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Homogeneity Test on Collimators for Boron-Neutron Capture Therapy based on SNI 8506:2018

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ABSTRACT

A serial homogeneity test based on Indonesian Standard SNI 8506:2018 were undertaken to investigate 12 manufactured collimators by using double wall single image radiography (DWSI) technique with an x-ray machine ranging from 120 to 150 kV. The standard stated that the film density should be measured on seven different points, and the result obtained must not exceed ± 0.05 from the average density. This paper outlines a testing work for the collimators, calculating the density on six different points in the film. Six different points were selected due to technical constrains of the collimator manufacturing and radiography capabilities of the selected laboratory. The results of film the density for the 12 collimators are: (1) 2.59; (2) 2.57; (3) 2.14; (4) 1.88; (5) 2.10; (6) 1.96; (7) 2.33; (8) 2.28; (9) 2.06; (10) 2.18; (11) 2.24; and (12) 2.33. The result shows that collimator-2 has the most homogenous density. This study concludes that established parameters and process are needed to manufacture the collimator for BNCT in achieving proper performance testing based on the standard.

INTRODUCTION

Boron-Neutron Capture Therapy (BNCT) is a cancer treatment utilizing a combination of radiopharmaceuticals and neutron reactions [1,2]. The high-energy or fast neutrons generated by the neutron generators require slowing down into epithermal neutrons using one of the main components of a collimator called moderator [1]. A neutron collimator is a system used to produce a neutron flux corresponding to the neutron flux for BNCT therapy. Neutrons produced from neutron sources (accelerators, generators, and nuclear reactors) have very high energy (fast neutrons). For this reason, collimate to produce a neutron flux that matches the neutron flux for the BNCT system [3].

Collimators are an important part of BNCT therapy instrument because they steer random neutrons and convert epithermal neutron fluxes from neutron sources into thermal neutron fluxes suited for BNCT system use. A collimator usually consists of a reflector, a moderator, a filter, gamma shielding, and an aperture. This collimator reflector is tubular with pure nickel material (>95 %) and made using the centrifugal casting technique, which is a casting method by pouring molten metal in a rotating mold, where there is the potential for discontinuities such as cracks and inhomogeneity of the material's inner structure [3,9].

According to the Indonesian Standard (SNI) 8506:2018 - medical device for cancer therapy using Boron-Neutron Capture Therapy (BNCT) method - part 1: collimator - general requirements and performance testing. It requirements for neutron collimators and homogeneity testing of one of its main components meet the requirements for its use in internal radiation therapy. The homogeneity test function determines the distribution of the constituent elements of component materials

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distribute for each volume and area [3]. This paper outlines the results of the homogeneity test based on the SNI 8506:2018 using 12 different collimators.

THEORY

The BNCT cancer treatment (Fig. 1.) is done by injecting the boron carrier compound, either sodium boroncaptate (BSH) or boron phenylalanine (BPA) into the patient [4,16]. The boron will subsequently be transported to the targeted tumor [4,5]. Then, the targeted tumor will be irradiated using epithermal neutron. The neutrons will be captured by the ^{10}B isotope, resulting in alpha particles and ^{7}Li, and killing the tumors [6-8,14].

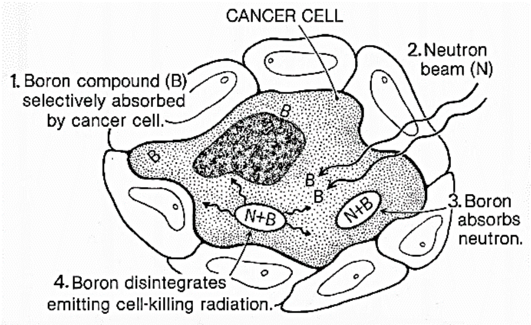


Fig. 1. Boron neutron capture therapy (BNCT) [17].

