JP9950335

3.18 Measurement of secondary gamma-ray production cross sections of vanadium induced by D-T neutrons

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The secondary gamma-ray production cross sections of vanadium induced by D-T neutrons have been measured. The experimental values were compared with the theoretical calculation results by SINCROS-Ⅱ and the evaluation result based on experimental data compiled by Simakov. The calculation results supported our data, while Simakov's evaluation did not agree with the present result very well.

1. Introduction

Vanadium is a candidate element for the structural material of the fusion power reactor, because of its low activation property. Concerning this, at JAERI[1] and Osaka University[2], neutronics experiments such as neutron integral experiment and measurement of charged particle emission reaction cross section were done for vanadium. In the present study, the secondary gamma-ray production cross sections of vanadium induced by D-T neutrons have been measured because there exist very few measurements of secondary gamma-ray data of vanadium. The measured raw data were corrected carefully considering the sample size and air attenuation. The theoretical calculations for the cross sections were done to compare with the measured data.

2. Experimental Techniques

The measurement was carried out using OKTAVIAN pulse line at Osaka University as D-T neutron source. The pulse frequency and beam current were 2MHz and about 10μA, respectively. An HP-Ge semiconductor detector was used to measure gamma-rays with a high energy resolution. The absolute value of neutron flux was determined by the activation method with Al foils, and the relative value was monitored by using NE213 scintillator. Fig.1 shows the experimental geometry. The sample shape was a hollow cylinder(30mm-OD,26mm-ID,70mm in length) in order to suppress neutron multiple scattering and attenuation of produced gamma-rays in the sample. The flight path for the TOF measurement was 184cm. Fig.2 shows the block diagram of electronic circuits. Gamma-ray scattering angle was fixed at 125deg. so that we didn't have to consider the angular distribution for secondary gamma-rays to estimate the total gamma-rays production cross sections. The HP-Ge detector was shielded heavily by lead, polyethylene, heavy concrete, cadmium, and so on.

3. Measured Pulse Height Spectra

Figs.3, 4a and 4b show the TOF spectrum, foreground spectrum and background spectrum, respectively. As shown in Fig.3, the time interval between n-signal and γ-signal was about 30ns. Extracting the signals in the regions of FG and BG described in Fig.3, foreground and background spectra were obtained as in Figs.4a and 4b. We can find discrete gamma-rays from vanadium in Fig.4a by comparing with 4b.

4. Data Analysis

The data analysis was done as follows:

(1) Data corrections by MCNP-4A and absorption coefficient for air
(2) Derivation of experimental values
(3) Theoretical calculation with SINCROS-Ⅱ
(4) Comparison with other experimental data

(1) Data corrections

For deriving the gamma-ray production cross sections from vanadium, some corrections were considered. We calculated the effect of neutron multiple scattering and gamma-ray attenuation in the sample as a function of the sample thickness by using MCNP-4A. The result is shown in Fig.5. The correction factor is 12.7% for the present sample, the thickness of which is 2mm. Gamma-ray attenuation by air was also corrected with the absorption coefficient. The correction factor is 1.8% at 500keV and 1.3% at 1MeV for example. The correction factor for air is shown in Fig.6.

(2)Derivation of experimental values

①Gamma-ray Production Cross Sections

The cross sections were obtained using the following expression:

$$\sigma = \frac{C \cdot 4\pi R^2}{T \cdot N \cdot \phi \cdot S \cdot f}$$

where

C: net counts of the peak in the pulse height spectrum
T: measurement time (sec)
f: intrinsic efficiency for HP-Ge detector
R: distance between sample and detector (cm)
Φ: neutron flux at the sample($cm^{-2} \cdot s^{-1}$)
S: active area of the detector facing toward the sample(cm^2)
N: number of V-51 nuclei

The neutron flux at the sample was measured by using the activation method with Al foils. The average neutron flux was estimated to be 4.0×10^4 n/sec/cm^2.

②Uncertainties

The experimental results had uncertainties based on several factors. These factors were assumed to introduce independent random errors. Therefore the overall uncertainty could be written as the square root of the linear summation of the individual factors squared.

(3)Theoretical Calculation

We executed a theoretical calculation for vanadium by SINCROS-Ⅱ and the results were compared with the experimental data. Input parameter F2 which means the normalization factor for the Kalbach pre-equilibrium model was set to be 0.45. This value was determined by fitting experimental data of DDX for charged particle and secondary neutron emission reaction cross sections to the calculation results as shown in Fig.7.

