Improved Neutron Diagnostics using Compton Suppression Gamma-ray Spectrometer with Self-absorption correction

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1. Introduction

Various neutron diagnostic systems have been installed at the Korea Superconducting Tokamak Advanced Research (KSTAR) for more accurate detection of neutron flux.[1, 2] Among the systems, the neutron activation system (NAS) is the most reliable and robust tool, and the measurement data of it generally are to be used for the calibration of other systems.[3, 4] Hence, minimizing measurement error of the neutron activation system is very important, because the error of activation system must affect the measurement of other diagnostic systems. In this study, the encapsulated indium samples were installed and irradiated by the neutrons released from the nuclear fusion reactions in KSTAR. The Compton suppression gamma ray spectrometer, which can suppress the expected background, noise signal and Compton scatterings was used to measure the gamma rays of neutron activated samples.[5] Additionally, indium sample gamma ray self-absorption effect has been estimated.

2. Methods and Results

A neutron measurement experiment was performed for the KSTAR plasma operation shot #14322.

2.1 Activation foil

Activation foils, i.e. 8 indium foils as disk type (1 mm thick, 20 mm diameter, natural isotopic abundance) in capsule were prepared for irradiation. The capsule was made of polyethylene with diameter of 28 mm, and length of 50 mm (fig. 1). After the irradiation, the capsule was transferred by pneumatic transfer system to the counting system.

2.2 Measurement and Compton suppression system

The radioactivities of the activated nuclides were measured using a hyper pure germanium detector (GEM-MX7080P4, ORTEC) which has a carbon fiber window to minimize the attenuation of low energy photons. Measured spectra were collected with a computer-based multichannel analyzer (MCA) card system, which can reproduce the gamma ray spectra by using the MAESTRO (ORTEC). The energy resolution of the detector is 1.9 keV full width at half maximum (FWHM) at the 1.33 MeV peak of ^{60}Co.

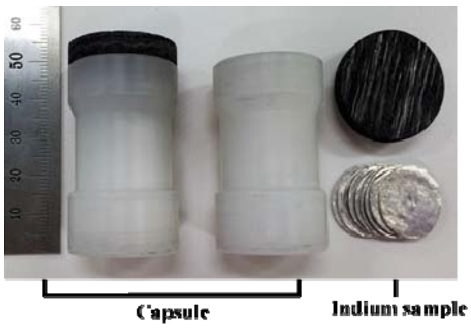

Fig. 1. Photograph of the capsule and indium foils.

NaI(Tl) guard detector was comprised of a cylindrical annulus with four Photo-multiplier Tubes (PMTs) (9HW9(4)2L-X, Saint-gobain), for efficient charge collection. The detectors are shielded by lead blocks in order to prevent the background radiations, and the HPGe detector cooled by an electrical cooler to reduce radiation noise. The MAESTRO-32 software (ORTEC) was used to collect the gamma-ray spectrum. Energy and efficiency calibrations of the counting system were performed using standard multi-nuclide sources which containing ^{241}Am (60 keV), ^{109}Cd (88 keV), ^{57}Co (112 keV), ^{123m}Te (159 keV), ^{51}Cr (320 keV), ^{113}Sn (392 keV), ^{85}Sr (514 keV), ^{137}Cs (662 keV), ^{88}Y (898 keV and 1836 keV) and ^{60}Co (1173keV and 1333 keV).

Measured absolute efficiency of the developed gamma spectrometer system. The spectrum fig. 2(a) shows the measured spectra of the calibrated multisource with and without Compton suppression. The plot fig. 2(b) is calculated absolute efficiencies from the measured spectra of multisource. It was found that the absolute efficiency at 336 keV measured by using the Compton suppressed system is about 3.81% and the not suppressed system is about 3.78 %.

2.3 Activation foil measurement

Activated indium foil was obtained from the KSTAR plasma operation shot #14322. The measurement spectra of the activated indium are show in fig. 3.

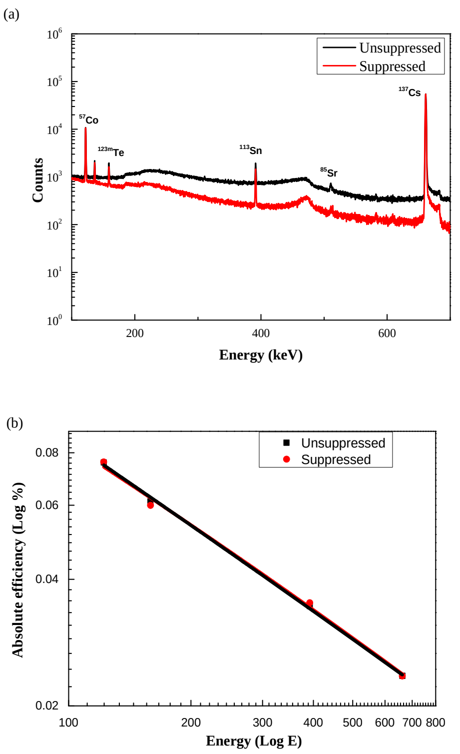

Fig. 2. (a) The measurement spectra which focusing the peaks from ^{57}Co (122 keV), ^{123m}Te (159 keV), ^{113}Sn (392 keV), ^{85}Sr (514 keV), ^{137}Cs (662 keV), and (b) the plots of absolute efficiency which was calculated by the interpolation of the measured absolute efficiencies of multi-nuclide source.