In obtaining the epithermal neutrons, several steps are required, as the neutrons produced by neutron generators (such as linear accelerators, cyclotrons, compact neutron generators, research reactors, or ^{252}Cf neutron source) are fast neutrons. A collimator is needed to moderate the fast neutrons to be epithermal neutrons. A collimator consists of a moderator, a reflector, a filter, gamma shielding, and an aperture [10-12,15].

Based on SNI 8506:2018 [3], a moderator material shall have a low atomic density, a low neutron absorption cross-section (<10 milibarn), and a high neutron-scattering cross-section to reduce the likelihood of gamma ray production from the moderation process. Examples of the reflector material include Al, Fe, MgF$_2$, AlI$_3$, ^{6}Li, Fe, ^{12}C, ^{27}Al, Al^{+}AlF$_3$, and heavy water.

Moreover, a reflector should have a low radiation-capture reaction cross-section (<10 milibarn) while a reflector material shall have a high neutron-scattering cross section (>1 barn) with 95 % purity. Examples of the reflector material include PbF$_2$, Ni-nat, and ^{208}Pb.

The function of filter is to absorb thermal neutrons, therefore it shall have a relatively high thermal neutron-absorption cross-section (>1 barn), for example ^{7}Li, Cd, ^{6}Li, LiF, and boron carbide.

Gamma shielding is required to attenuate gamma radiation, therefore it shall have good gamma absorption (> 1 barn) and low neutron absorption cross-section (<10 milibarn). The viable materials are Bi, ^{208}Pb, and ^{nat}Pb.

The last component, the aperture, requires a high neutron-scattering cross-section (>1 barn) and a low neutron-absorption cross-section (<10 milibarn). The aperture diameter should be adjusted to the irradiated target. Examples of the aperture materials include Ni, Pb, ^{91}Zr, and Li$_2$CO$_3$-polyethylene.

METHODOLOGY

The research employed a quantitative method of experimental procedures, as shown in the flowchart in Fig. 2.

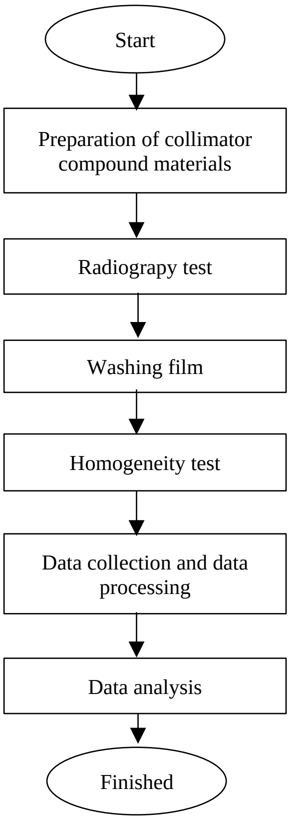


Fig. 2. Flowchart of research method.

The research data was in the form of density values, collimator film images and then data processing in the form of homogeneity analysis.

This experiment used the following material compositions of 12 reflectors with 97.89 % Ni, 0.92 % Si, 0.26 % S, and 0.90 % Fe. These criteria were met according to SNI 8506:2018, as Nickel had the proficient capability to remove fast neutron and decelerate them to be the epithermal neutrons [19] and the purity was above 95 %. As 12 reflector pieces were manufactured, the total length of the reflectors was 1560 mm [9]. The reflectors used in this study were tubes with an inner diameter of 160 mm, an outer diameter of 190 mm, and a length of 130 mm. The reflectors were produced using horizontal centrifugal casting. The design of the centrifugal casting machine [9] was shown below in Fig. 3.

