Measurement of (n,2n) reaction cross section using a 14MeV pencil beam source

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The method has been established to measure (n,2n) reaction cross section with the coincidence detection technique using a pencil beam DT neutron source at FNS, JAERI. Using a cylindrical manganese, the (n,2n) cross section was measured precisely with the foil activation method, was used to check the experimental method. It was confirmed from the experimental results that this method has been generally established. It is expected that complete (n,2n) reaction cross section measurements for elements producing stable-isotope by (n,2n) reaction are possible in combination with the coincidence detection and TOF methods.

1. Introduction

The (n,2n) reaction is of primary interest in the application for fusion reactors, because it is a neutron multiplication reaction and has a large cross section value for light and heavy nuclides in the energy range of several MeV to 14MeV. Number of elements, which (n,2n) cross sections were measured for, is less than half of the total number of stable isotopes, because in the past (n,2n) reaction cross section measurements, the foil activation method was generally used. This means that the measurement became difficult unless appropriate radioisotopes were produced by the reaction. In other words, by using the foil activation method, the (n,2n) reaction cross section of a certain nuclide can be measured. This means that if a sample element has two isotopes, the total measurement for the element is impossible in principle by the foil activation method.

On the other hand, there exist some other methods to obtain (n,2n) reaction cross section values[1)]; that is nuclide-dependent special methods such as the detection of charged-particles emitted following the (n,2n) reaction. For example, light elements such as beryllium, neutron multiplication measurements were done using a very large tank type scintillator to catch two neutrons by the (n,2n) reaction. The accuracy of those methods is however not so high compared with the activation method. Consequently, it seems that there is no method to accurately measure (n,2n) reaction cross sections available to every natural element. In

addition, especially for light elements such as beryllium, a little complicated neutron correlation between angular and energy distributions are expected. An appropriate method to measure such differential spectrum data was not reported so far. Such double differential cross sections of angle-energy correlation data are also very important for the fusion reactor design.

In the present study, using a beam-type DT neutron source at fusion neutronics source (FNS) of JAERI, the method was established to accurately measure (n,2n) reaction cross sections and its energy and angular distributions of simultaneously emitted two neutrons with the coincidence detection technique for all the existing elements, especially applying to elements having no experimental data.

2. Experimental

As well known, measurement of (n,2n) reaction cross section is possible in principle with the coincidence detection technique for two neutrons emitted simultaneously. However one must shield detectors to prevent direct neutrons from the source entering the detectors, the pencil beam DT neutrons was developed by making a narrow hole through a very thick shield between the target room and the measurement room as shown in **Fig.1**. The average neutron intensity is 1×10^6 neutrons/sec/cm^2 at the exit of the collimator. The neutron flux rapidly decreases outside the 2cmϕ beam region, therefore neutron detectors can be arranged near the sample without any material assemblies radiation shield. On the beam line at 60cm from the collimator, a small sample was positioned, that means the sample was placed at 350cm from the neutron source. At this sample position, neutron flux is about 0.9×10^6 neutrons/sec/cm^2. The dimension of the sample are 1.5cm$\phi\times$3cm long. Two spherical NE213 (40mmϕ) detectors were arranged, the distance between sample and detector was equally 10cm for two neutron detectors. (**Fig.2**)

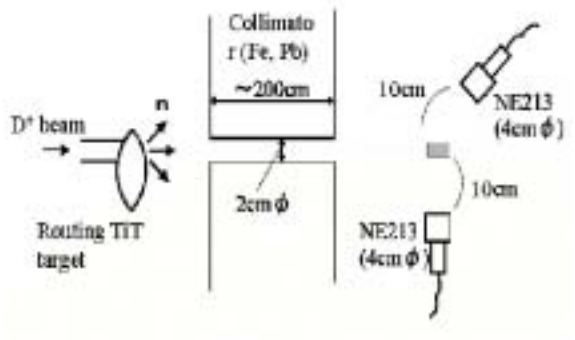

Fig.1 Experimental arrangement

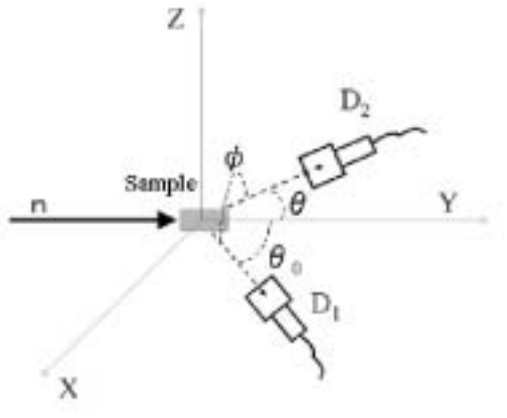

Fig.2 Arrangement of detectors and sample

The measurement was carried out with the coincidence detection technique and n/γ pulse shape discrimination technique to measure only two neutrons from (n,2n) reaction. The

