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Calibration Measurements for the Efficiency and Response Function of the NE213 Scintillator by a ^{252}Cf Spontaneous Fission Source—Application of a Two-Dimensional Pulse Height Analysis System

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Abstract—**This paper describes calibration measurements for the efficiency and response function of the NE213 scintillator as an application of a two-dimensional pulse height analysis system. In this method, a ^{252}Cf spontaneous fission source with a continuous spectrum is employed by taking each fission event as a pulsed neutron source, and the efficiency and response function of the NE213 scintillator can be estimated by the two-dimensional measurements of the time-of-flight spectrum (neutron energy spectrum) and pulse height spectrum.**

I. Introduction

THE efficiency and response function of the NE213 liquid scintillator (proton recoil detector) is a very important factor in spectrum measurement of fast neutrons because the efficiency of the detector affects the accuracy of the energy spectrum obtained by the neutron time-of-flight method, and a good response function is needed when estimating the final energy spectrum by the unfolding process from the measurement of the pulse height distribution by a recoil proton detector. Calibration measurements for the efficiency and response function of the NE213 scintillator are described here as an application of the two-dimensional pulse height analysis system developed around a personal computer for the spectral measurement of fast neutrons.

Much work has been done to estimate the efficiency and response function of the NE213, usually experimentally by a monoenergetic fast neutron source such as a Van de Graaff accelerator [1], [2]. However, this method needs complex apparatus and many energy points. Therefore, response functions are mainly obtained by Monte Carlo estimation such as the O5S code [3]. They do not give perfect results because of detector imperfections in relation to the characteristics of the light yield by the proton, among other reasons. It is still necessary to make experimental measurements as there are systematic differences, even for the same type of detector, depending on the light connection between the scintillator and the photomultiplier.

We have developed an experimental calibration method for the efficiency and response function of the NE213 liquid scintillator using a two-dimensional pulse height analyzer and a fast neutron source which produces a continuous neutron spectrum such as a ^{252}Cf spontaneous fission source [4]–[6]. In this method, the detection efficiency and response function of the NE213 can be easily derived using the known neutron spectrum from the source.

II. Experimental

A. Experimental Apparatus and Methods

In the developed calibration method, the ^{252}Cf spontaneous fission source is used as a pulsed neutron source by taking each fission event, and the efficiency and response function of the NE213 scintillator is estimated by the two-dimensional measurement for the time-of-flight spectrum (neutron energy spectrum) and pulse height spectrum.

A block diagram of the calibration measurement system for the efficiency and response function is shown in Fig. 1. The time of a fission event is indicated by the detection of a neutron or a γ ray emitted by the NE102 detector set near the ^{252}Cf spontaneous fission source. On the other hand, a neutron evolved from the fission is detected by the NE213 detector, located some distance from the source.

The time interval between the two signals was analyzed by the time-to-pulse-height converter (TPHC), and the output signal from the TPHC was fed as an x-input signal into the two-dimensional multichannel analyzer. The flight time (i.e., the energy of the neutron) is measured by this method. Simultaneously, the pulse height signal from the NE213 detector feeds a y-input signal into the two-dimensional multichannel pulse height analyzer. The pulse height distribution of the NE213 detector for each neutron energy is thereby estimated by the simultaneous measurement of the neutron

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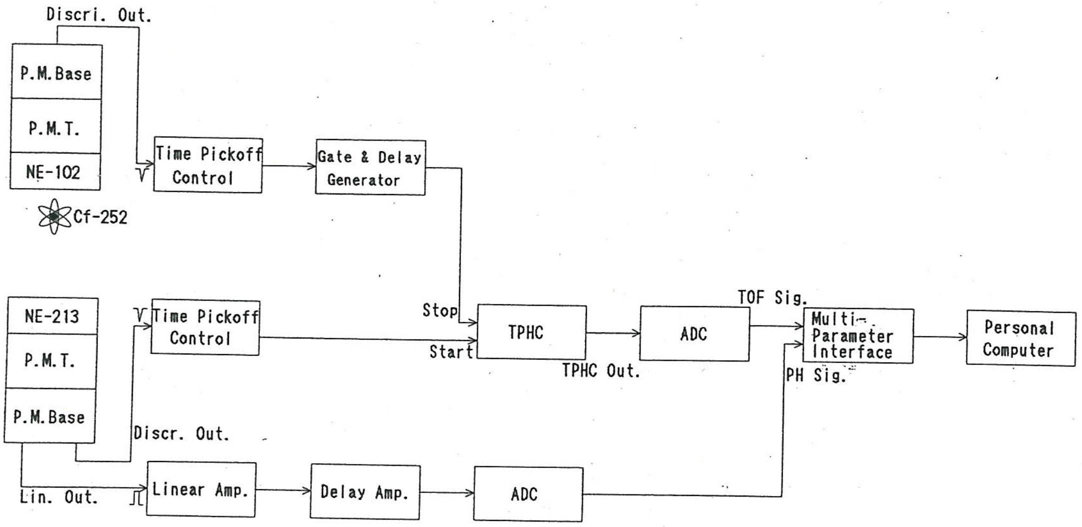