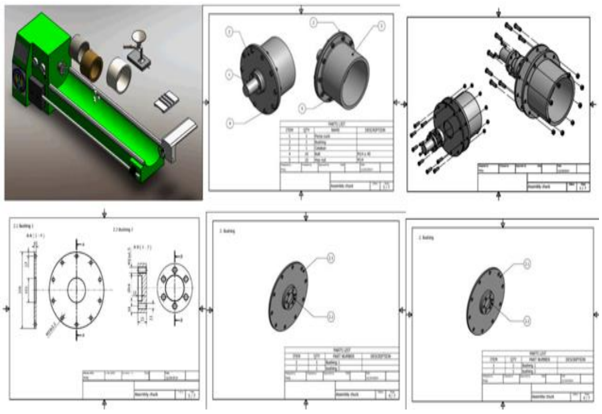


Fig. 3. Centrifugal casting machine design [9].

The equipment used were Industrial X-ray Machine Revo 300D, penetrameter, radiographic film, densitometer, film viewer, solution developer, fixer, and stopbath, dryer, radiation protection equipment (surveymeter, pocket dosimeter), radiation sign and yellow rope.

To meet the performance requirements of neutron collimators, the homogeneity of the collimators had to be tested on one of its main components, namely the reflector component because this component function as an important role in producing the quality of neutrons to match the direction and dimensions of the neutron beam so that it can be used in cancer therapy with the Boron Neutron Capture Therapy (BNCT) method.

A similar homogeneity reflector test was done by Simangunsong et al [18] using single wall single image technique and Iridium-192. This study found that reflectors 1 and 5 were found to contain cracks, and porosity was identified in almost all of the reflectors. The aim of this study was to determine the homogeneity of the reflector. To find the homogeneity, this study was using a double wall single image (DWSI) technique, adhering to the methodology listed by SNI 8506:2018

The test was using a double wall single image (DWSI) technique. The radiation source used for the testing was an x-ray machine ranging from 120 to 150 kV and the exposure distance (source to film/SFD) was determined using the thickness of the outer diameter of the sampling materials, varying from 1 cm to 5 cm. The focal spot was also used and the exposure angle was varied at 0°, 90°, 180°, and 270°. The radiography method was based on the ASME Boiler and pressure vessel code, section V, 2007 standard [3,13]. Then the film was processed and its density of the seven different points were measured.

The ASME standard requires the difference of the obtained density shall not vary more than ± 0.05 from the average density. The average density value of the film referred to ASME section V appendix VII, the density value for acceptable x-ray radiography was in the range of 1.5 - 4.

Once conformity is met, the testing documents of the collimator should indicate: i. Supplier or manufacturer’s name; ii. Factory name or collimator type; iii. Reflector material type; iv. Moderator material type; v. Filter material type; vi. Gamma shield material type; vii. Aperture material type; viii. The number and release date of the standard [3,13].

To follow up on the film results from the irradiation process, it was carried out film reading. Film reading in this study included reading the density value of the film and the types of defects that might be present in the film. Density value readings werre used to determine film acceptability criteria according to ASME section V. The criteria used include the presence or absence of identification and location markers on the collimator, average density value, limitation of geometric obscurity value, density value variation, radiographic sensitivity, and minimum visible IQI wire. In addition to determining the criteria for film acceptability, density values are also used to conduct homogeneity analysis. Homogeneity analysis was intended to determine the level of distribution of constituent elements of component materials are evenly distributed for each volume and area. This homogeneity analysis is regulated in the SNI 8506:2018 standard [18].

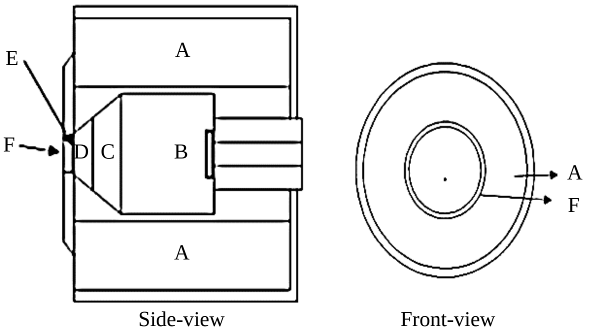
RESULTS AND DISCUSSION

Homogeneity in reflector was desired because the aim of the reflector is to produce a homogenous distribution of thermal neutron for the boron in the patients' body, so the dose received by the healthy tissue surrounding the targeted tumor of the patients' body will be minimized [20].

