^{245}CM FISSION CROSS SECTION MEASUREMENT IN THE THERMAL ENERGY REGION

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A new cross section measurement for the ^{245}Cm(n,f) reaction in the thermal energy region has been performed at the GELINA neutron facility of the Institute for Reference Materials and Measurements (IRMM) in Geel, Belgium. The energy of the neutrons is determined applying the time of flight method using a flight path length of about 9 m. In the present work, the incident neutron energy covers 10 meV up to a few eV. A 98.48% enriched ^{245}Cm sample was mounted back-to-back with a ^{10}B sample in the centre of a vacuum chamber together with two surface barrier detectors positioned outside the neutron beam. One detector measured the $^{10}B(n,\alpha)^{7}Li$ reaction products for the neutron flux determination, while the second one registered the ^{245}Cm(n,f) fragments. In this way, the neutron flux can be determined simultaneously with the fission fragments. A control measurement has been performed replacing the ^{245}Cm sample with a ^{235}U sample in order to check that the well-known ^{235}U(n,f) cross section can be reproduced. Our measurement yielded a $^{245}Cm(n_{th},f)$ cross section of 2131±43±173 b and a Westcott factor g_f=0.939±0.019.

1. Introduction

In order to improve the prediction of heavy actinide concentrations in reactor fuel elements and to reduce the long-term nuclear waste radiotoxicity by using transmutation, cross sections for neutron-induced reactions are required by nuclear industry for many minor actinides, in particular for the ^{245}Cm(n,f) reaction. In the resolved resonance region, only a few old measurements exist for this reaction: Browne's measurement [1] which covers the thermal region up to 35 eV, Moore's one [2] which starts at 20 eV up to 3 MeV and White's one [3]

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from 10 eV up to 63 eV. Recently, the ^{245}Cm fission cross section has been measured by Calviani [4] at the n_TOF facility (CERN), but the results are not yet available in the EXFOR database and will not be used in the present paper for comparison. In addition, for the ^{245}Cm thermal neutron-induced fission cross section, a strong dispersion between measurements is observed as reported by Popescu et al. [5]. This dispersion is partly due to the poor knowledge of the so-called Westcott factor, which describes the deviation of the cross section from a 1/v shape. Up to now, this Westcott factor has been determined from Browne's measurement which is the only one performed in the thermal energy region by the time of flight (TOF) procedure. In this context, a new measurement of the ^{245}Cm(n,f) cross section has been performed between 0.01 eV up to 2 eV.

2. Experimental setup

The measurement was carried out at the GELINA neutron time of flight facility of the Institute for Reference Materials and Measurements in Geel (Belgium). This accelerator delivers a pulsed and compressed electron beam that hits a rotating U target, hence producing bremsstrahlung gamma rays. These gamma rays create neutrons via (γ,n) and (γ,f) reactions. The neutrons are then moderated in 4 cm thick water-filled beryllium containers. The length of the flight path is 9.3 m.

The neutron-induced fission cross section was measured using two different repetition frequencies of the accelerator: 800 Hz and 50 Hz. With 800 Hz, a cadmium filter must be placed in front of the chamber in order to remove overlapping neutrons from previous bursts. So, the incident neutron energy range is in between 0.5 eV up to a several hundred keV. Preliminary results obtained with this repetition frequency have been already published elsewhere [6]. With a 50 Hz repetition frequency, overlapping neutrons from two consecutive bursts do not occur anymore, and therefore the cadmium filter can be removed. In this way, the thermal energy region can be investigated.

The curium sample was mounted in the centre of a vacuum chamber, back-to-back with a ^{10}B layer as shown in Fig. 1. Two Si-Au surface barrier detectors, positioned outside the neutron beam, are used. The first one (fission side) detects the fission fragments from the (n,f) reactions while the second one (boron side) registers alpha particles coming from the ^{10}B(n,α) reactions. In this way, the neutron flux can be determined simultaneously with the fission fragments. These detector signals are then amplified, digitized, and stored in a personal computer.

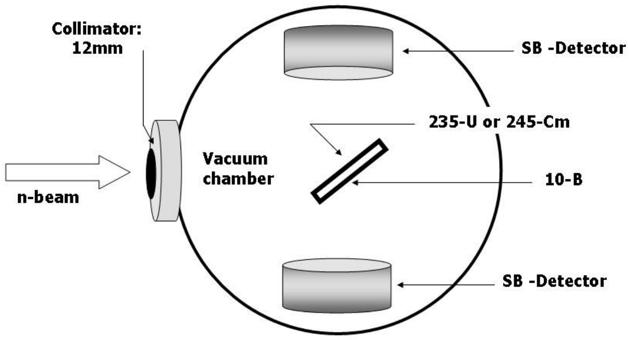

Figure 1. Schematic view of our experimental setup used for the ^{245}Cm neutron-induced fission cross section measurement.