Fig. 1. Block diagram of the electric circuit.

energy (i.e., the time of flight) and the pulse height. The detection efficiency and the response function can be obtained by comparing the pulse height distribution for each energy with the known spontaneous fission neutron spectrum for ^{252}Cf.

To eliminate unnecessary TPHC responses, the few usable output signals of the NE213 were employed as the start signal for the TPHC, and the stop signal was fed as an NE102 signal through the delay generator, thereby producing a reversed time scale.

The final result with this calibration method is obtained by comparing with the prompt neutron spectrum of the ^{252}Cf spontaneous fission source. Therefore, the accuracy of the ^{252}Cf fission spectrum is important. Much data concerning the fission spectrum were obtained, and they showed good agreement, especially in the energy interval 0.25–8 MeV range where the accuracy was within 5% [7]. The distribution shows a Maxwellian shape, with an average energy of 2.13 ± 0.027 MeV [8], [9]. This is represented in the following equation:

$$\chi(E) \propto \sqrt{E} \cdot \exp(-E/T). \qquad (1)$$

Here, $\chi(E)$ is an energy distribution, T is the temperature parameter, and E is energy. We used a T value of 1.42 MeV for the data processing.

B. Measurement

We employed the two-dimensional simultaneous measurement of the dual parameter for the pulse height and neutron flight time. The distance between 30 μCi of the intensity ^{252}Cf source and the detector was fixed to 150 cm; the time of flight through the distance corresponds to the neutron energy. We put the source and detectors on a table 1.5 m above the floor in order to reduce the scattered background. We estimated the scattered background by subtracting it from the foreground spectrum which was obtained by holding a 1 m iron and graphite shadow cone between the source and the detector.

A common mode of application of proton recoil detectors is set at a finite discrimination level (bias) to eliminate all the pulse amplitudes below a given pulse height. This discrimination process eliminates noise pulses that arise spontaneously in the counting system, and inevitably some recoil events [10]. We evaluated the effect of bias level on the efficiency of the proton recoil detector and the response functions by measurements for various bias levels.

The scintillation response caused by electrons is fairly linear. Therefore, gamma ray sources such as ^{60}Co were used to calibrate the energy scale of the detector output. The Compton edge, defined as the channel where the rate is half the maximum count rate at the peak of the edge, was assigned the value of one light unit.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Figs. 2 and 3 show measured results for a $5''\phi \times 5''t$ NE213 liquid scintillator, presented as a contour (original photograph is a 16-color map) and an isometric display. All measured data are described in Fig. 2, but the x-axis data (time-of-flight and, therefore, energy data) which were sampled at all 16 channels are shown in Fig. 3. The appearance of the output pulse height distribution for the NE213 detector to various neutron energies is well understood from Fig. 3.

The time of flight spectrum at various bias levels is shown in Fig. 4. Fig. 5 shows the detection efficiency for some bias levels obtained from the time-of-flight spectra subtracted from the background counts such as neutrons unrelated to the observed fission, γ rays, and thermionic noise from the photomultiplier and electric noise from the circuits. The effect of bias level on counting efficiency is shown graphically in Fig. 6. The ratio of the rejected pulse of protons below the bias level increases at pulses by the lower energy neutron.