former is a technique to selectively measure two particles emitted simultaneously such as two neutrons from (n,2n) reaction by coincidence detection. The (n,3n) reaction is also detected by this method, but it can be neglected because the threshold energy is mostly larger than 14MeV as shown in **Fig.3**. The latter technique was employed to exclude coincident signals of $n\gamma$ and $\gamma\gamma$ pairs through nuclear reactions such as $(n,n'\gamma)$, $(n,2n\gamma)$ etc by discriminating γ-ray signals with the rise-time spectrum of dynode signals. Two delay amplifiers with different gain were used to extend the dynamic range of the detector and to cover the range from 100keV to 10MeV. The electronic circuit used in the present experiment is shown in **Fig.4**.

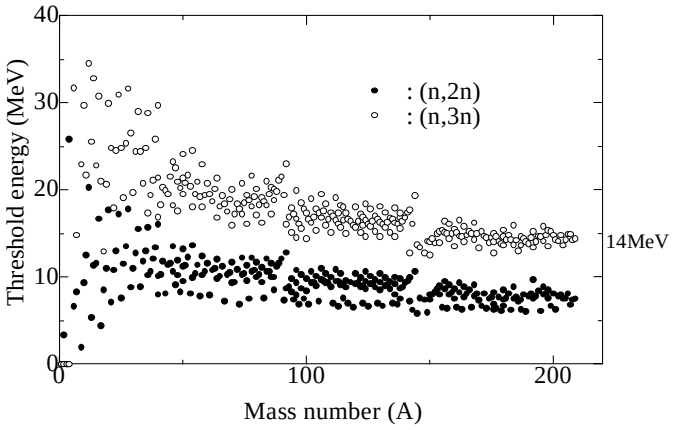

Fig.3 Threshold energy of (n,2n) and (n,3n) reaction

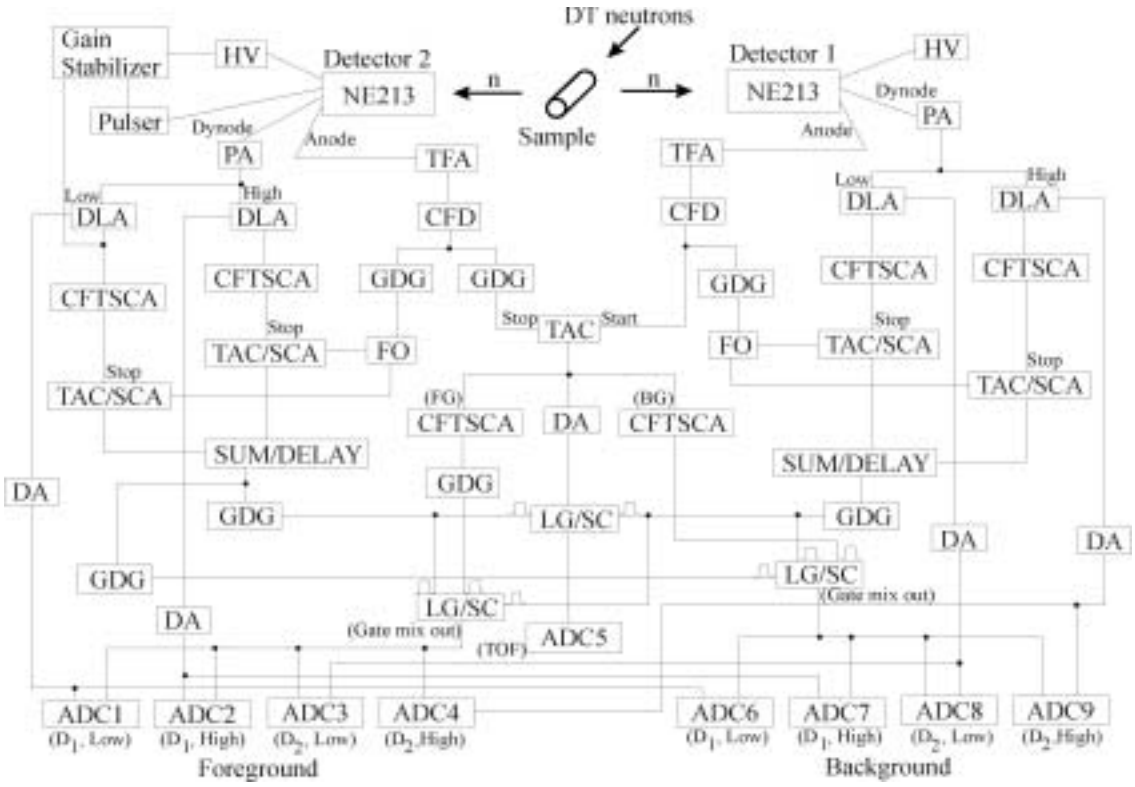

Fig.4 Electronic circuit of the (n,2n) reaction cross section measurement

Foreground (FG) and background (BG) indicated in the figure correspond to coincident and time-independent signals, respectively, as shown in **Fig.5**, which shows the time difference distribution between anode signals of the two NE213 detectors. A large peak

corresponding to the FG signals is found as coincident events of two of (n,2n) neutrons detected. Since the correlated neutrons are emitted simultaneously and so that their signals are of course detected almost simultaneously, a 250ns delay is added to one anode signal. The BG counts are successfully suppressed and a good S/N ratio was achieved. In the coincidence measurement, the time spectrum of anode signals of both detectors was measured with time-to-amplititude-convereter (TAC). And the correlated spectrum region was gated to detect only coincident signals. The dynode signals were fed to the pulse shape discrimination circuit including delay line amplifier, timing single channel analyzer and TAC, to exclude gamma-ray signals.

