

Low-energy neutron spectrometer using position sensitive proportional counter—Feasibility study based on numerical analysis

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Abstract

There is no direct technique to measure a neutron energy spectrum, particularly in the lower energy region, because the reaction Q value for detection is much larger than the neutron energy to be measured. However, such techniques are becoming a necessity, for example, in medical applications such as boron neutron capture therapy. In this study, a new spectrometer to measure low-energy neutrons (from thermal to 100 eV) is investigated numerically. We propose a unique approach of estimating the neutron energy spectrum by analyzing the distribution of neutron detection depths in the detector using an exact relation between the neutron energy and nuclear reaction cross-section. The proposed spectrometer has been established to be feasible to manufacture. The conversion performance of the neutron detection depth distribution to the neutron energy spectrum has also been proven to be acceptable, with the unfolding process based on Bayes' theorem, even though the detector response function is non-distinctive (without peaks or edges). The present spectrometer is now under development, and its practical performance will be reported as soon as the prototype detector is completed. © 2008 Elsevier B.V. All rights reserved.

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1. Introduction

There is no direct technique to measure the low-energy neutron spectrum. Measurements on thermal neutrons are generally performed using a proportional counter such as BF_3 and fission chamber. However, such detectors only indicate the detection of a neutron, since the nuclear reactions required to detect a neutron have a large Q value compared with the neutron energy to be measured. In other words, these detectors can be used to measure the energy spectrum of neutrons having high energies, comparable to or larger than the reaction Q value. Neutron detection is also possible with activation foils. However, the detection technique with the activation foils is available only by off-line analysis. Although the intensity of the neutron flux can be accurately measured by this method, it is not used to analyze neutron energy. A less common method of using

several types of foils having different resonance peaks can be employed to estimate the neutron spectrum. This method requires an unfolding process with a special code like SAND-II [1]. Usually, it is difficult to obtain an accurate spectrum with this method, because the unfolding process is regarded typically as an underdetermined problem, i.e., the number of foils is less than that of the energy bins. If a pulsed neutron source is used, a time-of-flight method can be adopted. In this method, a slightly complicated technique of processing detector signals is required to determine the neutron energy from the measured time-of-flight of the neutron. Sometimes correction of the neutron emission time from an object such as an experimental assembly existing between the neutron source and detector is necessary, but the resulting accuracy is high.

Measurement of a low-energy neutron spectrum has become crucial. Very few free neutrons exist in nature, most of which are created by the interaction of cosmic rays with air. Though they affect human bodies, their energy

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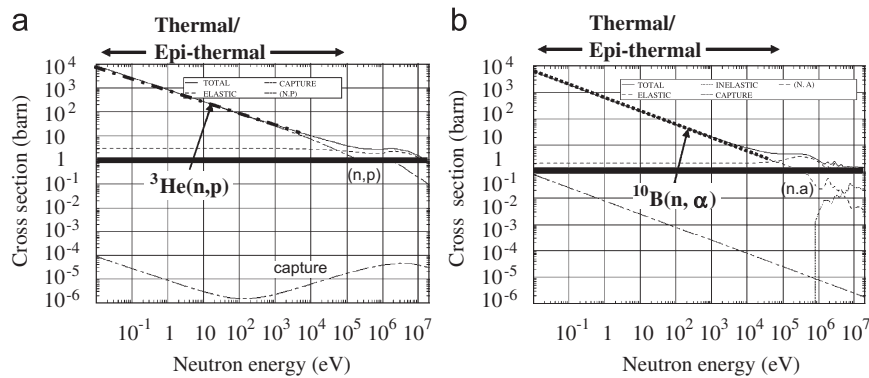


Fig. 1. Reaction cross-sections of (a) ^3He and (b) ^{10}B .

information is difficult to accurately ascertain. For example, even though the intensity was estimated using gold foil [2], a precise energy spectrum was not obtained. Considering possible radiation exposure by nuclear accidents like JCO accident [3], it is desirable to be able to measure and estimate the radiation dose accurately by considering the energy of the neutrons in the environment. In the case of nuclear physics experiments like nuclear data measurements, special techniques such as the time-of-flight method and crystal spectrometer are utilized. However, the measurement of the low-energy neutron spectrum over several decades with a simple detector is difficult. In addition, neutrons are recently beginning to be utilized for cancer therapy, i.e., boron neutron capture therapy (BNCT) [4]. New accelerators have been designed and will be constructed for producing thermal or epithermal neutrons, instead of conventional nuclear reactors [5]. New techniques will be required to accurately characterize the neutron field for BNCT.

In this study, a new spectrometer, to measure low-energy neutrons from thermal to 100 eV, is investigated numerically. The idea uniquely proposes that the neutron energy spectrum can be estimated by analyzing the distribution of neutron detection depths in the detector with the help of a definite relation between the neutron-nuclear reaction cross-section and the neutron energy. In the following sections, the principle of the detector and existing problems to be solved are described. Thereafter, the feasibility is discussed through precise numerical analyses, with an emphasis on the reproduction performance of the energy spectrum from the neutron detection depth (position) distribution in the detector.

2. Spectrometer details

2.1. Principle of the spectrometer

It is difficult to directly obtain data regarding the energy of low-energy neutrons. In this study, we consider another physical quantity which varies with the neutron energy. It is obvious that the neutron-nuclear cross-section can be used for this purpose, because it is a probability of neutron-

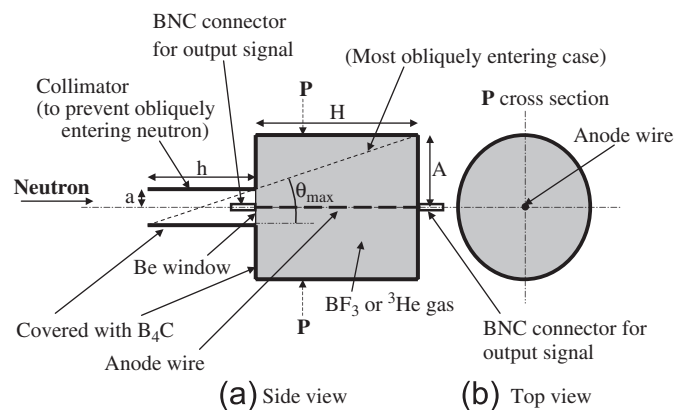


Fig. 2. Conceptual model of a low-energy neutron spectrometer, based on a position-sensitive proportional counter.

nuclear reaction with a nuclide, and this probability can vary depending on the neutron energy. The reaction position¹ can also vary in a neutron detector, depending on the neutron energy. If the reaction cross-section is larger, the distance from the detector entrance to the position at which the reaction occurs becomes smaller, and vice versa. In other words, the reaction position “distribution”, measured by the detector, varies with the incident neutron energy, because the reaction probability at depth r is expressed as $\Sigma \exp(-r\Sigma)$, where Σ is the neutron macroscopic cross-section in the detector. Now, selecting ^{10}B or ^3He as the detection medium, the neutron energy and the reaction cross-section share a one-to-one correspondence with respect to the low-energy region, as shown in Fig. 1. The one-to-one correspondence is crucial for determining the neutron energy from the reaction position distribution in the present spectrometer as explained later. Fortunately, ^{10}B and ^3He in gas are already available at present for a neutron detector.

Fig. 2 shows a basic neutron detector model. The detector is a proportional counter having one wire in a cylindrical casing. Because we wish to measure the reaction

¹The reaction position may not be the same as the detection position. This is discussed in Section 2.3.4.

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