	2.5 ± 0.00
A6	0.4 ± 0.00	0.4 ± 0.01	4.0 ± 0.00
A7	0.15 ± 0.01	0.15 ± 0.00	1.5 ± 0.00
A8	0.10 ± 0.02	0.10 ± 0.00	1.0 ± 0.03
A9	0.17 ± 0.04	0.17 ± 0.03	1.7 ± 0.06
B1	0.50 ± 0.01	0.70 ± 0.04	15.0 ± 0.05
B2	0.05 ± 0.00	0.25 ± 0.08	2.0 ± 0.03
B3	0.06 ± 0.03	0.09 ± 0.00	15.0 ± 0.03
B4	0.07 ± 0.03	0.07 ± 0.00	2.5 ± 0.03
B5	0.02 ± 0.00	0.35 ± 0.03	5.0 ± 0.02
B6	0.07 ± 0.09	0.07 ± 0.01	2.5 ± 0.01
B7	0.03 ± 0.01	0.03 ± 0.01	1.0 ± 0.00
B8	0.03 ± 0.03	0.10 ± 0.01	1.0 ± 0.00
B9	0.03 ± 0.02	0.03 ± 0.02	1.5 ± 0.003

Table 2. The dose measurement on 2-meter from the beamline height before, during and after the installation of collimator at the different position around BNCT research facility.

	Before Installation(0kW)	During Installation(0kW)	After Installation (750kW)
Position	Dose at 2-meter height, μSv		
A1	0.01 ± 0.04	0.01 ± 0.00	7.0 ± 0.03
A2	0.06 ± 0.03	0.06 ± 0.00	1.5 ± 0.03
A3	0.04 ± 0.03	0.04 ± 0.00	3.0 ± 0.03
A4	0.03 ± 0.03	0.03 ± 0.00	3.0 ± 0.03
A5	0.05 ± 0.06	0.05 ± 0.00	4.0 ± 0.03
A6	0.04 ± 0.01	0.04 ± 0.00	3.0 ± 0.03
A7	0.05 ± 0.01	0.05 ± 0.00	1.7 ± 0.03
A8	0.04 ± 0.01	0.04 ± 0.00	1.5 ± 0.03
A9	0.05 ± 0.02	0.05 ± 0.03	1.5 ± 0.03
B1	0.45 ± 0.03	0.55 ± 0.00	10.0 ± 0.03
B2	0.55 ± 0.03	0.65 ± 0.00	12.0 ± 0.03
B3	0.55 ± 0.00	0.80 ± 0.01	12.0 ± 0.03
B4	0.01 ± 0.00	0.01 ± 0.01	3.5 ± 0.03

B5	0.15 ± 0.00	0.35 ± 0.03	2.0 ± 0.03
B6	0.06 ± 0.03	0.06 ± 0.02	1.5 ± 0.03
B7	0.09 ± 0.00	0.09 ± 0.01	0.7 ± 0.03
B8	0.08 ± 0.00	0.06 ± 0.00	0.5 ± 0.03
B9	0.08 ± 0.00	0.08 ± 0.02	0.7 ± 0.03

3.2 Neutron and gamma measurement at BNCT research facility during standard operation power

Neutron beam at 13 different positions in the RTP thermal column section were recorded to test the newly installed collimator and test the leakage that occurred for the BNCT research facility in the thermal column. Positions 1, 2 and 3 are Radiation areas for BNCT applications that require a high neutron flux rate of 1.0 x 10^ 9 neutron.cm- 2 s- 1 [8]. This application only uses a low reactor power of 250 kW. Therefore, this study is limited to the power rate for this BNCT application only.

Table 3 shows the recorded neutron beam readings for positions 1, 2 and 3 measured at a power of 50 kW due to the safety factor of the worker which may cause excessive radiation exposure. Neutron surveillance meters are different from TLD that have access to record dose in areas that are farther and safer to use than neutron survey meters. The result of neutron dose for locations 1,2 and 3 clearly indicate that the collimator in the installation works well through a dose increase of more than 200%. Positions 4 to 13show that the shielding for the BNCT research facility are safe for RTP. This test can also look at identifying leaks found in the BNCT research facility itself. Up to 250kW, the maximum dose of neutrons recorded at position 8 is 6.26 μSv while the minimum dose recorded for the same power is 0.93 μSv. From a power of 10 kW to 250 kW. The results clearly show that the collimator works well to supply neutrons for BNCT applications and the shielding used also work well and record neutron doses that are still controlled and meet the standards for radiation workers.