The measurement is performed in two separate runs. For the first one, we use a highly enriched U sample. It permits us to determine the detection geometry factors on both sides and to check if the well known ^{235}U(n,f) cross section can be reproduced. For the second run, the U sample is replaced by the curium one, maintaining the same detection geometry.

3. Measurement with the 235-U sample

The fission fragments counting rate measured on the fission side (Y_f) can be written as follows:

$$Y_f - Y_f^{BGR} = 0.5 \times \varepsilon_f N_U \varphi(E_n) \sigma_f (E_n) \quad (1)$$

The ^{235}U(n,f) pulse-height spectrum integrated over all incident neutron energies is plotted in Fig. 2 (left part).

With the discriminator setting used on the boron side, only the alpha particles are detected (see Fig. 2, right). Hence, the measured counting rate Y_B is given by:

$$Y_B - Y_B^{BGR} = \varepsilon_B N_B \varphi(E_n) \sigma_B (E_n) \quad (2)$$

In eqs. (1) and (2), N_U and N_B are the number of uranium and boron atoms, $\varphi(E_n)$ is the neutron flux, ε_B and ε_f are the detection geometry factors, σ_f is the neutron induced fission cross section and σ_B is the ^{10}B(n,α)^{7}Li reaction cross section. Y_f^{BGR} and Y_B^{BGR} represent the backgrounds on both sides which were measured by adding several 'black resonance' filters in front of the chamber.

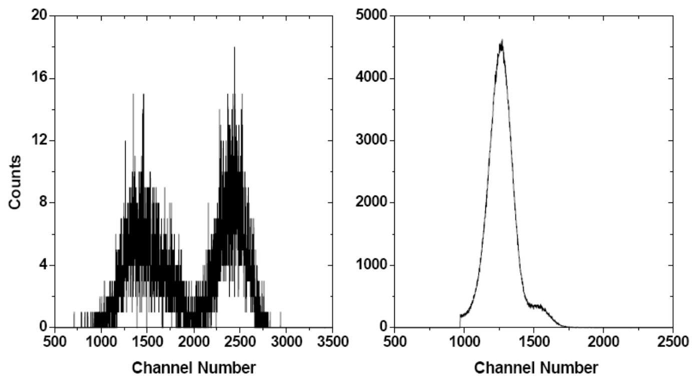

Figure 2. Pulse height spectra measured on the uranium (left) and boron (right) sides.

From the above equations and using the JEFF3.1 cross sections for σ_f and σ_B, it is possible to extract the $\varepsilon_f / \varepsilon_B$ ratio. Then, the $^{235}U(n,f)$ cross section can be deduced by applying the following equation:

$$\sigma_f(E_n) = \frac{\varepsilon_B}{\varepsilon_f} \frac{N_B}{N_U} \frac{0.5\left(Y_f - Y_f^{BGR}\right)\sigma_B^{JEFF31}(E_n)}{\left(Y_B - Y_B^{BGR}\right)} \qquad (3)$$

Results are shown in Fig. 3 and are compared with the JEFF-3.1 evaluation file. The very nice agreement which could be achieved gives confidence in our energy calibration and in the good functioning of our experimental setup.

4. Measurement with the 245-Cm sample

The thickness of the curium oxide sample is 50 $\mu g/cm^2$. The active diameter is 15 mm. The isotopic composition in March 2003 is given in Table 1.

Table 1. Isotopic composition of the ^{245}Cm sample.

Isotope	244Cm	245Cm	246Cm	247Cm	248Cm
Abundance	1.11	98.48	0.405	0.008	0.002

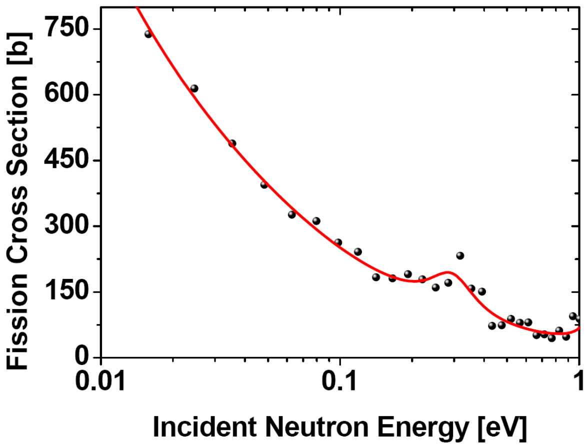

Figure 3. Neutron-induced fission cross section of ^{235}U (circle) compared with the JEFF3.1 evaluation (line).

