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PREPRINT UCRL-82991

Lawrence Livermore Laboratory

FISSION CROSS SECTION OF ^{245}Cm FROM 10^{-3} EV TO 10^4 EV

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October 15, 1979

This paper was prepared for submission to the International Conference on Nuclear Cross Sections for Technology, October 22-26, 1979, Knoxville, Tennessee.

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The neutron-induced fission cross section of ^{245}Cm has been measured from 10^{-3} eV to 10 eV using the LLL 100-MeV linac. The resonance data are analyzed with a multilevel-multichannel R-matrix code. The statistical distribution of R-matrix parameters extracted from the analysis are investigated and comparisons are made with previous work.

[$^{245}\text{Cm}(n,f)$, 10^{-3} eV - 10 keV, multilevel R-matrix analysis, deduced levels, σ_p , σ_{th} , $\sigma_{\text{0.01}}$]

Introduction

The neutron-induced fission cross section of ^{245}Cm described below is part of an ongoing series of measurements aimed at determining neutron cross sections in the transplutonium mass region. Many of these cross sections are important for calculating heavy actinide concentrations in reactor fuel elements. This has application in both production of heavy isotopes and also in actinide-waste recycling schemes. The location of ^{245}Cm in the reactor production chain makes its cross section particularly important. Its predecessor, ^{244}Cm , has a small capture cross section that acts to retard the mass transfer to heavier isotopes. The mass loss to fission or transferred through to ^{246}Cm depends on the fairly large fission and capture cross section of ^{245}Cm and on the energy dependence of the incident neutron spectrum.

Previous measurements and a review of work to date on the fission cross section of ^{245}Cm are given by Browne, et al.¹ The experiment described in this paper was only recently completed (July, 1979) and the conclusions drawn from the R-matrix analysis are preliminary.

Experimental Procedure

The data for this experiment were taken using the LLL 100-MeV linac. Electrons from the linac were focused on a target consisting of water cooled tantalum plates coupled to an H₂O moderator. The data were accumulated in two overlapping measurements from 10^{-3} eV to 100 eV and from 0.5 eV to 10^4 eV respectively with the fission sampler viewing only the H₂O moderator at both flight paths. The neutrons were collimated with a series of polyethylene, borated polyethylene and lead collimators and their energies were measured by time-of-flight techniques.

The fission sample consisted of approximately 189 μg of isotopically enriched (>99%) ^{245}Cm electroplated onto a 0.05 mm-thick nickel hemispherical foil to a density of $123 \mu\text{g}/\text{cm}^2$. A fission sample of ^{235}U was also included in this measurement. The ^{235}U sample was prepared by vapor deposition onto 0.006 mm thick titanium foils to a density of approximately $500 \mu\text{g}/\text{cm}^2$. Fission fragments were detected using a hemispherical ionization chamber for ^{245}Cm and a parallel-plate ionization chamber for ^{235}U . Signals from each chamber were amplified using fast, current sensitive preamplifiers. The ionization chambers used an Ar-CO₂ (96%-4%) mixture at a pressure of approximately one atmosphere.

The neutron flux was measured from 10^{-3} eV to 100 eV using 2-mm thick NE901 (2.4% natural) lithium glass and from 0.5 eV to 10^4 eV using 1-mm thick NE905 (6.6% enriched ^6Li) glass scintillators, which were positioned in the neutron beam between two 5-cm diameter photomultiplier tubes. Fission events from

the ionization chambers and signals from the lithium glass scintillators were each collected in time-of-flight arrays of approximately 2000 channels.

Both the ^{245}Cm and ^{235}U low energy (10⁻³ to 100 eV) fission data were reduced to relative cross sections by normalization to the measured flux trace. The ^{235}U relative cross section was normalized to the known 20.3 sec ^{235}U fission cross section.² The normalization constant along with the ratios of the $^{245}\text{Cm}/^{235}\text{U}$ masses and the relative efficiencies of the two fission chambers, determined from pulse height spectra, provided the proper normalization for the ^{245}Cm relative cross section. The ^{245}Cm resonance data (0.5 to 10^4 eV) were normalized to the low energy cross section between 0.6 and 1.0 eV.

Data Analysis

The fission cross section was analyzed on a VAX 11/780 computer with the Multichannel R-matrix code, MULTIR, of Acha et al.³ The code performs a least-squares fit to total, scatter, fission, and capture cross sections and allows for resolution and lifetime broadening of resonance data. In addition to the MULTIR code a sophisticated graphics package utilizing the television monitor display system (TMDS) was written to allow instant graphical comparison of least-squares fits to the fission data with each iteration program. This system allows for convenient and timely analysis of the data. Though there are two compound nuclear states (3^+ and 4^+) formed by the interaction of a neutron with the $7/2^+$ ground state of ^{245}Cm , all states in the 0-80 eV region were assumed to be of one spin group, namely 4^+ . A three channel R-matrix, consisting of one neutron and two fission channels, was used to obtain the fits in Figs. 1 through 4. A constant 40 meV width was used for the capture widths of all resonances in this analysis.

