Study of n/γ discrimination of He-3 Proportional Counter for the Development of Neutron Survey Meter

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1. Introduction

There are many mixed neutron-gamma radiation fields in many nuclear engineering fields such as inside or outside of nuclear power plant and accelerator facilities. In these sites, it is important to separate the gamma ray signal to obtain only the neutron signal and to measure the accurate neutron dose.

In case of the He-3 proportional counter, the height of the signal due to the gamma ray is lower than that of the neutron, so the signal of gamma rays can be easily discriminated by the pulse height threshold [1]. However, if the gamma ray exposure rate increased, the pulse height is measured higher because of the pile up effect, so that gamma rays cannot be separated by the criteria at the lower exposure rate [2]. Therefore, in order to properly discriminate the gamma rays while minimizing the loss of the neutron signal, it is necessary to find the relationship between the exposure rate and the level of pile up effect.

In this study, we investigated the correlation between the exposure rate and the level of pile up effect through the experiment using He-3 proportional counter with various gamma ray sources. Finally, we determined n/γ discrimination channel corresponding to the maximum deposit energy of gamma ray and confirmed whether it can be applied to the development of the neutron survey meter in the future.

2. Methods and Results

2.1 Method of n/γ discrimination of He-3 proportional counter

When the neutron is incident into He-3 gas, the nuclear reaction that takes place in the gas is:

$$ {}^{3}_{2}He + n \rightarrow {}^{3}_{1}H + {}^{1}_{1}H \quad Q{:}\,764\ \ keV \qquad (1)$$

The triton and the proton have about 191 keV and 573 keV, respectively. The ideal pulse height spectrum expected from a He-3 tube of very large volume forms a peak at a Q value of 764 keV. However, in the He-3 tube of actual size, some charged particles generated near the wall no longer deposit the full reaction energy (764 keV) in the gas. If triton or proton strikes the tube wall, a smaller pulse is produced. So as in Fig. 1 spectrum forms a continuum to the left of the peak by the wall effect and ends at about 191 keV [3].

When the gamma ray is incident into the detector, it reacts mainly on the wall, not the gas. Because the gamma ray-induced electrons have a longer range than the charged particles produced by neutrons, they are likely to escape completely from the He-3 tube. Thus, there is the maximum energy that can be lost within the volume of the detector. Above this energy, signals of gamma ray are not observed [1]. Therefore, as shown in Fig. 1, the gamma-ray spectrum is located on the left side of the neutron spectrum. This characteristic makes it possible to separate the neutron and gamma rays. As shown in Fig. 1, the energy at which the gamma ray spectrum ends can be defined as the criteria for n/γ discrimination. We will call this criteria discrimination Ch (energy) from now on.

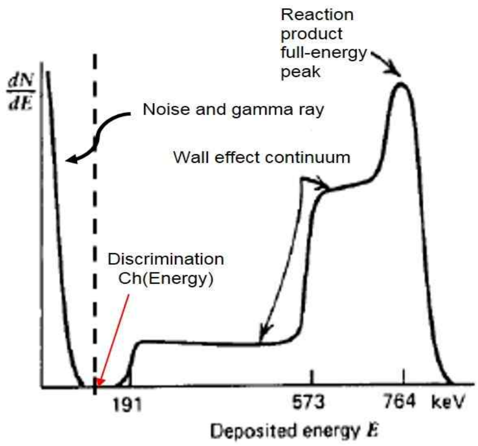

Fig. 1. Pulse height spectrum in mixed neutron-gamma radiation field for a He-3 proportional counter [3].

2.2 Influence of gamma ray exposure rate

Gamma rays can no longer be separated and can overlap with the neutron spectrum in an environment of high gamma ray exposure rate. As the exposure rate increases, the frequency of the gamma ray signal increases. The individual pulses begin to superimpose and grow. In the detector, these pulses are recognized as large enough that they cannot be distinguished from the neutron pulses. As a result, gamma ray spectrum moves to the up and right as shown in Fig. 2 [4]. Thus, the discrimination Ch should be changed.

