Measurement of Capture Cross Section of *Dy* and *Hf* in the Energy Region from 0.003 *eV* to 10 *eV*

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Applying a detector assembly of $Bi_4Ge_3O_{12}$ (BGO) scintillators (each size: 5×5 cm^2, 7.5 *cm* thick) to prompt capture gamma-rays measurement as a total energy absorption d etector, the absolute measurement of capture cross sections of nat-*Hf* and nat-*Dy* has bee n made in the energy region from 0.003 *eV* to 10 *eV* by the linac time-of-flight (TOF) method using a 12.7 *m* station. Incident thermal neutron flux was absolutely determined by using the BGO detection system with a *Sm* sample. To extend the neutron flux me asurement from the thermal neutron region to higher neutron energies, the $^{10}B(n, \alpha\ \gamma)$ re action was applied. Absolute capture yield for the sample was obtained by the saturated capture yield at a large resonance of the sample. The inside of the through-hole in the BGO detection system is covered with ^6LiF tiles of 3 *mm* in thickness, which are usef ul to shield neutrons scattered by the sample below 100 *eV*. The effects by the scattere d neutrons at higher energies have been investigated using a graphite sample.

The measured capture cross section of *Dy* shows good agreement with the existing expe rimental data and the evaluated data in ENDF/ B-VI. The present values of *Hf* are also in good agreement with those of the previous data and the JENDL-3.2 and ENDF/B-V I data.

Ⅰ. Introduction

Dysprosium (*Dy*) and hafnium (*Hf*) are promising absorbing materials for control rod s of thermal reactors[1-3] and are often used as activation foils for neutron dosimetry [4]. The neutron capture cross sections of these samples are of great importance for design and development of nuclear reactors. In the past, many capture cross sections have been investigated experimentally and theoretically[5~11]. Below thermal neutron energy region, Knorr and Schmatz[5] derived the capture cross section of *Dy* using the neutron trans-mission data. Widder[6] measured the data between 0.1 *eV* and 2 *eV* by using a Moxon-Rae detector. For *Hf*, Blair obtained the capture cross section between 0.01 and 0.8 *eV* [10]. These evaluated data are given in JENDL- 3.2[12] and ENDF/B-VI[13].

Much effort has been spent to overcome the various difficulties in the measurement, especially in the resonance energy region. According to the Nuclear Data Request List[14], accuracy of 5 % is requested for both reactions in the thermal and resonance energy regions. Therefore, it is still necessary for us to measure and improve these capture cross sections using the recent experimental techniques.

This paper describes the absolute measurement of neutron capture cross sections of *Dy* and *Hf* using the BGO detection system as a total energy absorption detector as we did before[15]. In order to determine the neutron flux impinging on the sample, the neutron detection efficiency was calibrated by a *Sm* sample and/or a ^{10}B sample at thermal neutron energy. The ^{10}B sample was employed to measure the energy dependent neutron flux. The detection efficiency of the capture events for the BGO detectors was obtained by the saturated yield method[15]. Finally, the measured results are compared with the existing experimental data and the evaluated cross section values in JENDL-3.2[12] and ENDF/B-VI[13].

Ⅱ. Experimental Method

1. Samples

The *Dy* and the *Hf* samples were a metallic plate 1.8×1.8 cm^2 (purity was 99.9 %) and the thickness was 0.025 *mm,* respectively. The sample was set at the center of the through-hole of the BGO detection system. To measure the absolute thermal neutron flux, we used a metallic plate of *Sm* (99.8 %), 1.8×1.8 cm^2 and 0.5 *mm* thick. Boron-10 sample (powder in a thin A*l* case of 1.8×1.8 cm^2 and 0.5 *mm* in thickness) was also employed to measure the energy dependent neutron flux as we used before[15].

2. Experimental Arrangement

The experimental arrangement is almost same as before[15]. The flight path used in the experiment was in the direction of 135° to the linac electron beam. Photoneutrons from the water-cooled *Ta* target hit a capture sample placed at the distance of 12.7 *m* from the target. The neutron collimation system was mainly composed of B_4C, CH_4, Li_2CO_3 and *Pb* materials, and tapered from about 12 *cm* in diameter at the entrance of the flight tube to 1.5 *cm* at the detector. The neutron intensity during the time-of-flight (TOF) experiment was monitored by a BF_3 counter placed in the neutron beam.

3. Pulsed Neutron Source

Fast neutrons, which were produced by the 46 *MeV* linac at the Research Reactor Institute, Kyoto University (KURRI), were moderated by an octagonal water tank, 30 *cm* in diameter and 10 *cm* thick. The operating conditions of the linac were as follows; the repetition rate of 40 *Hz,* the pulse width of 3 μs, the electron energy of 30 *MeV* and peak current of 0.4 *A*.

4. Data Acquisition

Output signals from the BGO detectors were led to the coincidence circuit, by which the signal-to-noise ratio could be improved. In case of the ^{10}B sample, the conventional TOF measurement (anti-coincidence method) was made, because the $^{10}B(n, \alpha \gamma)$ reaction had no cascade gamma and emitted a single gamma-ray of 478 *keV*. The detailed description of the TOF measurement and the data taking is seen in the previous paper[15].

