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New Evaluation of Dysprosium Neutron Resonance Parameters

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1. Introduction

Dysprosium has been used as a slow neutron absorber in the fuel assembly of Advanced Heavy Water Reactor (AWAR) to achieve a negative coolant void reactivity. Dysprosium as occurring in nature has as many as seven isotopes namely, ^{156}Dy, ^{158}Dy, ^{160}Dy, ^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy. Of these, the isotope ^{164}Dy has the largest absorption cross-section for thermal neutrons [1]. Dysprosium is also a fission product from the thermal fission of ^{235}U, ^{233}U, and ^{239}Pu. The accumulation of fission products in the reactor core increase with the burn-up of the nuclear fuel and the poison effect becomes more important. In addition, it is difficult to separate from minor actinides such as americium, curium, and other higher fission products. If spent nuclear fuel is to be reprocessed and it is desired to burn up the minor actinide burning core [2]. Therefore, it is necessary to understand dysprosium effect on the neutron population over all energy regions in a nuclear reactor system, where it is in the capacity of a fission product poison or a neutron absorbing control rod.

The neutron resonance parameters of Dy isotopes were obtained in the energy range 10 eV to 1 keV from SAMMY Reich-Moore analysis [3] of high resolution capture measurements performed at the electron linear accelerator (Linac) facility of the Rensselaer Poly-technic Institute (RPI). In the energy range 10 eV to 1 keV, the analysis used as prior values the ENDF/B-VII.1 resonance parameters [4]. The results are compared to the ENDF/B-VII.1 evaluation. Some statistical properties were investigated for the two isotopes with the most resonances, ^{161}Dy and ^{163}Dy.

2. Experimental Procedure

This is the first experiment to use high-purity Dy isotopes of ^{161}Dy, ^{162}Dy, ^{163}Dy, ^{164}Dy. Table 1 lists the isotopic content of the dysprosium samples used in this experiment.

The electron beam impinges on a water-cooled tantalum target where electrons interact and produce bremsstrahlung, which generates photoneutrons. The resulting neutrons are moderated and collimated as they travel through a long evacuated flight tube to the sample and detector. The neutron energy for a detected event is determined using TOF method.

Table 1: Isotopic composition of Dysprosium isotopes.

	Isotopic Composition [%]						
	^{156}Dy	**^{158}Dy**	**^{160}Dy**	**^{161}Dy**	**^{162}Dy**	**^{163}Dy**	**^{164}Dy**
^{161}Dy	0.02	0.02	0.35	**95.66**	2.53	0.90	0.56
^{162}Dy	<0.01	<0.01	0.08	1.24	**96.17**	1.79	0.72
^{163}Dy	<0.01	<0.01	0.03	0.36	1.23	**96.86**	1.52
^{164}Dy	<0.01	<0.02	0.02	0.15	0.35	1.03	**98.45**

When an incident neutron is captured in the sample, a compound nucleus in an excited state is formed. The compound nucleus then de-excites to the ground state with the subsequent emission of gamma rays. The detection of these gamma rays allows one to measure the fraction of neutrons of a given energy that are captured if the incident neutron flux is known. This fraction of captures is known as the capture yield. Thus, for a uniform thickness sample and a parallel neutron beam incident perpendicularly to this sample, the capture yield is defined as the number of detected capture gamma rays divided by the product of the detector efficiency times the number of incident neutrons. Mathematically speaking, the capture yield is defined as the number of captures per incident neutron. In time of flight measurements the capture yield, Y_i in TOF channel *i* was calculated by

$$Y_i = \frac{C_i - B_i}{K\phi_{sm_i}}$$

where, C_i is dead-time-corrected and monitor-normalized counting rate of the sample measurement, B_i is dead-time-corrected and monitor-normalized background counting rate, K is product of the flux normalization factor and efficiency, and ϕ_{sm_i} is smoothed, background-subtracted, and monitor-normalized neutron flux.

The incident neutron flux shape was determined with the use of a thick $^{10}B_4C$ sample that is mounted on the sample changer. The measured flux shape is usually normalized directly to a saturated capture resonance. This capture yield and its associated statistical uncertainty provided input to the SAMMY data analysis code that extracted the neutron resonance parameters.