The response function of a bias level of a 0.085 ^{60}Co light unit is shown in Fig. 7. The solid line represents the response function for this type of NE213 detector obtained by the O5S Monte Carlo code; the calculated results show good agreement with the experimental results. It may be considered that

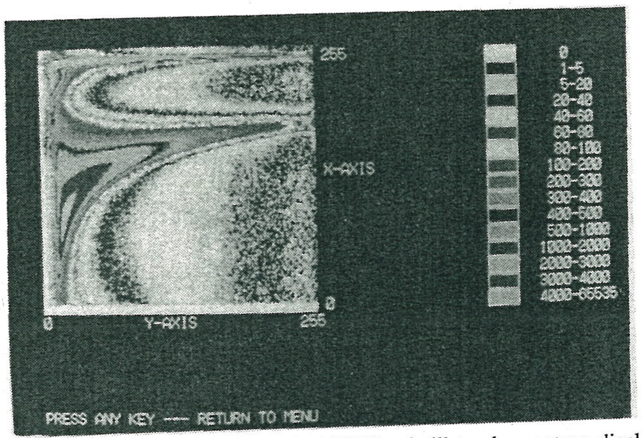

Fig. 2. Response functions for the NE213 scintillator by contour display (original photograph is a 16-color map).

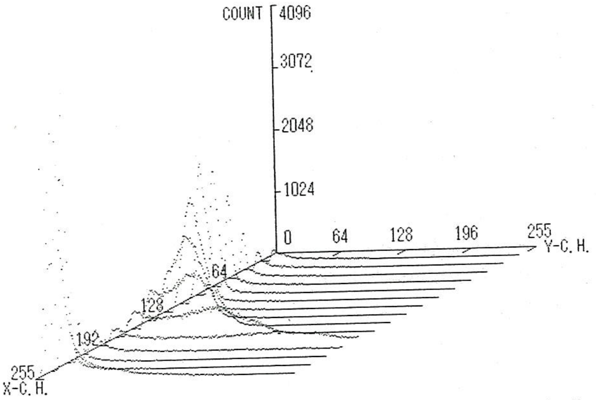

Fig. 3. Response functions for the NE213 scintillator by isometric display.

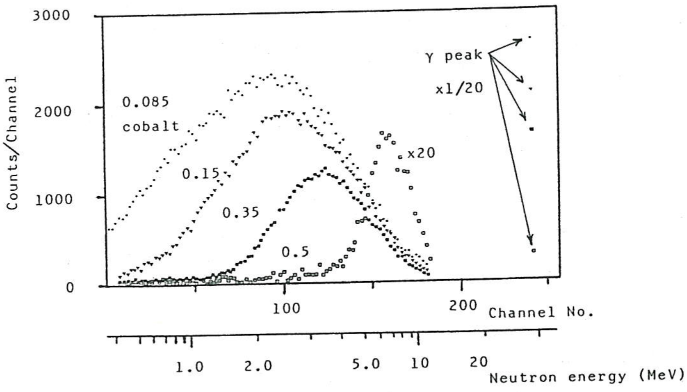

Fig. 4. Time-of-flight spectra of ^{252}Cf fission neutrons at several bias levels.

the deviation in the low pulse height region was caused by the small change in bias level, and the deviation in the high pulse height region was caused by the noise.

The accuracy of the results obtained by this method depends on both the accuracy of the source spectrum and the extent of the component unrelated to the objective fission event. This also depends on the source intensity and the bias level. Decay emissions from the 100 μCi ^{252}Cf source occur every 270 ns on the average. If we can observe only the reaction of the fission, there may be one decay every 9.0 μs (3% in the decays). With a 200 ns analyzing time (up to 294 keV of neutron energy can be analyzed at a 1.5 m flight distance), it is possible to use about 100 μCi of source intensity when detecting all emitted γ rays following α decay (97% of ^{252}Cf decay). The γ ray energy caused from an α decay is 156, 100, and 43 keV. Less than 30% of the γ ray emissions for 156 and 100 keV are detected with the 0.085