The density of radiographic film indicatef the level of blackness of the image on the film. Films with a high level of blackness have a high density as well. Quantitatively, the density of radiographic film was expressed as the logarithm of the ratio of the intensity of light coming on the film to the intensity transmitted by the film.

The homogeneity test was performed, with the results indicating that the dimension and the materials of the collimator were met the requirements as listed in the SNI 8506:2018 - medical device for cancer therapy using Boron-Neutron Capture Therapy (BNCT) method - part 1: collimator - general requirements and performance testing, which referews normatively in ASME standard.

The geometry and dimensions of all neutron collimator components are shown in Fig. 4.



Legends:
A = Reflector
B= Moderator 1
C= Moderator 2
D= Filter
E= Gamma Shield
F= Aperture

Fig. 4. All neutron collimator components.

A total of 12-unit reflectors were produced with the same materials and dimension. Albeit the collimator manufacturing had similar process and equivalent treatment, due to uncertainties of the established parameters and process the 12 collimators might have different characteristics. All the reflectors were tested using the DWSI technique and the density was measured at the seven different points in the film, shown in Fig. 5. is then interpreted by the radiographer to determine the type of defect, the size of the defect, and the position of the defect that may be present on the reflector.

Fig. 5. Typical film density as a result of homogeneity test using DWSI technique.

The test was conducted with four sides of the examination area (ROI), namely 0-1, 1-2, 2-3, and 3-0. With each side there were two films (top and bottom) with identification A and B. Thus one collimator required 8 films.

The measured film densities were described in Table 1.

Table 1. Measured density.

Collimator	Density						Average Density
	1	2	3	4	5	6	
1	3.27	3.59	1.83	2.10	2.42	2.29	2.59
2	2.58	2.59	2.51	2.41	2.90	2.41	2.57
3	2.16	2.04	2.22	2.07	2.07	2.21	2.14
4	1.85	1.88	1.95	1.72	2.20	1.67	1.88
5	1.79	2.27	2.49	2.39	2.29	1.35	2.10
6	2.32	1.74	2.05	-	-	1.73	1.96
7	3.31	-	1.77	1.77	-	2.45	2.33
8	2.21	1.65	2.78	2.40	2.49	2.14	2.28
9	1.8	-	2.09	1.23	2.82	2.37	2.06
10	1.98	7.51	2.51	-	2.44	2.29	2.18
11	1.99	1.96	2.13	-	2.78	2.36	2.24
12	1.83	1.97	1.41	1.99	2.43	4.34	2.33

As shown in the test results on the reflectors, reflectors whose density difference value measured by their average density is more than 0.05 mean that the reflectors was not homogeneous. It was shown that reflector 2 had the most homogenous density. Based on the obtained result, further studies were needed to determine: (1) the proper technique to manufacture the reflectors. The 12 reflectors showed 12 different densities, and only one showed homogeneity, showing that the manufacturing process had neither the methods nor the means to produce uniform reflectors . From the test results, it was found that only 1 reflectors had a level of homogeneity in accordance with SNI 8506: 2018. This was due to variations in the rotational speed used when casting by the horizontal centrifugal casting method for the 12 reflectors from the optimal rotational speed obtained in this experiment, namely 2200 rpm [9]; (2) the purity of the collimator materials for each component (a reflector, gamma shielding, a filter, and an aperture) had to be validated, as they have a major contribution to the homogeneity;(3) further tests were needed to complete the conformance test. While the horizontal centrifugal casting method was found to be economically efficient and pose superior capability in producing high density reflectors, the density homogeneities were not uniform. This showed that a standardized horizontal centrifugal casting method was needed before proceeding to the mass-production of the reflectors. Combining the result from Simangunsong et al [18], it might be possible that porosity and crack contributed to the non-homogeneity of the reflectors as well.

