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Neutron Spectrometric Analysis: Characterization of ^{3}He Detector Response and Chemometric Data Analysis of Pulse-Height Spectra

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1. Introduction

Among many nucleonic gauges using a variety of sources such as alpha, beta, gamma, neutron or X-ray radiation, neutron-based techniques have been successfully used in landmine detection, cargo inspection and soil analysis as well as in the industrial process monitoring such as cement, glass, coal industries, etc [1-8]. In general, there are three categories of neutron-based methods: fast neutron analysis (FNA), thermal neutron analysis (TNA) and neutron moderation. FNA and TNA utilize the slow or fast neutrons for the generation of characteristic prompt gamma-ray to identify the element of interest in many applications. The neutron moderation is attractive for the process monitoring of the moisture content in the bulk samples [1,2]. In spite of its many advantages, the false-alarm rate of the neutron method is of great interest in the field operations. Detector response in neutron spectrometry is dependent on many parameters such as impurities, bulk density, and distance between source and detector, etc. In addition, “wall effect” and “edge effect” should be taken into account in the analysis of the pulse height spectrum when the spectral data is obtained by using gas proportional counters because those effects are not predictable. Single channel analyzer (SCA) is simple but unable to predict random perturbations while spectral data obtained by using multi-channel analyzer (MCA) can be used to improve the accuracy of the neutron-based method.

In this study, ^{252}Cf was used as a radioisotopic neutron source, because ^{252}Cf shows rather high flux neutrons with a weak radioactivity. Pulse-height spectral data obtained by using ^{3}He gas proportional counter was analyzed by partial least-squares regression (PLSR) method as a multivariate data analysis tool.

2. Methods and Results

2.1 Experimental Setup for Neutron Method

^{252}Cf source was used as a radioisotope neutron source in this study, because it has a high specific activity, low background gamma-ray emission [6]. In the present study, there were no shielding materials like lead or cadmium between source and detector. Fig. 1 shows ^{252}Cf source stored in a stainless steel drum containing high-density polyethylene for a neutron shield. Neutron source moves to the top of the vertical port from the center of the drum pneumatically when measuring the samples. Neutron pulse-height spectrum was obtained by using a ^{3}He proportional counter (model types P4-0806-207 manufactured by Reuter-Stokes). ^{3}He proportional counter coupled to ORTEC NIM pulse counting modules was positioned at the certain distance from the neutron source in Fig. 1.

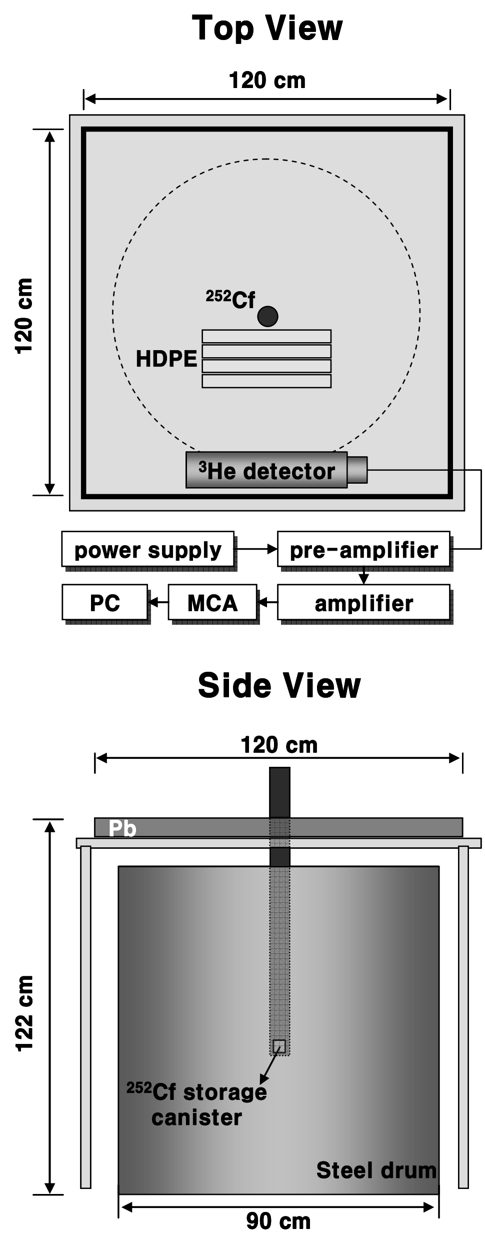

Fig. 1. Schematic Diagram of in-house developed neutron measurement system composed of source, detector, etc.