2.3 Activation foil measurement

Activated indium foil was obtained from the KSTAR plasma operation shot #14322. The measurement spectra of the activated indium are show in fig. 3.

The estimation of the neutron flux within the KSTAR from the measured data of activation sample can be performed with other's simulation result. This simulation result also provided the relation between the neutron flux at the irradiation end and the total neutron yield from KSTAR plasma [3].

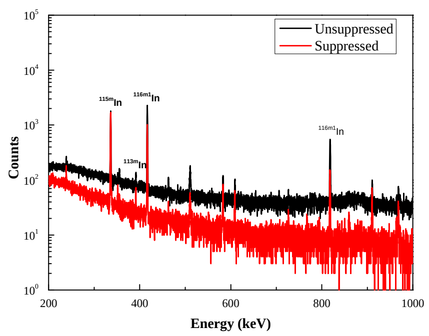

Fig. 3. The measurement spectra of activated indium foils by neutron.

The measurement spectra of the activation sample with and without Compton suppression. Based on the measurement data, the specific activity of indium foils irradiated by the neutron flux was calculated, and the result is 541.3 Bq/g and 543.0 Bq/g with and without Compton suppression, respectively.

2.4 Self-absorption effect calculation

The Monte Carlo N-Particle Transport Code 2.7.0 (MCNP 2.7.0) was used for self-absorption correction by calculating probability of un-attenuated 336 keV gamma-ray. It was calculated with the assumption that the sample was uniformly radio-activated, and the 336 keV gamma-ray has been produced along z-axis (fig. 4).

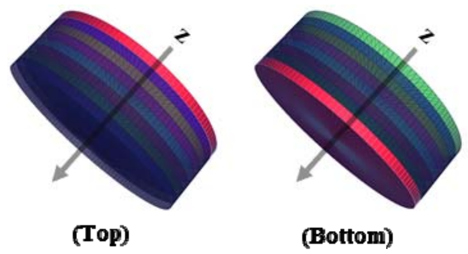

Fig. 4. The geometry of indium samples used in calculating self-absorption effect with source location only on the top and the bottom shown in red.

The calculation result shown in Table 1. 43.2 % of gamma-ray is lost, when produced in the top 0.8 mm portion and 3.7 % of gamma-ray is lost, when produced in the bottom 0.8 mm portion by self-absorption. Gamma-ray self-absorption effect in indium foils was corrected in this experiment. Considering all the indium foil volume from the top to the bottom portions, 24.9 % of gamma-ray has been calculated as attenuated.

Table I: The calculation result of the probability with un-attenuated 336 keV gamma ray.

Source location	Probability
Top	56.80 %
Bottom	96.30 %
All	75.10 %

The specific activity of indium sample irradiated by the neutron flux was calculated, and the result is 720.8 Bq/g and 723.0 Bq/g with and without Compton suppression respectively.

The statistical error of peak is reduced from 3.9 % of not suppressed to 2.3 % of Compton suppressed. An experimental measurement of neutron flux within KSTAR was performed during the KSTAR operation shot #14322 using the developed Compton suppression gamma spectrometer. A 9.03 g of indium pellet was used as the activation sample, and the estimated averaged total neutron yield was 1.40E+14 n/s. The statistical error of the measured sample activity in the Compton suppressed system was estimated to be about 2.3 % from the counting error (0.26 %) and the detector efficiency error (2.34 %), and the statistical error of the measured sample activity in the not suppressed system was estimated to be about 3.9 % (from the counting error 0.26 % and the detector efficiency error 3.9 %) which is decreased than Compton suppressed system.

3. Conclusions

The Compton suppression system has been used to detect the gamma rays from neutron activated indium foils for reducing the measurement errors. From the experimental results, the statistical error was decreased by Compton suppression system. It was found that the system could reduce the measurement error effectively. Therefore, it is concluded that introducing the Compton suppression system for NAS, more accurate measurement is possible. This method has been successfully used for KSTAR, and will be implemented at International Thermonuclear Experimental Reactor (ITER) and ITER Test Blanket Module (TBM).

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