(4)Comparison with other experimental data

Our experimental values were also compared with the evaluation result based on other experimental data compiled by Simakov et al.[3]. He collected and examined the experimental data on discrete gamma-ray production cross sections under the support of IAEA. He averaged several other experimental data obtained at various laboratories to give the evaluated experimental data. The data were normalized with respect to incident neutron energy, angular distribution and so on. The neutron energy was selected as 14.5MeV. On the other hand, in our measurement, the energy was 14.1MeV. We used the compiled data of vanadium for this comparison.

5. Results

Table 1 shows the obtained gamma-ray production cross sections. The table excludes the data in evaluated nuclear data files, because insufficient data of discrete gamma-rays exist for vanadium. It is found from Fig.7 that SINCROS-Ⅱ can well reproduce the experimentally obtained neutron and charged particle DDXs. Thus the present calculation results are reliable.

Fig.8 shows the ratios of SINCROS-Ⅱ results and Simakov's data to our experimental data. The results by SINCROS-Ⅱ support our data, giving the conclusion that the consistency among neutron, charged particle and gamma-ray was confirmed in the theoretical calculation. On the other hand, Simakov's data fairly deviated mainly because the number of experimental data of vanadium is few, i.e., 2 to 4. Simakov's evaluation should be re-examined considering the reliability of the experiments included.

6. Conclusion

The secondary gamma-ray production cross sections of vanadium have been measured. The experimental data were compared with the theoretical calculation results and the evaluation results based on other experimental data. From the results of comparisons, we can conclude as follows:

①The calculation results by SINCROS-Ⅱ supported our data.

②The consistency among neutron, charged particle and gamma-ray was confirmed in the calculations by SINCROS-Ⅱ.

③The data evaluated by Simakov should be re-examined.

References:
[1] Maekawa,F. et al. Fall Meeting of the Atomic Energy Society of Japan,A-11(1997)
[2] Kokooo et al. Annual Meeting of the Atomic Energy Society of Japan,E-6(1998)
[3]Simakov,S.P., Pavlik,A., Vnach,H., Hlavac,S. 「Status of Experimental and Evaluated Discrete γ-ray Production Cross Section at E_n=14.5MeV」 INDC(CCP)-413