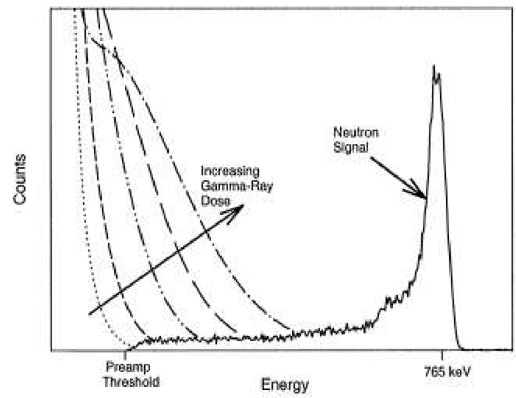

Fig. 2. Pulse height spectrum for a He-3 proportional counter with increasing gamma ray exposure rate [4].

2.3 Experimental design

In order to find how many channels are shifted to the right as the exposure rate increases, several sources with different activity were used. The source was measured by attaching on the detector window. Table I indicates the activity and average exposure rate in the active volume of detector, for each gamma ray source used in the experiment. After the background measurement, gamma rays from each source were measured and additionally gamma rays from Co-60 and Cs-137 were measured simultaneously for the result at higher exposure rate. Finally, the measurement was carried out with 7.4 μCi Cf-252 source to obtain neutron spectrum together.

Table I: Activity and average exposure rate of various gamma ray sources.

Source	Activity (μCi)	Avg. Exposure rate (mR/h)
Co-60	2.9371	59.2811
Cs-137	7.9029	39.6204
Ba-133	5.1621	23.8970
Na-22	0.9641	17.8920

The CANBERRA 133NH30/5 He-3 Proportional counter was used as the detector, CANBERRA Model 2006 for preamplifier, Ortec`s 572A for amplifier, Ortec`s 556 for high voltage power supply and Ortec`s 919E for multichannel analyzer. The schematic of the experimental setup is presented in Fig. 3.

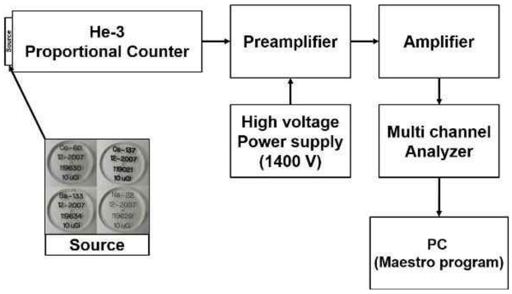

Fig. 3. Schematic view of the experimental setup.

2.4 Results of experiment

As the gamma ray exposure rate increased, more pile up occurred. As a result, the counts at the peak were increased (Fig. 4(a)) and the channel at which the spectrum ends moved to the right (Fig. 4(b)).

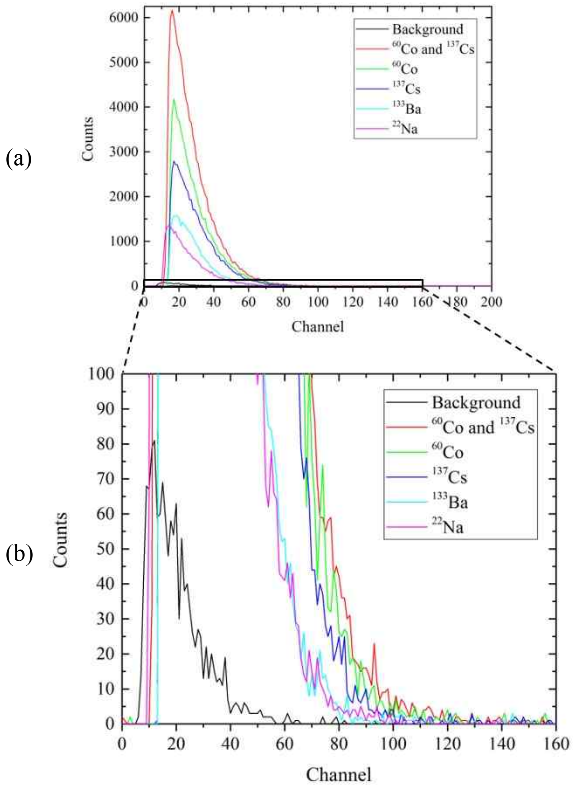

Fig. 4. (a) Pulse height spectrum of each source for He-3 proportional counter, and (b) that on an enlarged scale.