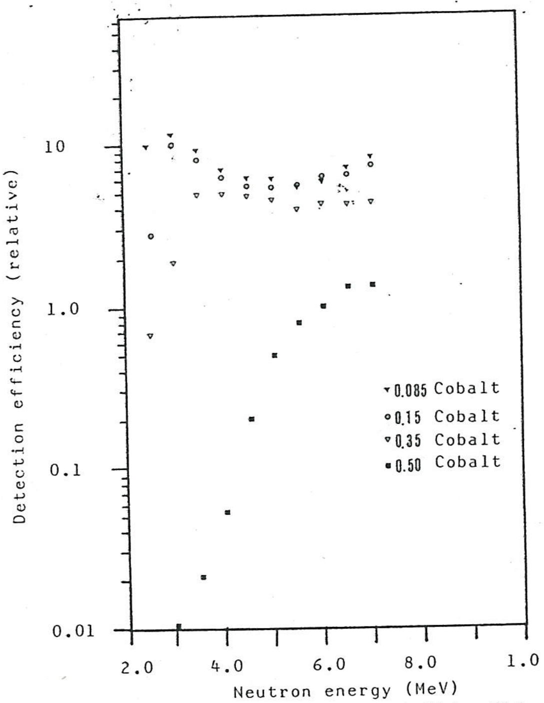

Fig. 5. Detection efficiencies of NE213 (5″ ϕ × 5″ t).

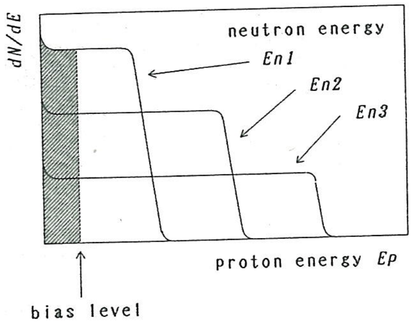

Fig. 6. Effect of bias level on proton recoil detector efficiency.

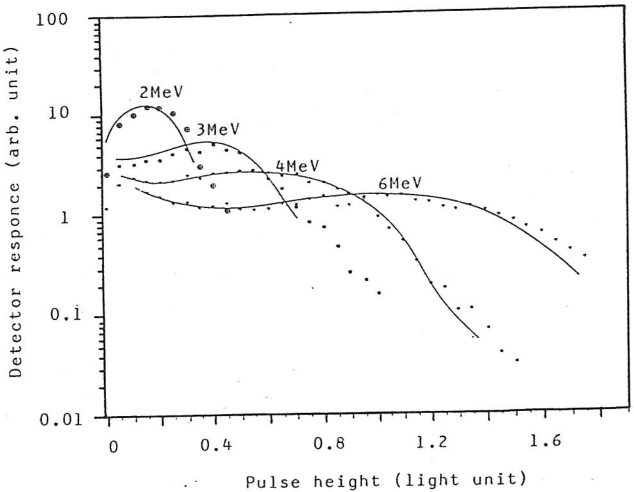

Fig. 7. Response functions for various energy neutrons along the axis of the 5″ ϕ × 5″ t NE213 scintillator.

^{60}Co light unit at the bias level setting. Furthermore, the detection number decreases more rapidly with the solid angle between the detector and the source, and source intensities up to 1 mCi should be used.

IV. CONCLUSION

Experimental evaluation of the detection efficiency and the response function was simultaneously performed by the two-dimensional pulse height analysis system, even by a neutron source having a continuous spectrum such as ^{252}Cf. The radioisotope of ^{252}Cf enables stable measurement for long periods, different from an accelerator, and it can be used below 100 μCi of source intensity. This method also has the advantage of easy calibration under the experimental conditions where the detection system is employed. The accuracy of the results depends on the ^{252}Cf source spectrum, and good accuracy may be expected when considering published values of the ^{252}Cf prompt fission spectrum.

APPENDIX I

The NE213 scintillator is frequently used in spectrum measurements of fast neutrons, especially as a detector in the MeV energy region. Recently, it has frequently been used for such measurements in the field of neutron measurements for nuclear fusion reactors [11], [12]. The detector was made of a mixed solvent dissolved POPOP (1,4-di-(2-5-phenyloxazolyl)-benzene) as the wavelength shifter in a Xylene and Naphthalene solution, and light emissions by recoil protons were used for neutron detection. When response functions to the various monoenergetic neutrons are obtained, the neutron energy spectrum can be estimated by unfolding the pulse height distribution. This method is suitable for time measurements and is possible for the two-dimensional measurements because of the very short time of fluorescence decay. The decay time of the detector has a fast component when excited with gamma rays and a slower component when excited with neutrons; the long component increases with incident particle mass. It may be possible to eliminate γ rays by using a pulse shape discriminator.

