# Measurement of secondary gamma-ray production cross sections of structural materials for fusion reactor

## —Extraction of discrete and continuum components—

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Abstract

A new method to deal with measured spectrum of secondary gamma-rays induced by D-T neutrons with Ge detector is proposed. Subtracting background components and discrete peaks from the raw secondary gamma-ray spectrum, the continuum component of secondary gamma-ray was successfully extracted. By using unfolding process, the continuum component of the secondary gamma-ray production cross section was derived. The measured cross section data obtained by this method are very useful for precise evaluation of secondary gamma-ray production cross sections.

## 1. Introduction

In a fusion reactor design, secondary gamma-ray production cross section data are important because of the necessity of estimations for nuclear heating, radiation damage, radiation exposure, and so on. The experimental data are discrete gamma-rays($S_{DC}$ ) obtained with Ge detector or continuum energy spectrum($S_{NaI}$) with NaI detector. In nuclear data files, continuum spectra are mainly included considering the measured continuum spectra($S_{NaI}$) with NaI detector. Because with Ge detector, only prominent discrete gamma-rays can be measured, but residual continuum component($S_{CC}$) can not be extracted.

In the present study, we propose a new method to process a measured gamma-ray spectrum with Ge detector. At first, we separate gamma-rays induced by D-T neutrons into two components shown in Fig .1 : One is the discrete component($S_{DC}$) including relatively prominent discrete peaks. The other is the continuum component($S_{CC}$) which includes a continuous energy spectrum containing small discrete peaks. The gamma-ray spectrum for the latter has not been obtained experimentally. We extract these two data from the measured spectra with Ge detector by a special data processing procedure. The obtained data were compared with the theoretical calculation result with SINCROS-Ⅱ as well as the evaluated nuclear data. The calculation contained the effect of direct reactions calculated with DWUCKY. These measured data are very useful for precise evaluation of secondary gamma-ray production cross section, i.e., mixture of discrete and continuum components.

## 2. Experiment

Measurements of secondary gamma-ray production cross sections have been carried out at the D-T neutron source facility OKTAVIAN of Osaka University. We adopted the TOF method to separate prompt gamma-ray signals from the whole time spectrum. An HP-Ge detector was used as a gamma-ray detector. The Ge crystal volume was 177.9 $cm^3$. Elements which are considered as candidates of the structural material for the fusion reactor were chosen as sample materials. In the present paper, the result for vanadium was presented. The shape of the vanadium sample was a hollow cylinder(OD : 30 mm, ID : 26 mm, length : 70 mm). Using such a thin sample, we could suppress neutron multiple scattering and attenuation of produced gamma-rays in the sample.

The experimental arrangement is shown in Fig. 2. The scattering angle was fixed at 125 deg. so that we didn't have to consider the angular distribution for secondary gamma-rays to estimate the total gamma-ray production cross section. The detector was heavily shielded with lead, heavy concrete, polyethylene, and so on. With the electronic circuit shown in Fig. 3, we obtained foreground spectrum, background spectrum and TOF spectrum.

## 3. Measured spectra

Figures 4, 5a and 5b show TOF, foreground and background spectra, respectively. Utilizing the signals in the areas of FG and BG described in Fig.4, spectra for FG and BG were obtained as shown in Figs. 5a and 5b, respectively. In the foreground spectrum, several discrete gamma-rays were observed. Though some of them were background gamma-rays, the peaks from the vanadium sample could be found by comparing Fig. 5a with 5b, Besides gamma-rays from the sample, the FG spectrum contains time-independent background component(TIB) and time-dependent background component(TDB). The BG spectrum in Fig. 5b corresponds to the TIB component. Fig. 6 shows the sample-out FG spectrum which contains the TIB and TDB components. The TDB component was obtained with FG and BG spectrum in the sample-out measurement.

## 4. Data analysis

At the first step, we subtracted the TIB and TDB components from the foreground spectrum in the sample-in measurement to obtain the net foreground spectrum. Then the prominent discrete peaks were removed from the net foreground spectrum using the response functions of the peaks were calculated with MCNP-4B. The residual spectrum is shown in Fig. 7 together with the net foreground spectrum. On the second step, the spectrum was unfolded using the unfolding code HEPRO to obtain the $S_{CC}$ having only the continuum component.