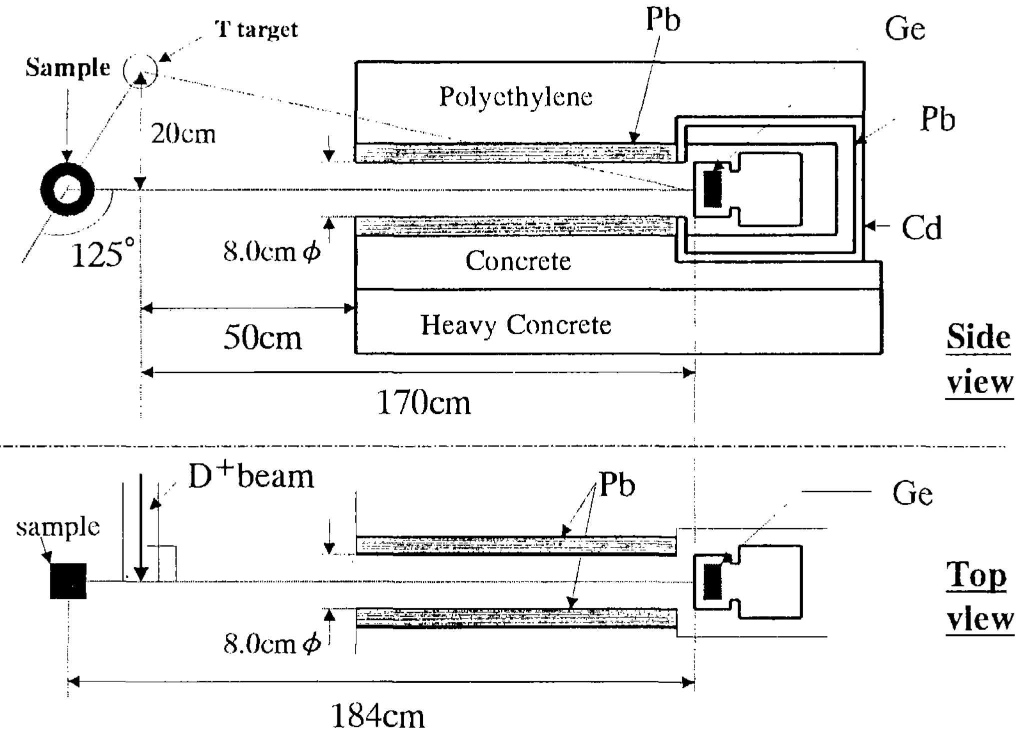


Fig.1 Experimental Geometry in OKTAVIAN

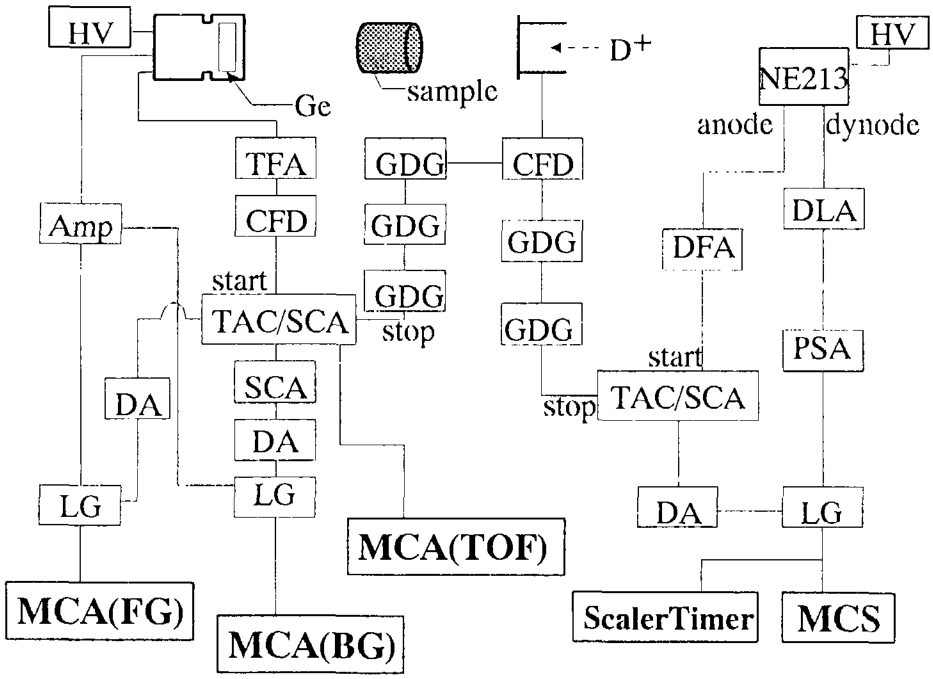


Fig.2 Block diagram of electronic circuits for TOF system

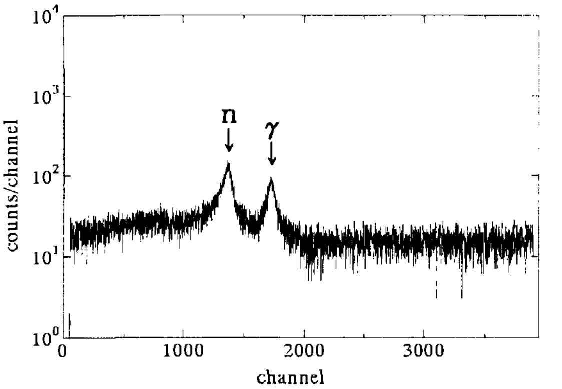


Fig.3 TOF Spectrum for V-51

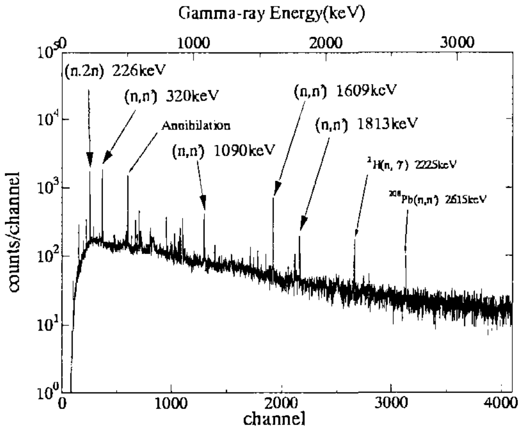


Fig.4a Secondary Gamma-ray(Foreground) Spectrum from V-51(At 125 deg.)