As described for the ^{235}U measurement, the background measurement was performed by adding several 'black resonance' filters in front of the chamber: Cd, Rh, Au, Mn, W and Co. The low energy part of the background spectra are plotted in Fig. 4. On the fission side (right part of the figure), the observed strong background is due to spontaneous fission events from ^{244}Cm and ^{246}Cm. The corresponding time of flight spectrum is also plotted, showing, as expected, a flat behavior. Then, the $^{245}Cm(n,f)$ cross section can be determined applying eq. (3). Preliminary results obtained in this way are plotted in Fig. 5 from 0.01 eV up to 2 eV. Results deduced from the 800 Hz run [6] and the JEFF3.1.1 evaluation are also shown in the figure. Our measured thermal neutron-induced fission cross section yields:

$$\sigma_f\left(E_n = 0.0253\,\text{eV}\right) = \left(2131 \pm 43 \pm 173\right)\text{b}$$

where the first mentioned uncertainty (43 b) corresponds to the statistical uncertainty, whilst the second one (173 b) is an estimation of the systematic errors. Our thermal fission cross section value is in good agreement with Browne's one [1]. From our experimental data, we have also calculated the Westcott g_f factor [7], defined as:

$$g_f\left(T\right) = \frac{2}{\sqrt{\pi}\sqrt{E_0}E_T^{3/2}\sigma_f\left(E_0\right)}\int_0^\infty \sigma_f\left(E\right) E \exp\left(-\frac{E}{E_T}\right) dE$$

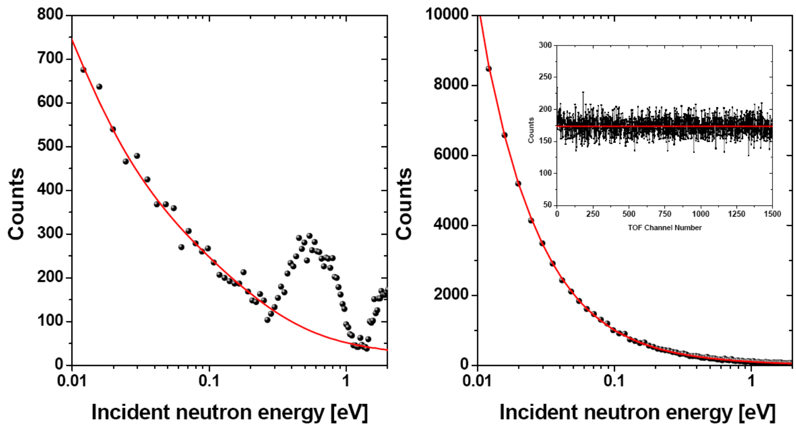

Figure 4. Background measurements obtained with 'black resonance' filters on the boron (left) and fission (right) sides. On the fission side, the background is entirely due to the ^{244}Cm and ^{246}Cm spontaneous fission, yielding a flat behavior of the TOF spectrum (see insert).

Using T=293.6K and E_0=E_T=25.3meV, we have found: g_f=0.939±0.019, which can be compared with the recommended value proposed by Mughabghab [8]: g_f=0.954±0.033.

5. Conclusion

The neutron-induced fission cross section of ^{245}Cm has been measured at the GELINA facility in the thermal energy region. From a preliminary analysis of our experimental data, a new thermal fission cross section and a new Wescott factor were determined. Combining the present measurement with the one in the resonance energy region will lead in a near future to a new set of resonance parameters.

Acknowledgments

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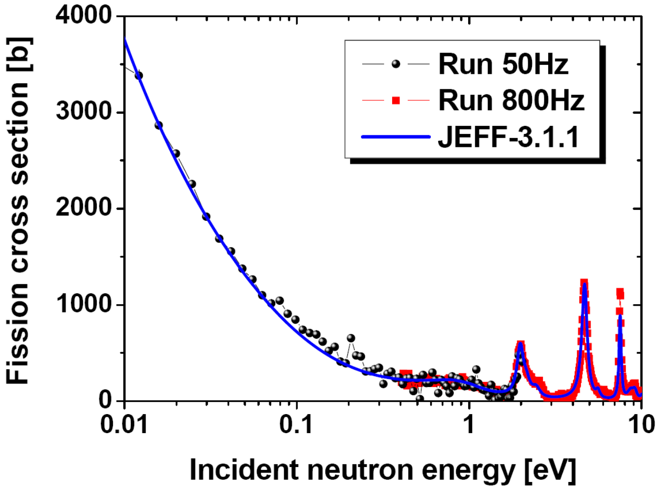

Figure 5. Preliminary results of the neutron-induced fission cross section of ^{245}Cm in the thermal energy region (circles). Data in the resonance energy region (squares) from Ref. [6] are also plotted together with the JEFF3.1.1 evaluation.

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