Progress in Nuclear Energy 94 (2017) 126–132

Contents lists available at ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Neutron transmission and capture measurements and analysis of Dy from 0.01 to 550 eV

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ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form
9 September 2016
Accepted 28 September 2016
Available online 15 November 2016

Keywords:
Dysprosium
Resonance parameters
Dy164 thermal cross section
Dy164 resonance integral

ABSTRACT

Neutron capture and transmission measurements were carried out from 0.01 to over 600 eV on both natural Dy and samples highly enriched in ^{164}Dy. These data were analyzed for resonance parameters utilizing the SAMMY Bayesian analysis code to simultaneously fit both the capture and transmission data. Parameters were obtained for 17 resonances in Dy isotopes up to 18 eV and for the ^{164}Dy resonances near 147, 450 and 540 eV. The thermal capture cross section (at 0.0253 eV) and capture resonance integral were determined for ^{164}Dy.

1. Introduction

Natural dysprosium has a high neutron thermal capture cross section of 950 b, of which approximately 80% is from capture in ^{164}Dy. Since ^{164}Dy is produced inside a reactor as a fission product or it can be used as a burnable poison to control a reactor (Raaijmakers, 1965), it is important to know the ^{164}Dy cross section accurately over the energy range of neutrons inside a reactor. Total cross section measurements in the thermal energy region have been reported by Sher et al. (1961), Moore (1961), and Vertebnyj et al. (1971). Earlier cross section measurements of Dy isotopes in the resonance region have been reported by Mughabghab and Chrien (1970) (transmission) and Liou et al. (1975) (transmission and capture). Kim et al. (2003). measured a single 0.5-mm thick sample of natural Dy in transmission at 10.8 m and reported resonance parameters below 10 eV. However, these measurements used thick samples of Dy which made it difficult to obtain accurate information on the large ^{164}Dy resonances. It was thus decided to carry out a new set of measurements with samples over an order of magnitude thinner than used in the earlier measurements. These thinner samples were also well suited for measurements in the thermal energy region.

Neutron capture and transmission measurements were thus carried out at the Rensselaer Polytechnic Institute (RPI) Gaerttner LINAC Center from 0.01 to over 600 eV on both natural Dy and samples highly enriched in ^{164}Dy. Both metallic and liquid samples were employed for these measurements. Resonance parameters were deduced for resonances in the Dy isotopes up to 18 eV and for the ^{164}Dy resonances near 147, 450 and 540 eV. The thermal capture cross section (at 0.0253 eV) and the capture resonance integral for ^{164}Dy were determined from these parameters.

2. Experimental conditions

2.1. Overview of measurements

Transmission and capture measurements were carried out using the time-of-flight (TOF) method predominantly with samples

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http://dx.doi.org/10.1016/j.pnucene.2016.09.019
0149-1970/

highly enriched in ^{164}Dy. The experimental details used for data acquisition are listed in Table 1. The experimental method and details are essentially the same as those reported in detail by Leinweber et al. (2014) and will only be briefly described here. The RPI Gaerttner LINAC Center linear accelerator was used to produce energetic electrons and these electrons, in turn, impinged on water-cooled Ta plates to produce neutrons via the photoneutron reaction. The thermal transmission and capture measurements used the enhanced thermal neutron target (Danon et al., 1993, 1995) whereas the epithermal transmission and capture measurements used the bare bounce target (Overberg et al., 1999). The thermal transmission measurements utilized a 0.3-cm-thick ^{6}Li glass scintillator detector mounted directly on a photomultiplier at the 15 m flight station. The epithermal transmission measurements utilized a 1.27-cm-thick (0.5 in) ^{6}Li glass detector at the 25 m flight station with the glass viewed by two photomultipliers located outside of the neutron beam (Barry, 2003). The thermal and epithermal capture measurements utilized the 16-section NaI multiplicity detector (Block et al., 1988) located at the 25 m flight station.

The neutron intensity from the accelerator was monitored with moderated fission chambers located at a ≈9 m flight path, a ^{6}Li glass ring detector placed in the epithermal transmission flight tube and, when applicable, the ^{6}Li glass detector located at the 15 m flight path. These monitor detectors were used to remove the effects of beam intensity fluctuations, as well as correct for different collection times for the various sample and open positions.