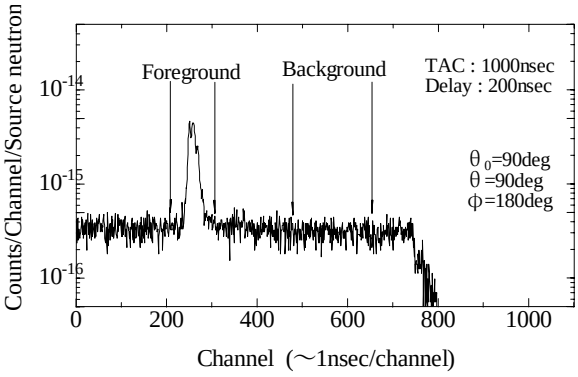

Fig.5 Time difference spectrum between anode signals of the two detectors

3. Data processing

The net raw neutron spectrum is deduced by the following equation:

$$y = y_{FG} - \alpha y_{BG}$$

where, y_{FG} and y_{BG} represent net raw foreground and background respectively, α is the ratio of the gate widths between FG and BG in the time difference spectrum of the two anode signals. The cross section can be obtained by the next equations:

$$N\sigma\phi\eta(d\Omega_1/4\pi)(d\Omega_2/4\pi)f_1 f_2 R_1 = y_1$$
$$N\sigma\phi\eta(d\Omega_2/4\pi)(d\Omega_1/4\pi)f_2 f_1 R_2 = y_2$$

where, N is the number of manganese atoms, σ is the (n,2n) reaction cross section, ϕ is the neutron flux at the sample, η is the neutron multiplicity of (n,2n) reaction, that is η=2, $d\Omega_1$, $d\Omega_2$ are solid angles of the detector1 and detector2, f_1, f_2 are the efficiencies of the detector1 and detcetor2, R_1, R_2 are the response functions of the detector1 and detector2, y_1, y_2 are the pulse height spectrum of the detectors, respectively.

The terms, $y_1R_1^{-1}$ and $y_2R_2^{-1}$ were calculated by the FORIST[2] unfolding code, and the detector efficiency and response functions were evaluated by the SCINFUL[3] code.

4. Results and discussion

Fig.6 and **Fig.7** show raw neutron pulse height spectra in low gain and high gain respectively. It is confirmed that the FG spectrum was sufficiently larger than that of BG by over one order of magnitude considering that the ratio was 1.8 times of the gate width difference between FG and BG.

