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Development of Bonner Sphere Spectrometer for Neutron Source with 30 MeV Proton Cyclotron

Gyuhaeng Jo[a], Soobin Lim[a], Bong-Ki Jung[b], Kyoung-Jae Chung[a*]
[a]*Department of Nuclear Engineering, Seoul National University, 1, Kwanak-ro, Kwanak-gu, Seoul, Republic of Korea*
[b]*KAERI, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea*
[*]*Corresponding author: jkjlsh1@snu.ac.kr*

1. Introduction

A neutron source is currently in development at Advanced Radiation Technology Institutes (ARTI), Jeongeup. In order to generate accelerator-based neutrons, a target-moderator-reflector-shield (TMRS) is being installed at RFT-30 cyclotron which can accelerate protons up to 30 MeV [1]. To obtain the neutron spectrum by TMRS, a Bonner sphere spectrometer (BSS) which is a set of thermal neutron detectors combined with different moderation mediums such as HDPE (High Density Polyethylene) is equipped in the TMRS room. This spectrometer with diverse sphere sizes has capability to obtain neutron spectrum through spectrum unfolding method [2, 3].

In this paper, Monte Carlo simulation result for TMRS obtained by MCNP6.2 is included in order to predict the neutron flux by TMRS and compare it with the BSS experiment result [4]. Additionally, measurement of neutrons emitted by $^{252}_{98}$Cf is also included to confirm that BSS has characteristics that neutron counts vary with its sphere size.

2. Method and Results

2.1. Monte Carlo Simulation Result for TMRS

The target is placed at the center of TMRS in order to generate neutrons impinged by 30 MeV protons. The moderator at the neutron beam line cools down the generated high energy neutrons, and HDPE around the target is installed in order to reduce the loss of neutrons by elastic collisions. Additional lead and HDPE around the reflector are equipped at TMRS for removing gamma rays and neutrons deviating from the intended beam line. Fig. 1 illustrates a brief structure of the TMRS system.

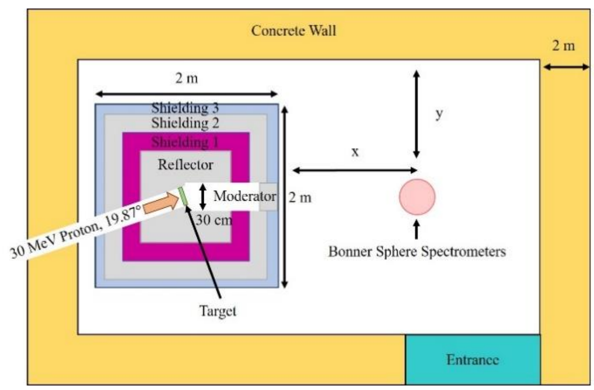


Fig. 1. TMRS design based on RFT-30 cyclotron

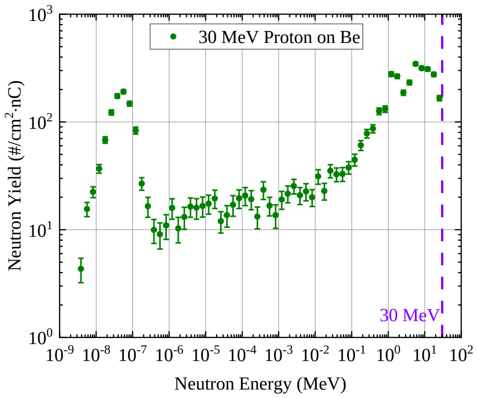


Fig. 2. MCNP6.2 result at the point 35 cm away from the designed TMRS when applying 30 MeV protons

Fig. 2 is a plot of neutrons generated by TMRS with Be target. The region near 30 MeV indicates neutrons that experienced no or negligible moderation. In contrast, the peak at the spectrum appearing below 1 eV shows the neutrons that are fully thermalized through moderation. Between the two regions, there are neutrons with a wide range that have not gone through full thermalization.

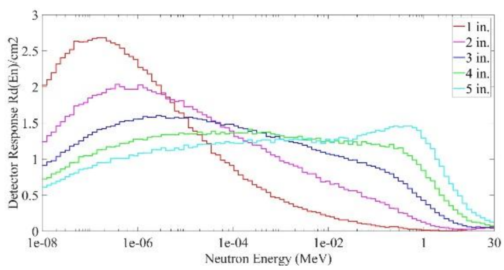


Fig. 3. Detector response function varying with sphere sizes

Thus, the neutron spectrometer designed for this TMRS must be able to detect neutrons ranging from thermal to 30 MeV. Bonner sphere spectrometer with diverse sphere sizes can satisfy this condition since hydrogen nuclei at HDPE reduce the neutron energy effectively via elastic collision. Fig. 3 illustrates the response function depending on the sphere size. By measuring BSS with a diverse size of moderators, one can control degree of the moderation and can determine its energy region of interest.