2.2. Sample information

The natural dysprosium sample and the enriched 164 isotope material for the liquid samples were obtained from Trace Sciences International. The metallic enriched ^{164}Dy sample was supplied by Kyungpook National University in the Republic of Korea. Several types of samples were used for these measurements; Table 2 lists the sample thicknesses (elemental number densities) and Table 3 lists the isotopic compositions of the enriched samples. The uncertainties in the isotopic compositions of the enriched and natural samples are estimated as ±1 atom percent.

2.2.1. Solid samples

The 10 mil Dy sample (1 mil = 0.001in = 0.00254 cm) was a natural metal sample and was used for measuring Dy capture in both the thermal and epithermal neutron energy regions and transmission in the epithermal region. For capture measurements this sample was enclosed in an empty quartz cell (the same type cell used for the liquid samples) so that the incident flux on the 10 mil sample is the same as the flux on the liquid samples. The 20 mil Dy sample was used for the thermal transmission measurement. The uncertainty in the number density was estimated at ±1% for these samples.

The ^{164}Dy metal sample was used in the Week 3 epithermal capture measurement. It was somewhat irregularly shaped, so the uncertainty in its number density was estimated at ±11%.

Table 1
Experimental details showing accelerator and data acquisition parameters.

Measurement	Overlap filter	Neutron target	Electron pulse width (μs)	Average electron current (μA)	Electron energy (MeV)	Neutron energy region (eV)	Channel width (μs)	Rep. Rate (pps)	Flight path (m)
Thermal transmission	none	Enhanced thermal	2.1	10.5	48	E < 0.11 0.11 < E < 5.3 5.3 < E < 24	32 2 0.5	25	14.973 ± 0.006
Epithermal transmission	Cd	Bare bounce	0.060	20.5	54	E < 45 44.7 < E < 262 262 < E < 600	0.5 0.0625 0.03125	225	25.597 ± 0.006
Thermal capture	none	Enhanced thermal	1.0	8.2	50	E < 0.12 0.12 < E < 4.0 4.0 < E < 23	8 0.5 0.125	25	25.444 ± 0.006
Epithermal capture (week 1)	Cd	Bare bounce	0.044	14.5	55	E < 45 44.7 < E < 262 262 < E < 600	0.5 0.0625 0.03125	225	25.564 ± 0.006
Epithermal capture (week 2)	Cd	Bare bounce	0.036	14	60	E < 45 44.7 < E < 262 262 < E < 600	0.5 0.0625 0.03125	225	25.564 ± 0.006
Epithermal capture (week 3)	B_4C	Bare bounce	0.018	17.2	58	E < 1000	0.0128	225	25.564 ± 0.006

Table 2
Sample thicknesses as elemental number densities in atoms per barn. The ^{164}Dy metal sample was produced from material highly enriched in ^{164}Dy; LX-15 and LX-22 contained pure D_2O and were used as compensator samples in the transmission measurements. The other LX samples were solutions containing enriched ^{164}Dy, D_2O, remnants of deuterated nitric acid (used in sample preparation), and H_2O that was inadvertently picked up during the preparation.

Sample	^{164}Dy	Elemental number densities				
	Enrichment (%)	Dy (a/b)	D (a/b)	N (a/b)	O (a/b)	H (a/b)
Dy natural metal (10 mil)	28.18	8.05E-04				
Dy natural metal (20 mil)	28.18	1.61E-03				
Dy-164 metal	98.45	2.27E-04				
LX-12	98.60	8.59E-05	2.45E-02	4.16E-04	1.34E-02	1.84E-04
LX-13	98.60	2.20E-04	2.20E-02	1.06E-03	1.40E-02	4.69E-04
LX-14	98.60	5.57E-04	1.63E-02	2.70E-03	1.57E-02	1.19E-03
LX-15			2.62E-02		1.31E-02	
LX-18	98.60	1.48E-05	1.04E-02	7.15E-05	5.40E-03	3.15E-05
LX-19	98.60	3.54E-05	1.01E-02	1.72E-04	5.52E-03	7.56E-05
LX-21	98.60	2.29E-04	7.23E-03	1.11E-03	6.78E-03	4.90E-04
LX-22			1.09E-02		5.43E-03	
LX-23	98.60	9.06E-05	9.08E-03	4.39E-04	5.77E-03	1.94E-04