Table 3. Neutron dose measurement at different reactor power and position around BNCT research facility.

	Neutron Dose, μSv			
Position	10 kW	50 kW	100 kW	250 kW
1	8.83 ± 1.26	2500.00 ± 0.18	-	-
2	14.00 ± 1.00	820.00 ± 0.15	-	-
3	12.87 ± 0.81	56.00 ± 0.16	-	-
4	0.06 ± 0.04	0	0.03 ± 0.02	2.06 ± 0.03
5	0	0.13 ± 0.04	0.08 ± 0.02	1.00 ± 0.33
6	0	0.04 ± 0.08	0.09 ± 0.01	0.93 ± 0.47
7	0.06 ± 0.04	0.10 ± 0.02	0.20 ± 0.11	6.26 ± 2.21
8	0.13 ± 0.06	0.08 ± 0.00	0.20 ± 0.01	2.47 ± 0.38
9	0	0.15 ± 0.06	0.02 ± 0.03	1.37 ± 0.59
10	0	0.09 ± 0.01	0.17 ± 0.10	0.94 ± 0.32
11	0	0.04 ± 0.08	0.01 ± 0.02	1.11 ± 0.33
12	0	0.09 ± 0.01	0.09 ± 0.01	1.20 ± 0.39
13	0.08 ± 0.01	0.04 ± 0.07	0.06 ± 0.06	2.04 ± 0.73

Referring to Table 4, the gamma produced by testing show the recorded dose is greater than the neutron dose. If we look at points 1, 2 and 3 which are the current flow and also the study area of BNCT application, the gamma dose at 50 kW power is higher than the recorded dose during 250 kW power. This occurs due to the occurrence of gamma instability and the mixing of gamma dose during collimator installation. However, the gamma ray dose at the beamline is still under control and will not interfere with BNCT operations in the future [8]. Positions 7 and 8 that need to be considered because they have a high gamma ray dose rate of 28.47 µSv and 22.08 µSv. Gamma ray leaks at positions 7 and 8 need to be improved by placing lead shields that have the ability as shields for gamma beam [9]. Improving the shielding is very important to ensure the safety of employees remains at a controlled level. At a power of 250 kW, the maximum gamma ray dose is recorded at position 1 while the minimum dose recorded is at position 9. With this test, it can help employees to take optimistic measures before conducting research of BNCT on RTP in the future.

Table 4. Gamma dose measurement at different reactor power and position around BNCT research facility

	Gamma Dose, µSv			
Position	10kW	50kW	100kW	250kW
1	3706.67 ± 4.5	25300.00 ± 5.50	500.00 ± 0.98	7000.00 ± 3.80
2	92.33 ± 9.71	41366.67 ±0.03	800.00 ± 1.59	3000.00 ± 0.83
3	403.33 ± 4.16	3275.00 ± 3.90	700.00 ± 0.07	500.00 ± 4.82
4	0.05 ± 0.03	0.73 ± 0.40	0.98 ± 0.07	2.28 ± 0.65
5	0.08 ± 0.02	1.36 ± 0.15	2.88 ± 1.09	4.62 ± 1.22
6	0.06 ± 0.01	1.46 ± 0.62	1.52 ± 0.42	2.69 ± 0.14
7	0.20 ± 0.03	6.55 ± 0.55	12.53 ± 1.56	28.47 ± 1.10
8	0.05 ± 0.03	4.44 ± 1.15	8.96 ± 1.31	22.08 ± 0.32
9	0.04 ± 0.01	0.49 ± 0.08	0.66 ± 0.34	0.61 ± 0.23
10	0.04 ± 0.01	0.38 ± 0.08	0.63 ± 0.06	1.41 ± 0.39
11	0.05 ± 0.01	0.66 ± 0.32	0.35 ± 0.01	0.74 ± 0.26
12	0.06 ± 0.02	0.34 ± 0.10	0.56 ± 0.21	1.24 ± 0.51
13	0.03 ± 0.00	2.71 ± 0.76	3.70 ± 0.36	7.26 ± 0.03

4. Conclusions

Referring this research was conducted to provide a basic safety assessment of the BNCT facility installed at the PUSPATI TRIGA reactor. To accomplish, a set of radiation measurements were taken around the newly-installed BNCT facility during its commissioning. Based on the measurements, it can be safely concluded that the collimator and shielding of the BNCT were properly designed and installed

5. References

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