2.2. Experimental Setup

To demonstrate the variation in the neutron count by the sphere size, 3 in. HDPE sphere is measured in comparison with the same detector without the HDPE sphere.

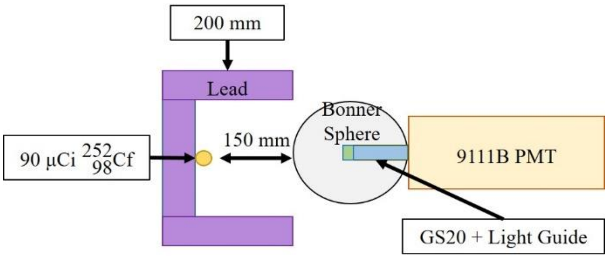


Fig. 4. $^{252}_{98}$Cf-emitted neutron detection experimental setup

As shown in Fig. 4, 0 in. and 3 in. Bonner sphere spectrometers are located 150 mm away from encapsulated 90 μCi $^{252}_{98}$Cf for 300 s, and generated pulses during the experiments are recorded by a 250 MHz digitizer, DT5725 from CAEN.

GS20 scintillator, detection medium of the BSS, is a type of glass scintillator that contains a high $^{6}_{3}$Li concentration for thermal neutron capture. Advantages when using GS20 are fast decay constant which is about 18 ns and the capability of neutron-gamma discrimination [5].

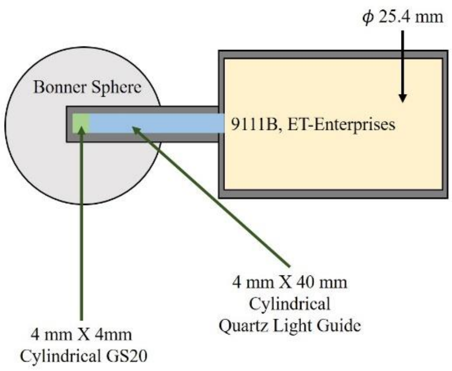


Fig. 5. Structure of BSS for each photomultiplier tube (PMT)

Fig. 5 is a simplified diagram of a BSS detector. A 4 × 4 mm cylindrical GS20 is located at the center of each HDPE sphere. Scintillation light is transported through 4 × 40 mm quartz light guide to 1 in. 9111B series PMT with a bi-alkali photocathode manufactured by ET-enterprises. All components are covered by aluminum casing except for the spheres.

2.3. Measurement with $^{252}_{98}$Cf-emitted Neutrons

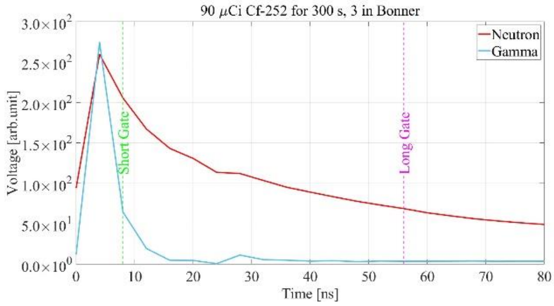
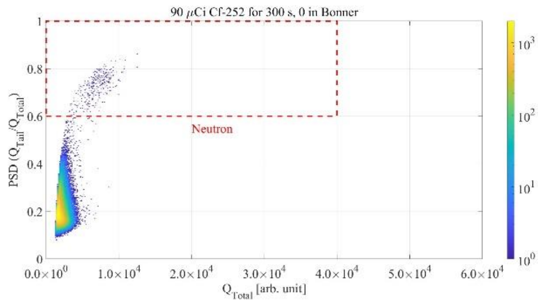


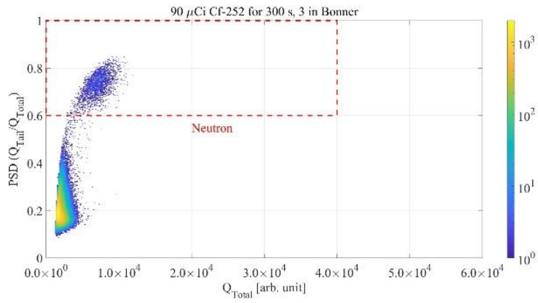
Fig. 6. Averaged neutron and gamma pulse obtained from BSS