Polyethylene block placed between source and detector was investigated for characteristic detector response of ^{3}He proportional counter via the neutron transmission experiments. Thickness of polyethylene block was increased up to 20 cm.

2.2 Pulse-height Spectrum Measurement

Fig. 2 shows a typical pulse-height spectrum measured by using of ^{3}He proportional counter. When the detector tube is not sufficiently large enough to avoid the "wall-effect", all the reactions occurring near the wall cannot deposit the full kinetic energy of the reaction products. Low-energy "wall-effect" continuum from triton and proton is added to the pulse-height spectrum. The kinetic energy of the nuclear reaction product is determined by the Q-value, and Q-value of the following reaction in the gas proportional counter tube is 764 keV.

$$ {}^{3}_{2}He + {}^{1}_{0}n \rightarrow {}^{3}_{1}H + {}^{1}_{1}p \qquad (1) $$

Kinetic energies of oppositely directed triton and proton are 191 and 573, respectively, and therefore the wall-effect continuum by triton and proton extends from 191 and from 573, respectively, up to full energy peak at 764 keV.

As shown in Fig. 3, wall-effect continuum in the pulse-height spectrum appeared as the thickness of the polyethylene increased. Full energy peak corresponding to all the (n,p) reactions occurred at an energy equal to the sum of neutron energy and Q-value.

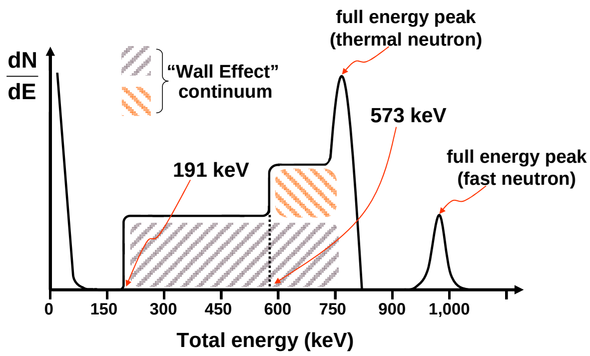

Fig. 2. A typical pulse-height spectrum from ^{3}He proportional counter in which there is a "wall-effect".

2.3 Partial Least-squares Regression (PLSR) Method

PLSR method was used to identify a quantitative relationship between thickness of polyethylene block and neutron pulse-height spectra. PLSR method could provide a good quality of the quantitative model over the wide range of thickness of polyethylene block, compared to the ordinary univariate data analysis by using SCA.

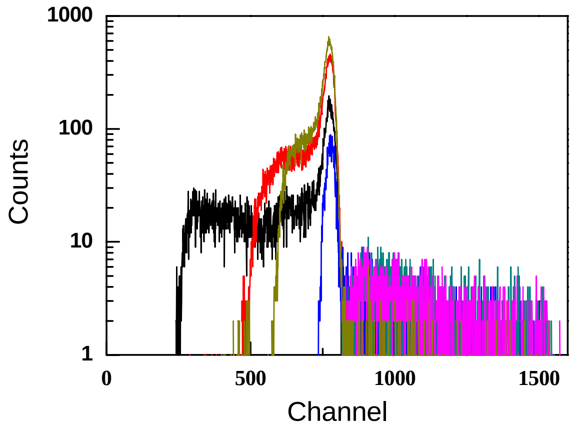

Fig. 3. Measured pulse-height spectrum of polyethylene block counting for 100 seconds.

3. Conclusions

The pulse-height spectrum was analyzed using ^{3}He proportional counter and polyethylene block as a representative hydrogenous material. ^{3}He detector response should be carefully examined as the thickness of the block increased above a certain value since the wall-effect continuum and full energy peak corresponding to the (n,p) reactions induced by the thermal neutrons generated via the elastic scattering of the neutrons by the hydrogen in polyethylene block.

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