In case of the background measurement, a thick ^{10}B plug (1.11 g/cm^2) was placed before the BGO detection system to black out the neutron beam.

Ⅲ. Results and Discussion

Absolute measurement of the capture cross section was performed through the flux determination with thermal neutrons, calibration of the BGO detection efficiency for capture gamma-rays, derivation of the capture yield, and the correction for capture yield. The measured neutron capture cross sections of *Dy* and *Hf* are shown in Figs. 1 and 2. The experimental uncertainties are in the range of 2.5 to 6.2 %, which are mainly due to the statistical ones and the systematic errors in the background subtraction, the standard cross section of the $^{10}B(n, \alpha\ \gamma)$ reaction, the correction for multiple scattering, neutron self- shielding, gamma-ray self-absorption, variation of the incident neutron energy spectra and deviation of the detector efficiency from linearity.

Figure 1 shows the measured result of *Dy*. The capture cross sections measured by Widder[6] is in good agreement with the present values. Theoretical results by Knorr and Schmatz[5] at lower energy region seem to be a little higher than the measurement. The ENDF/B-VI data are close to the present value not only at the off-resonance but also at the resonance energy region.

The data obtaibed by Blair[10] is in good agreement with the present measurement, as shown Fig. 2. The evaluated data in JENDL-3.2 and ENDF/B- VI show good agreement with the measurement.

In the resonance energy region, the resonance parameters have to be investigated by analyzing the measured data with a computer code, in future.

Ⅳ. Conclusion

The capture cross sections of *Dy* measured by Widder is in good agreement within the uncertainties with the present measurement. However, Knorr and Schmatz gave a little higher values below 0.005 *eV*. The ENDF/B-VI data show general agreement with the present result. In case of *Hf*, the data by Blair is in good agreement with the present measurement. The evaluated data in JENDL-3.2 and ENDF/B-VI are in general agreement with the present.

The data measured in the resonance energy region should be analyzed to get the resonance parameters in future.

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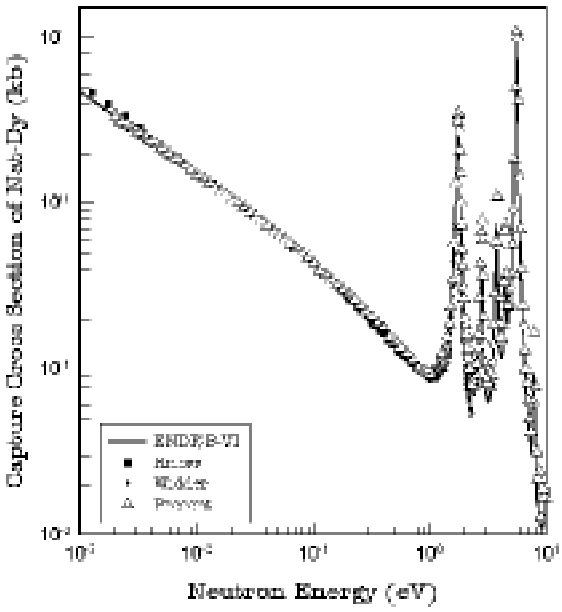

Fig. 1. The capture cross section of *Dy* between 0.003 and 10 *eV*.

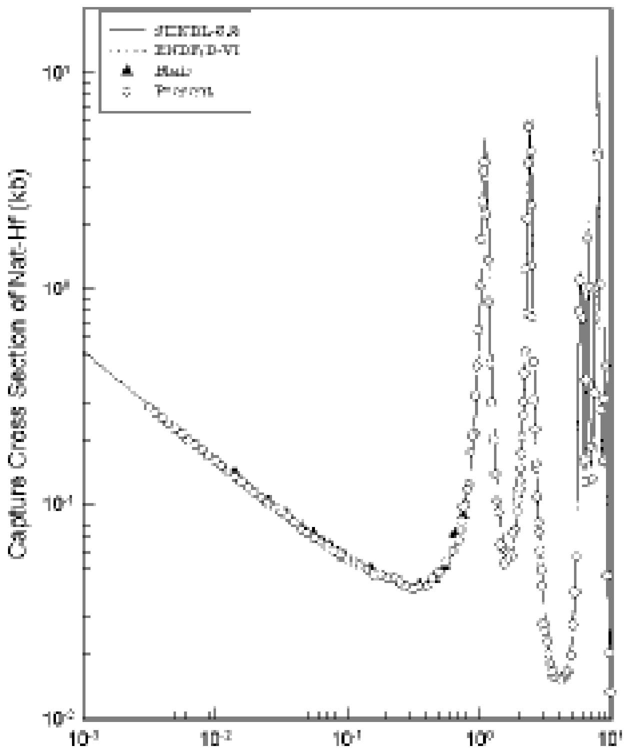

Fig. 2. The capture cross section of *Hf* between 0.003 and 10 *eV*.