Fig. 6 depicts the pulse shape difference between neutron and gamma signals. In order to discriminate all the pulses generated during the experiment, the pulse shape discrimination (PSD) method is applied. Q_{total} and Q_{tail} are defined which are V-t integral from pulse rise to signal tail and signal head to signal tail, defined as short gate and long gate. The PSD ratio can now be defined as below:

$$\text{(PSD Ratio)}=\frac{Q_{tail}}{Q_{total}} \quad (1)$$



(a) 0 in. Bonner sphere (without sphere)



(b) 3 in. Bonner sphere

Fig. 7. 2D PSD histograms for the experiment illustrated in Fig. 4

Table I: Counts for $^{252}_{98}$Cf-emitted Neutrons

	0 in.	3 in.
MCNP6.2	26±2	2258±12
At Fig. 7	330±18	2487±50

As shown in Table I, neutron count increments by 3 in. BSS are identified for both MCNP6.2 simulation and experimental result. Since $^{252}_{98}Cf$ is a fast neutron source, it is confirmed that neutron counts increase by moderation at the sphere. Discrepancies between them can be induced by excluding neutrons scattered from the surrounding during the simulation. Fig. 8 demonstrates spectrum variation of incident neutrons on GS20 without the sphere if the surrounding concrete wall with arbitrary size is reflected.

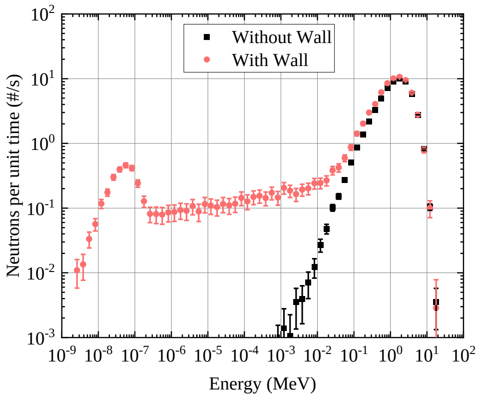


Fig. 8. Neutron spectrum depending on the concrete wall

PSD parameters such as the long gate are optimized with respect to the figure of merit (FOM) [6]:

$$\text{FOM}=\frac{\text{(Distance between two peaks)}}{\text{(Sum of full width half maximum of two peaks)}} \quad (3)$$

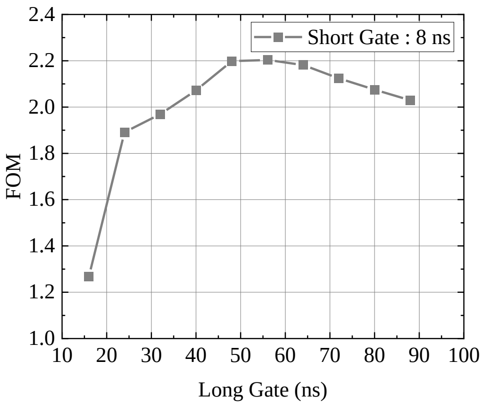


Fig. 9. FOM depending on long gate

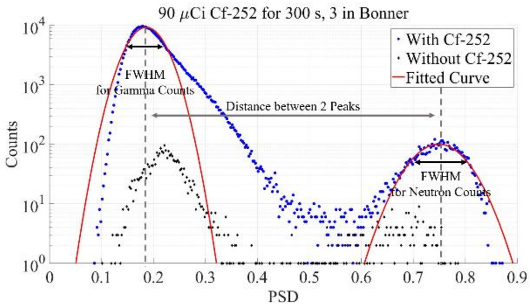


Fig. 10. FOM based on Fig. 8

Fig. 9 shows the change of FOM with increasing long gate. When the short gate is 8 ns, FOM is maximized when the long gate is 56 ns. Fig. 10 is the result of optimized FOM.

3. Conclusions

Monte Carlo simulation result based on TMRS installed at the end of the cyclotron beam line shows the wide range of neutron spectrum and therefore it is required to develop a BSS to measure such a wide spectrum effectively. Development of the BSS with GS20 scintillator and HDPE sphere is conducted and verified its feasibility with $^{252}_{98}Cf$ neutron source.

Further detection experiments will be conducted after completion of TMRS to obtain the neutron measurement and neutron spectrum unfolding will be implemented in near future.

Acknowledgments

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