In particular, it was confirmed that the channel at which the spectrum ends (Last Ch) increases almost linearly with exposure rate as shown in Fig. 5. Conservatively, if we look at the result of Co-60 + Cs-137, which has the highest exposure rate of 98.9015 mR/h, there are few signals after 156 Ch. Therefore, in the environment below 98.9015 mR/h, 156 Ch (206.6 keV) can be applied as discrimination Ch. However, since this energy is larger than the 191 keV of neutrons theoretically present, the loss of the neutron signal is concerned and the neutrons can be underestimated. Taking this into account, we set a new discrimination Ch 133 Ch (176.1 keV) based on Co-60, the second highest exposure rate source. In the environment below 59.2811 mR/h, there is almost perfectly no gamma ray signal after 133 Ch. Even if applied to measuring environment of 98.9015 mR/h, about 99.8% gamma ray signals can be removed. Also, the loss of the neutron signal can be expected to be smaller. Thus, 133 Ch (176.1 keV) can be applied as discrimination Ch. Fig. 6 shows an example of applying a discrimination Ch in mixed neutron-gamma radiation field.

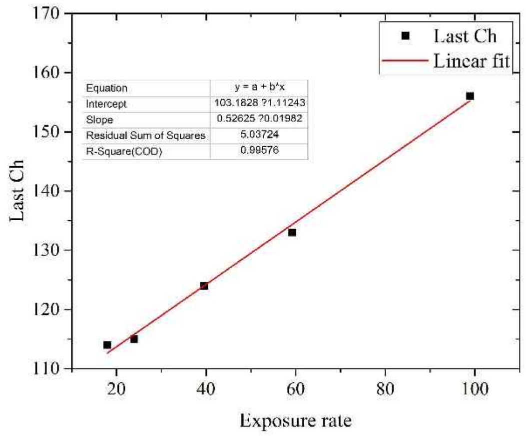

Fig. 5. A graph of the channel at which the spectrum ends (Last Ch) of gamma ray with increasing exposure rate

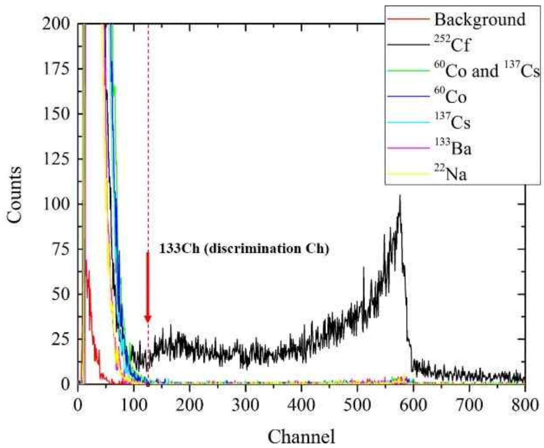

Fig. 6. Example of applying a discrimination Ch in mixed neutron-gamma radiation field.

3. Conclusion

As a result of the experiment, it was confirmed that there is almost no gamma ray signal after 133 Ch (176.1 keV) at the exposure rate not exceeding 59.1811 mR/h. In conclusion, it is considered that the signal below the Ch can be regarded as the gamma ray signal and can be separated. Even if applied to the environment of 98.9015 mR/h which is corresponding to the exposure rate from Co-60+Cs-137, about 99.8% gamma ray signals can be separated.

Considering that the number of sites in the nuclear power plant is less than 7 mR/h and the average annual gamma ray exposure rate in the area around the power plant is about 10.6~17.7 μR/h [5-6], the discrimination Ch of this study will be applied to the development of the neutron survey meter.

In the future, we will examine how neutron signals are lost when the discrimination Ch is used through experiments and simulations using neutron sources without gamma rays. In addition, the change of the spectrum shape will be confirmed as the change of the exposure rate using more various sources.

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