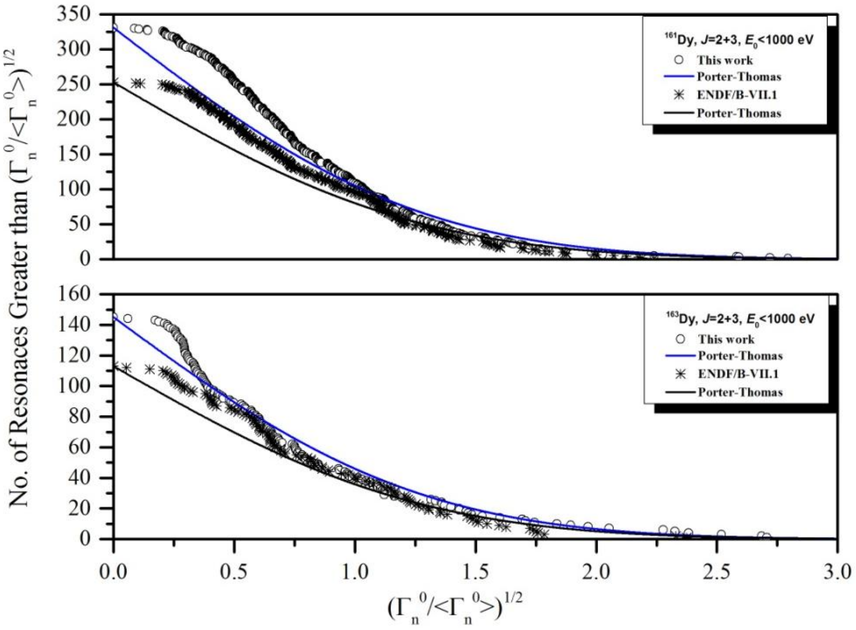

Fig. 1. Cumulative distribution of reduced neutron widths for ^{161}Dy and ^{163}Dy.

A more detailed description of the present measurement and analysis is given in Ref [4,5].

Statistical distributions of reduced neutron widths were investigated for the two isotopes with the most resonances, ^{161}Dy and ^{163}Dy. The reduced neutron widths were divided by the unweighted average reduced neutron width for each isotope and *J* value. These unitless ratios for *J* values in ^{161}Dy and ^{163}Dy were plotted as a cumulative distribution in Fig 1 and compared to χ^2 distribution with one degree of freedom, i.e., the Porter-Thomas distribution. ENDF/B-VII.1 neutron widths were processed in the same way and also plotted on Fig. 1. Neutron strength functions S_0 were measured for the two isotopes with the most resonances, ^{161}Dy and ^{163}Dy. The measured values are compared to those of ENDF/B-VII.1 and the *Atlas of Neutron Resonances* [6] in Table 2.

Table 2: Neutron Strength Function S_0, for two isotopes with the most resonances, ^{161}Dy and ^{163}Dy.

	S_0 ^{161}Dy	S_0 ^{163}Dy
This work	1.78±0.01	2.24±0.02
ENDF/B-VII.1	1.71	1.94
Atlas of Neutron Resonances	1.82±0.11	1.9±0.2

3. Result and Conclusion

The analysis of the experimental capture data was performed with the computer code SAMMY [3] This code uses the Reich-Moore formalism for the calculation of the cross-sections. The fit to the experimental data, taking into account the experimental effects (Doppler and resolution broadening, self shield-ing, multiple scattering, background and normalization corrections, *etc.*), is obtained by Bayes method.

The present measured resonance parameters were determined using the capture yields for four enriched Dy isotopic samples and a natural sample. The results of resonance parameters are given in Reference [4].

The distributions of reduced neutron widths for ^{161}Dy and ^{163}Dy were compared to those of ENDF/B-VII.1 and to the theoretical Porter-Thomas distribution. Many new resonances are expected to exist that have not been identified by ENDF/B-VII.1. If a few of the weaker resonances were p-waves rather than s-waves, the agreement with the Porter-Thomas distribution of level widths would improve. The strength function for ^{161}Dy and ^{163}Dy is larger than ENDF/B-VII.1.

The detailed list of resonance parameters and statistical properties for Dy isotopes are available and will be do commenter in the future publication.

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