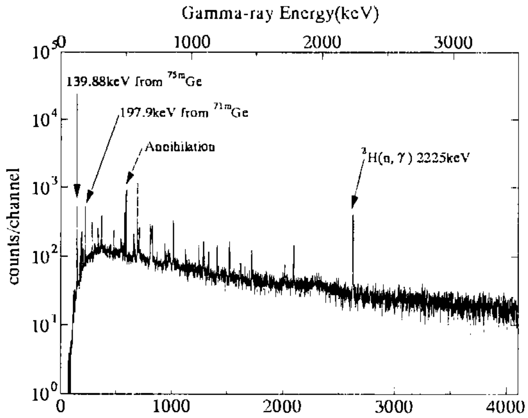


Fig.4b Background Spectrum

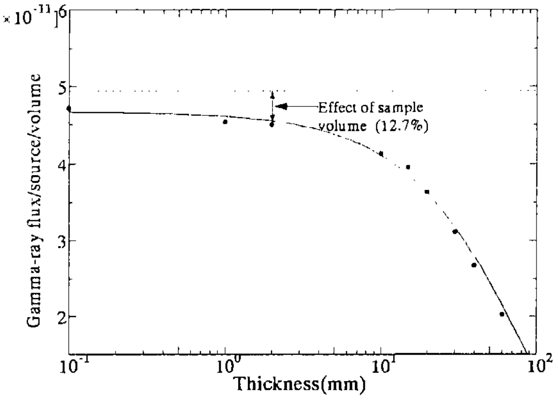


Fig.5 Caluclation results of neutron multiple scattering and gamma-ray attenuation inV-51 sample by MCNP-4a

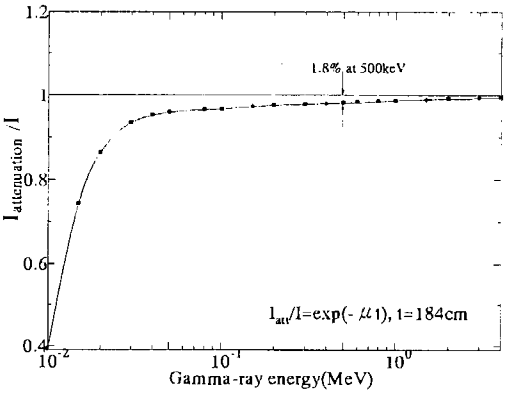
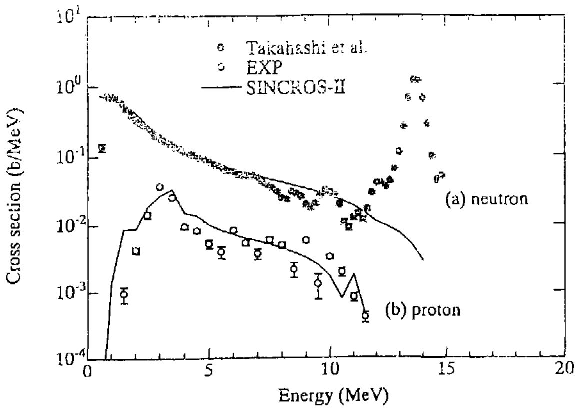


Fig.6 Correction curve about attenuation by air obtained from absorption coefficient

Table 1 Discrete γ-ray Production Cross Sections of vanadium

energy (keV)	cross section(mb) 125 deg.	SINCROS-II	S.P.Simakov
226	313±29	354	368±48
320	135±12	126	313±14
684	21.9±2.7	25.9	
815	3.1±1.0		19±1.6
836	10.7±1.5	17.3	31±3
910	42.8±5.0	58.9	88±6.9
929	38.0±4.3	55.8	49±2.4
946	10.0±1.4	1.62	19±1.5
1090	65.7±6.6	60.4	60±2.4
1121	3.6±1.0	3.07	13.4±1.5
1174	18.8±3.5	1.53	20±1.9
1437	17.2±2.0	18.8	18±2.9
1494	13.8±1.7	13.1	17.1±2.8
1554	15.8±1.7	17.6	30.3±1.8
1609	184±17	159	214±8
1777	10.0±1.3		32.5±8.5
1813	46.9±4.7	46.3	68.1±4.4
2004	6.52±1.0		11.6±3.8
2334	6.97±1.0	1.69	17.3±1.7



Figiure7 Comparison of neutron(a) and proton(b) emission cross sections of vanadium

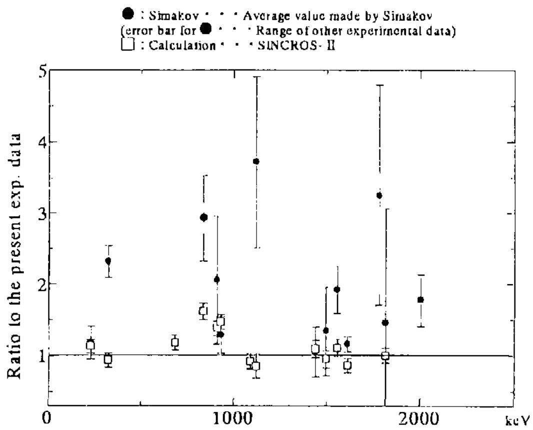


Fig.8 The ratios of SINCROS-II and Simakov's data to our experimantal data (present exp. = 1)