APPENDIX II

The prompt neutron spectrum of a ^{252}Cf fission source is usually shown with a Maxwellian distribution. But the National Bureau of Standards (NBS) of the U.S. has suggested that Maxwellian distributions should be multiplied by $\mu(E)$; however, this difference is small for a Maxwellian distribution, and the values coincide below 10 MeV of neutron energy [13].

$$\chi(E) = \mu(E) \cdot 0.6672\sqrt{E}\,\exp(-1.5E/2.13) \quad \text{(A1)}$$

Region	$\mu(E)$
0–0.25	$1 + 1.20E - 0.237$
0.25–0.8	$1 - 0.14E + 0.098$
0.8–1.5	$1 + 0.024E - 0.0332$
1.5–6.0	$1 - 0.0006E + 0.0037$
6.0–∞	$1.0\exp[-0.03(E - 6.0)/1.0]$.

The Watt distribution is rarely used. Magruno employed a comparatively hard high average energy Watt distribution in ENDF/B-V [14].

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REFERENCES

[1] V. V. Verbinski, W. R. Burus, T. A. Love, W. Zobel, N. W. Hill, and R. Textor, "Calibration of an organic scintillator for neutron spectrometry," *Nucl. Instrum. Methods*, vol. 65, pp. 8–25, 1968.

[2] Y. Uwamino, K. Shin, M. Fujii, and T. Nakamura, "Light output and response function of an NE-213 scintillator to neutrons up to 100 MeV," *Nucl. Instrum. Methods*, vol. 204, pp. 179–189, 1982.

[3] R. E. Textor and V. V. Verbinski, "O5S: A Monte Carlo code for calculating pulse height distributions due to monoenergetic neutrons incident on organic scintillators," ORNL-4160, Oak Ridge National Laboratory, TN, 1968.

[4] I. Kimura, "Prompt fission neutron spectrum" (in Japanese), *JAERI-M 9999*, pp. 35–55, 1982.

[5] T. Akimoto, "LINAC-TOF experiments in Hokkaido University" (in Japanese), Nucl. Eng. Res. Lab., Faculty of Eng., Univ. Tokyo, Tokyo, Japan, Rep. UTNL-R-0122, pp. 9–18, 1982.

[6] T. Akimoto, I. Murai, S. Chaki, Y. Ogawa, and I. Shoji, "A dual-parameter multichannel analyzer using a personal computer," *IEEE Trans. Nucl. Sci.*, vol. 36, no. 3, pp. 1354–1358, June 1989.

[7] H. H. Knitter, "A review on standard fission neutron spectra of ^{235}U and ^{252}Cf," *IAEA-208*, vol. 1, pp. 183–195, 1978.

[8] H. H. Knitter, A. Paulsen, H. Liskien, and M. M. Islam, "Measurements of the neutron energy spectrum of the spontaneous fission of ^{252}Cf," *Atomkernenergie*, vol. 22, pp. 84–86, 1973.

[9] L. Green, J. A. Mitchell, and N. M. Steen, "The Californium-252 fission spectrum from 0.5 to 13 MeV," *Nucl. Sci. Eng.*, vol. 50, pp. 257–272, 1973.

[10] G. F. Knoll, *Radiation Detection and Measurement*. New York: Wiley, 1979.

[11] K. Sugiyama, K. Kanda, K. Iwasaki, M. Nakazawa, H. Hashikura, H. Sekimoto, S. Itoh, K. Sumita, and A. Takahashi, "Neutronic experiments in a 120 cm lithium sphere," *Fusion Technol.*, vol. 2, pp. 1375–1380, 1984.

[12] K. Sugiyama, K. Kanda, M. Nakazawa, H. Hashikura, H. Sekimoto, S. Itoh, K. Sumita, and A. Takahashi, "Integral experiments in a 120-cm lithium sphere," *Fusion Technol.*, vol. 8, pp. 1491–1496, 1985.

[13] J. Grundl and C. Eisenhauer, "Fission rate measurements for materials neutron dosimetry in reactor environments," in *Proc. ASTM/EURATOM Symp. Reactor Dosimetry*, EUR-5667, part 1, 1977, pp. 425–454.

[14] B. A. Magruno, "Status of data testing of ENDF/B-V reactor dosimetry file," in *Proc. 3rd ASTM/EURATOM Symp. Reactor Dosimetry*, EUR-6313, vol. 2, 1980, pp. 903–913.