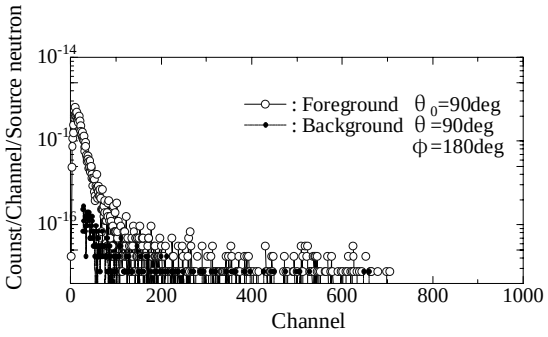

Fig.6 Raw neutron pulse height spectrum of low gain

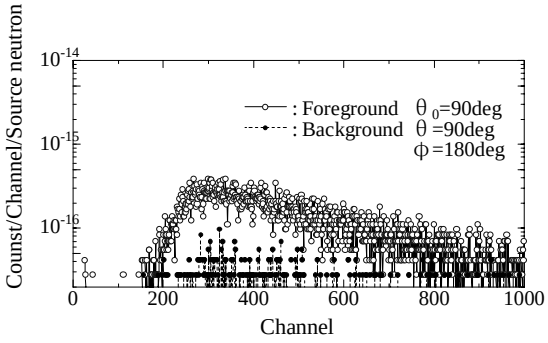

Fig.7 Raw neutron pulse height spectrum of high gain

Fig.8 shows neutron energy spectrum obtained by unfolding the pulse height spectrum with FORIST. In the figure, the error bars are not specified because the error bars are such large that the spectrum become not legible if specified. The one-σ values are found several tens percentages. However a fairly good agreement between experiment and JENDL fusion file is seen except for low energy region. The detector response matrix causes large discrepancies in the low energy region. Extrapolating the spectrum derived the cross section.

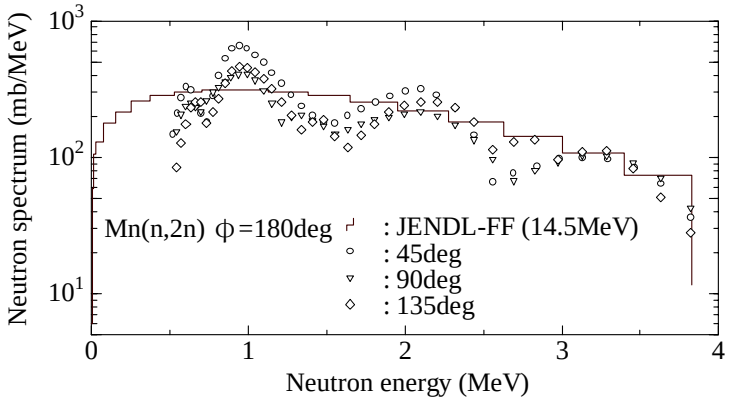

Fig.8 The energy spectrum of Mn(n,2n) reaction cross section

Fig.9 shows angular distribution for axial direction compared with the nuclear data of JENDL Fusion File. It seems that one can see a slightly forward oriented distribution. However, the accuracy is not so good as to conclude it. Nevertheless, the integral value, that is (n,2n) reaction cross section was obtained as 0.6 ± 0.1 barn.

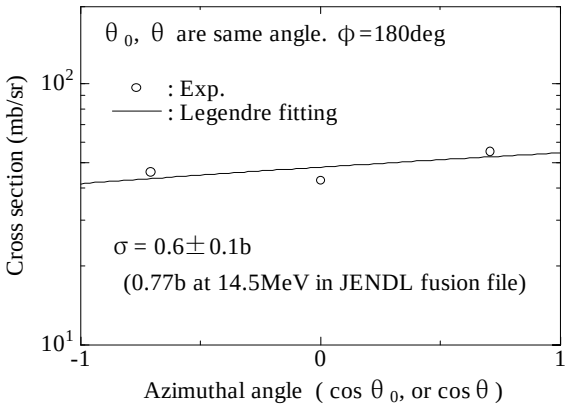

Fig.9 The angular distribution of Mn(n,2n) reaction cross section

5. Conclusion

Using a developed pencil beam DT neutron source at FNS of JAERI, the method has been established to measure (n,2n) reaction cross section and its energy and angular distributions of simultaneously emitted two neutrons with the coincidence detection technique. In the present measurement, the (n,2n) reaction cross section of manganese which is well known as measured repeatedly with the foil activation method was measured to check the experimental method. From the results, it was confirmed that the present method was basically successful to measure energy spectrum of two neutrons emitted through (n,2n) reaction, however one problem was found that the statistical accuracy was not sufficient to cover the whole angular correlation.

Reference

1) for example, see compiled data in EXFOR
2) R.H. Johnson et al., ORNL/RISC-40 (1976)
3) J.K.Dickens, ORNL-6462 (1988)