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Improvement of neutron counting method of the BF_3 detector in low intense neutron field

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1. Introduction

The ^3He detector is mostly popular detector for thermal neutron detection, however currently there is significant shortage in ^3He gas supply. When the BF_3 detector, a promising candidate, is used in low intense neutron field, the neutron counts are overestimated due to background pulses whose pulse height is similar to neutron pulse height. Although the counting events from the background pulses can be subtracted through a separate background counting, this cannot take into account the time variation of the background pulse. To solve this problem, a new method of measuring the two-dimensional (2-D) pulse height-shape distribution was developed in this study and it can discriminate neutron pulses against background pulses with a single measurement by using pulse shape analysis. The performance was evaluated by comparing accuracy and detection limit between the conventional and the new methods for various counting rates.

2. Methods

The BF_3 detector detects neutrons using $^{10}B(n,\alpha)$ reaction and the specification of the detector employed in this study is shown in Table 1. The neutron source is a D-D neutron generator developed at Seoul National University [1]. Neutron and background pulses of the BF_3 detector were discriminated through the rise time of each pulse. The signal processing system of measuring the 2-D pulse height-shape distribution was reported in detail previously [2,3]. In the previous research, it turned out that the rise time of neutron pulses is slower than that of background pulses. The neutron region at 2-D pulse height-shape distribution could clearly be defined [3].

Table 1. Specification of the BF_3 detector.

Model	LND 20264
Diameter	25.4 mm
Active length	508.0 mm
Gas pressure	700 Torr
Cathode material	1100 Aluminum
Sensitivity	17.5 cps/nv

3. Performance

3.1. Improvement in neutron counting accuracy

The accuracy of the neutron counting was compared quantitatively between the conventional method and the new method of collecting 2-D pulse height-shape distribution. Among various neutron measurements, 12 results were picked up as representative cases, and the neutron count rate from conventional one-dimensional (1-D) pulse height distribution (R_1) and the rate from 2-D pulse height-shape distribution (R_2) were obtained for each case. The neutron count rate R_2 was obtained in a 2-D spectrum by eliminating the background pulses with similar height but faster rise time than neutron events and therefore, can be defined as the net neutron count rate. Figure 1 shows the R_1/R_2, ratio for various neutron count rates. For the neutron count rates above 100 cps, the overestimation of the conventional method is less than 2%. However, in the region below 10 cps, the overestimation increased to 4 ~ 28% (include the uncertainty). The fluctuation in the overestimation in this region was caused by time variation of the fast rising background pulses. From the result of this section, measuring the 2-D pulse height-shape distribution is great importance for BF_3 measurement in weak neutron fields to keep accuracy in counting.

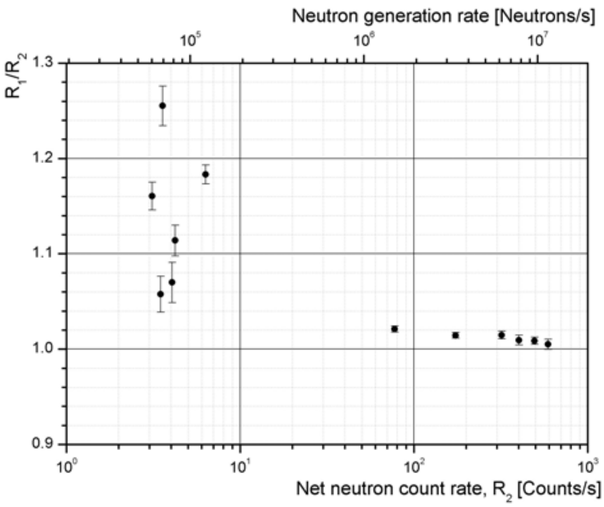

Fig. 1. Ratio of 1-D neutron count rate and net neutron count rate with different neutron count rate cases.

3.2. Lower detection limit

The detection limit is the net neutron counts which can be discriminated against the background counts at the neutron region, and it can be obtained from the following equation [4]:

$$L_D = 2.71 + 4.65\sqrt{\mu_B}$$

where μ_B is background count at the neutron region, constant 2.71 and 4.65 are 95% confidence interval matched values. The detection limit from 2-D pulse height-shape distribution measurement was 35 counts for 1 hr counting, which is converted to 0.01 cps. The detection limit from the 1-D pulse height distribution measurement was 376 counts for 1 hr counting. Therefore, the 2-D pulse height-shape analysis enabled to enhance the BF_3 neutron detection limit by a factor of 10. Given low activity or intensity neutron sources can be identified with the lower detection limit, collecting the 2-D pulse height-shape distribution greatly advantageous for weak field measurements. As an example, two methods were compared for a weapons- grade plutonium (WGPu) and a high enriched uranium (HEU) samples. A counting time of 1 hr is assumed. The properties of the two nuclear materials and the detection possibility are shown in Table 2. The two materials are assumed as metal because the specific neutron emission rate of metal is lower than that of oxide or fluoride. The mass was assumed as the significant quantity which is the approximate amount of nuclear material for manufacturing a nuclear explosive [6]. When the 2-D method is applied, both the WGPu and HEU samples can be detected while the HEU sample cannot be detected with 1-D pulse height analysis.

4. Conclusions

The method to prevent the overestimation of neutron counts in BF_3 counting was developed using the 2-D pulse height-shape analysis. The neutron count rate from the 1-D pulse height analysis was overestimated by 28% (max.) when the neutron count rate is below the 10 cps. The detection limit of neutron has been enhanced by a factor of 10 through application of the 2-D pulse height-shape analysis. It is expected that 2-D pulse height-shape distribution developed in this study will be useful for neutron counting for weak neutron fields.

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Table 2. Properties of metal weapons-grade plutonium (WGPu) and metal high enriched uranium (HEU) sphere samples and the detection possibility of 2-D pulse height-shape analysis and 1-D pulse height analysis by comparison of the detection limit.

		Metal WGPu	Metal HEU
Composition [mass %] a)		90.0 ^{239}Pu 10.0 ^{240}Pu	90.0 ^{235}U 10.0 ^{238}U
Mass, significant quantity [kg] b)		8	25
Density [10^3 kg/m^3] a)		15.92	19.07
Sphere radius [mm]		49.3	67.9
Neutron production rate per gram [n/s/g] a)		130	0.00136
Neutrons from the sphere [n/s] c)		10^6	34
Detection possibility	2-D (L_D : 11 n/s) d)	O	O
	1-D (L_D : 110 n/s) d)	O	X

a) From R.T. Kouzes. et. al. [5]
b) From IAEA Safeguards Glossary 2001 edition [6]
c) Assuming no multiplication
d) Counting time : 1 hr

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