## 5. Result and discussion

Experimental data of discrete gamma-ray production cross sections above 0.35 MeV are listed in Table 1 compared with the theoretical calculation result by the SINCROS-Ⅱ system and DWUCKY. The DWUCKY is based on the DWBA theory. The data includes the evaluated nuclear data in ENDF-B/Ⅵ not JENDL-3.2 because JENDL-3.2 includes just continuum energy spectra. In addition to them, the measured data were compared with the compiled data by S.P. Simakov et al[1]. Simakov's data were prepared by normalizing and averaging other experimental data which had been measured over the world. The calculation results supported our experimental value as a whole. On the other hand, Simakov's data deviated from our experimental data. Since the number of data which had been used to obtain the compiled data was very small, we concluded that some of his data were not reliable. ENDF-B/Ⅵ didn't have adequate discrete data to compare with ours.

Table 2 shows the total discrete data, the total continuum data and the total cross section data. And Fig. 8 shows the calculated energy differential cross sections together with our experimental data for the continuum component. In the table, discrete data are the sum of discrete cross sections above 0.35 MeV. We excepted the data for gamma-ray energies of 684, 815, 1777 and 2004 keV from the discrete data because these values could not be included in the theoretical calculation or Simakov's data. The experimental continuum data are obtained with the method developed in this study. It is noted that the present continuum value in Table 2 is preliminary. The energy region of the continuum and total cross section data is from 0.35 to 3.0 MeV. Evaluated data of JENDL-3.2 and ENDF-B/Ⅵ are also shown in the total cross section data. Our continuum and total cross section data are larger than the calculation result and ENDF-B/Ⅵ data. According to Fig. 8, our result shows a little larger data above 1 MeV. But we think that we could extract the $S_{CC}$ component successfully. Consequently, this method has a promising potential to enable to estimate the secondary gamma-ray production cross section data consisting mixture of discrete and continuum components from the measured spectra with Ge detector.

## 6. Conclusion

In design of a fusion reactor, secondary gamma-ray production cross section data are important. We introduced a new method to estimate discrete and continuum secondary gamma-ray production cross sections from the measured spectra with Ge detector. The procedure is as follows :

Step 1 : Subtracting TDB and TIB components from FG spectrum.

Step 2 : Removing dominant discrete peaks from net FG spectrum.(Then we got the residual Pulse Height Spectrum of $S_{CC}$ .)

Step 3 : Unfolding the PHS to obtain the $S_{CC}$ .

We applied this method to secondary gamma-ray spectra measurement of vanadium with an HP-Ge detector at the D-T neutron source facility OKTAVIAN. Though our result is not in agreement with the theoretical calculation result, by means of this method we will be able to estimate separately discrete and continuum components valuable for accurate evaluation of secondary gamma-ray production cross sections.


References :

[1] S.P. Simakov et al.
Report INDC(CCP)-413
IAEA (1998)


Table 1 **Discrete $\gamma$-ray Production Cross Sections above 0.35 MeV from vanadium sample**

| **energy** (keV) | **cross section(mb)** 125 deg. | Cal.* | S.P.Simakov | ENDF-B/VI |
|---|---|---|---|---|
| 684 | 21.9±2.7 | 27.6 | | |
| 815 | 3.1±1.0 | | 19±1.6 | |
| 836 | 10.7±1.5 | 19.2 | 31±3 | |
| 910 | 42.8±5.0 | 66 | 88±6.9 | |
| 929 | 38.0±4.3 | 51.6 | 49±2.4 | 0.9 |
| 946 | 10.0±1.4 | 5.5 | 19±1.5 | |
| 1090 | 65.7±6.6 | 58 | 60±2.4 | |
| 1121 | 3.6±1.0 | 3.0 | 13.4±1.5 | |
| 1174 | 18.8±3.5 | 1.5 | 20±1.9 | |
| 1437 | 17.2±2.0 | 17.6 | 18±2.9 | |
| 1494 | 13.8±1.7 | 13.5 | 17.1±2.8 | 0.1 |
| 1554 | 15.8±1.7 | 16.5 | 30.3±1.8 | |
| 1609 | 184±17 | 163 | 214±8 | 2.6 |
| 1777 | 10.0±1.3 | | 32.5±8.5 | 0.7 |
| 1813 | 46.9±4.7 | 47.8 | 68.1±4.4 | 0.7 |
| 2004 | 6.52±1.0 | | 11.6±3.8 | |
| 2334 | 6.97±1.0 | 1.69 | 17.3±1.7 | |

* : Theoretical Calculation with SINCROS-Ⅱ and DWUCKY