In addition, more technical problems might arise after the reflectors were to be exposed to fast neutrons, epithermal neutrons, and gamma radiation. Therefore, measuring the neutronic homogeneity and the strength of neutronic attenuation, as the main conformity indicators of the collimator's functionality, would be necessary.

CONCLUSION

It was found that among 12 reflectors, one reflector with an average density of 2.57 was the most homogeneous. A continuation of this testing, as a further testing of the reflectors in producing the epithermal neutrons, was still needed and could be performed using ionization chamber. Thus, measuring the absorbed dose to the patient using in-air and in a half-body phantom could be achieved accordingly. Improvements were needed in the manufacturing process, mainly to find the appropriate techniques in obtaining the uniform density of reflectors .

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AUTHOR CONTRIBUTION

Sigit Santosa, Khusnul Khotimah, Hanna Yasmine equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

REFERENCES

1. H. Kumada, T. Kurihara, M. Yoshioka *et al.*, Appl. Radiat. Isot. **106** (2015) 83.
2. I. Muratam, S. Tamaki, S. Kusaka *et al.*, Fusion Sci. Technol. **79** (2023) 465.
3. Badan Standardisasi Nasional, *Peralatan Medis untuk Terapi Kanker dengan Metode Boron Neutron Capture Therapy (BNCT) - Bagian 1: Kolimator - Persyaratan Umum dan Uji Kinerja*, in: SNI 8506:2018, BSN, Jakarta (2018). (in Indonesian)
4. S. I. Miyatake, M. Wanibuchi, N. Hu *et al.*, J. Neuro-Oncol. **149** (2020) 1.
5. W. A. G, Sauerwein and M. Ulčar, Cancer Biother. Radiopharm. **38** (2023) 147.
6. G. Gambargini, D. Magni, V. Regazzoni *et al.*, Radiat. Prot. Dosim. **161** (2014) 422.
7. R. F. Barth, Z. Zhang and T. Liu, Cancer Commun. **38** (2018) 15.
8. Y. W. Chen, Y. Y. Lee, C.F Lin *et al.*, Life **12** (2022) 566.
9. Mujiyono, Suharto, F. Nurjaman *et al.*, Indones. J. Phys. Nucl. Appl. **3** (2018) 21.
10. J. Chen, Z. Hu, J. Tong *et al*., Nucl. Instrum. Methods Phys. Res., Sect. B 5**08** (2021) 1.
11. S. I. Miyatake, S. Kawabata, R. Hiramatsu *et al.*, Neurol. Med. Chir. **56** (2016) 361.
12. S. Y. Taskaev, Phys. Part. Nucl. **46** (2015) 956.
13. ASME, *Rules for Construction of Power Boilers*, in: 2015 ASME Boiler and Pressure Vessel Code Section I, The American Society of Mechanical Engineers, USA (2015).
14. Z. A. Ganjeh and M. Eslami-Kalantari, Nucl. Instrum. Methods Phys. Res., Sect. A **916** (2019) 290.
15. W. A. G. Sauerwein, Cancer Biother. Radiopharm. **38** (2023) 192.
16. H. Fukuda, Cells **10** (2021) 2883.
17. I. M. Ardana and Y. Sardjono, J. Nucl. Reactor Technol. **19** (2017) 121.
18. D. C. M. Simangunsong, Y. Sardjono, B. Setyahandana *et al.*, ASEAN J. Sci, Technol. Dev. **36** (2019) 13.
19. B. W. Cheon, D. Yoo, H. Park *et al.*, Nucl. Eng. Technol. **53** (2021) 1970.
20. K. J. Riley, P. J. Binn, S. J. Ali *et al.*, Phys. Med. Biol. **49** (2004) 2015.