Figure 1 shows the fit to the data from 10^{-3} to 10 eV. It is evident that the low energy data are not yet fit perfectly. Two possible reasons are (1) that more than one bound state is necessary to correctly fit the region from 10^{-3} to 0.5 eV and (2) that the broad resonance at 1 eV is actually two states. Further work is required to resolve this question. Figure 2 shows the fit from 1 to 10 eV and includes two additional states at 7.5 eV and 9.0 eV not seen in previous measurements. It is clear that an excellent fit to this region has been obtained. Figure 3 is a fit to the region from 12 to 32 eV. A fairly dramatic lack of resonances is apparent from the small cross section in the region from 12 to 20 eV. At least three other measurements have been made^{3,4} for which analysis is complete and resonance parameters can be compared. Fairly good agreement between this work and that of Browne, et al.¹, and Berreth, et al.³, is obtained. The major work from 20 to 60 eV is that of Moore and Keyworth⁴. Their data were taken using the Physics 8 nuclear explosion as a

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Figure 1. Least-squares ratio of the R-matrix fit to the experimental data for the ^{245}Cm fission cross section from 1 to 10 eV.

neutron energy and the thermal equivalent cross section. A line would represent the ratio of the R-matrix fit to the experimental data. The ratio is mostly between 0.8 and 1.2, with some fluctuations and a sharp drop near 10 eV. In the present analysis, the R-matrix fit is based on the experimental data, and there are significant differences between the R-matrix fit and the experimental data, especially at low neutron energies. The R-matrix fit is based on the experimental data, and there are significant differences between the R-matrix fit and the experimental data, especially at low neutron energies.

Figure 2. R-matrix fit to ^{245}Cm fission cross section (multiplied by $\sqrt{E_n}$) from 1 to 10 eV.

Figure 3. R-matrix fit to the ^{245}Cm fission cross section with the R-matrix fit to the data.

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Figure 4. ^{245}Cm fission cross section from 30 eV to 80 eV with R-matrix fit.

Figure 5. Histogram showing the number of levels observed as a function of energy for the present work to 30 eV and that of Ref. 4 from 30 to 60 eV. The straight lines are least-squares fits to the data. The average level spacings are in units of eV.

for the discovery of two small resonances not seen before at 13.1 and 19.6 eV. Figure 6 is a plot of the number of levels vs. energy for the present analysis which includes 21 levels from 0 to 30 eV. The average level spacing is 1.5 eV. The histogram in Fig. 7 represents the variation of the sum of the reduced neutron widths, $\sum \Gamma_n^0$, as a function of energy. The slope of the least-squares fitted straight line yields a strength function of $(1.02 \pm 0.02) \times 10^{-4}$.

Fig. 8 shows the experimental distribution of reduced neutron widths compared to a Porter-Thomas distribution (chi-squared distribution with one degree of freedom) for the 21 levels up to 30 eV. The average reduced neutron width is 0.287 meV. In Fig. 9 we compare the experimental distribution of fission widths with a chi-squared distribution of three degrees of freedom. The maximum likelihood method was applied to the fission widths and yielded the most likely number of degrees of freedom to be

Figure 6. Histogram showing the number of levels observed as a function of energy for the present work to 30 eV.

Figure 7. Histogram showing the sum of the reduced neutron widths as a function of energy.

2.8 ± 0.8 . In the strong coupling picture of fission, the effective number of open fission channels, N , is equal to $2\langle \Gamma_f \rangle / \langle D \rangle$ which for the present case is 2.3.

Summary

The ^{245}Cm fission cross section has been measured from .001 eV to 10 keV. Preliminary resonance parameters have been obtained for levels below 30 eV. The average fission width is 550 meV. The neutron strength function (1.02×10^{-4}) is in reasonable agreement with neighboring nuclei. The average level spacing with energy appears to be different over the regions from 1 to 15 eV and 25 to 60 eV. For distributions of neutron and fission widths more levels need to be included for more statistically meaningful analysis. In the region of overlap with previous analysis up to 60 eV systematic differences occur which preclude folding in those parameters with the present work.

Figure 8. Distribution of reduced neutron widths for 21 levels from the present work to 30 eV.

Figure 2. Dependence of the total width of the distribution on the parameter x .

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The authors express their gratitude to the staff of the Institute of Nuclear Physics, Moscow State University, for their expert assistance in analyzing the results of the experiment. Our appreciation is due to P. I. Kostin, who developed the digital display for M-11 and made the total package operational on the BESM-6 computer. This work was most interesting and useful to us. The work was carried out in the Laboratory of Nuclear Physics, Moscow State University.

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