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FISSION CROSS SECTIONS IN THE INTERMEDIATE ENERGY REGION

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Abstract: Until recently there has been very little cross section data for neutron-induced fission in the intermediate energy region, primarily because no suitable neutron source has existed. At Los Alamos, the WNR target-4 facility provides a high-intensity source of neutrons nearly ideal for fission measurements extending from a fraction of a MeV to several hundred MeV. This paper summarizes the status of fission cross section data in the intermediate energy range (En > 30 MeV) and presents our fission cross section data for ^{235}U and ^{238}U compared to intranuclear cascade and statistical model predictions.

(^{235,238}U(n,f) cross section, ^{232}Th, ^{233,234,236}U, ^{237}Np, ^{239}Pu ratio to ^{235}U, fission, intranuclear cascade model, pre-equilibrium statistical model)

1. INTRODUCTION

Nearly all of the theoretical and experimental results for neutron-induced fission are based on information obtained at relatively low incident energies. There, the fission process proceeds through the stage of compound nucleus formation with a definite excitation energy and a well defined fissioning nucleus. The fission process at higher energies is substantially different. In one picture [1,2], it is believed that a medium-energy projectile interacts with the target nucleus, making a few incoherent scatterings with the constituent nucleons, depositing some energy and ejecting some of them. After the ejected nucleons leave the nucleus, the struck nucleons remaining inside the nucleus dissipate their energy through further collisions. The compound nucleus can thus have a wide range in excitation energy depending on the number and energy of nucleons that were ejected. A detailed description of the fissioning process at intermediate energies is therefore quite complicated: the Z and A distribution of the fissioning system, as well as its excitation energy, needs to be determined. A complete description of the process entails a thorough knowledge of the nuclear level density, fission barriers (which may be temperature dependent) and nuclear viscosity (which affects the fission decay width). Although there have been no high-resolution studies, the small amount of proton-induced fission data in the literature suggests that there is little structure in the fission cross section above the third-chance fission threshold near 20 MeV. This is confirmed with much better resolution by these data. At higher energies, above about 1 GeV, fragmentation begins to compete with fission causing a decrease in the fission cross section with increasing energy.

The number of neutron-induced fission cross section measurements in the energy region above 30 MeV and below about 1 GeV, which we will define for the purpose of this paper as the intermediate energy range, is very small. There is the data of Pankratov [3] which used monenergetic sources to cover the range from 5 to 37 MeV, with 5 points above 30 MeV for ^{238}U and 4 points for ^{232}Th; the results of Gol'danskii et al. [4] at 84, 120, and 380 MeV for ^{232}Th, and ^{235,238}U; and some recent unpublished measurements by Fomichev [5] from 0.7 to 45 MeV for the same materials.

The reason there is so little data is that fission cross section experiments require an intense neutron source with low background, and those conditions simply have not been available in the intermediate energy region until now. Using the 800 MeV pulsed proton beam from LAMPF to produce neutrons by spallation, the WNR target-4 facility [6] provides a source extending from about 100 keV to nearly 800 MeV, depending on the flight path chosen for the experiment, making it possible to perform fission cross section measurements for multiple samples in a single experiment over a broad energy range. The data that we are reporting here are part of a series designed to help resolve discrepancies for all of the long-lived actinides and to provide information about fission cross sections at energies above 20 MeV.

2. EXPERIMENTAL PROCEDURE

The WNR uses 800 MeV pulsed proton beam from the Clinton P. Anderson Meson Physics Facility (LAMPF) incident on a 7.5-cm long, 3-cm diam tungsten target to produce a 'white' source of neutrons extending to hundreds of MeV. This experiment was performed using a 20-m flight path of the WNR target-4 facility which viewed the neutron source at a production angle of 60°. The proton beam consisted of 150-ps wide pulses separated by 3.6 or 1.8 µs with about 3×10^8 protons in each pulse. The macroscopic duty factor of LAMPF gave a rate between 8000 and 16000 of these proton pulses/second.

The neutron beam was contained in an evacuated flight tube and passed through a 2.54 cm thick polyethylene (CH_2) filter to reduce frame overlap; a permanent magnet to sweep out charged particles; and a system of three iron collimators as shown in Ref. 7, giving a beam diameter of 12.7 cm at the fission sample location. Monte Carlo calculations performed to determine neutron inscattering from the collimators showed the amount to be approximately 0.01% at 10 MeV.

The fission reaction rate was measured in a fast parallel plate ionization chamber holding multiple foils of oxide fission material 10.2 cm in diameter. The fission-foil deposits were vacuum deposited onto 127 µm thick stainless steel backings. The foils used in this measurement were located in the chamber used earlier [8,9]. A ^{252}Cf deposit was included in the chamber to gain match pulse height spectra and for diagnostic purposes. Flight paths used for these results were obtained using ^{12}C neutron transmission resonances.

After passing through the fission chamber the neutron flux was determined using two detector systems. Although the setup for these fission measurements is similar to that described in Ref. [8], there are some differences. We installed two sets of proton-recoil telescopes to monitor the neutron flux, one covering the region up to 26 MeV, and the second overlapping that and extending to 250 MeV. The higher energy flux measuring detector system was a medium-energy proton recoil telescope (MET). That device consisted of one 7.62-cm square x 0.16-cm thick plastic scintillator paddle, a second 7.62-cm square 0.64 cm thick paddle, and a 7.62 x 7.62 x 17.78 cm^3 CsI(Tl) total energy detector aligned at a scattering angle of 15° relative to the incident neutron beam axis. Two thicknesses of carefully matched CH_2 and high-purity graphite targets were used in this system. The beam was then dumped in a concrete shield 15 meters from the MET. A measurement of the neutron fluence obtained using the ^{235}U(n,f) yield rate and the fission cross section results is shown in Fig. 1, where the solid line is an intranuclear cascade calculation. Additional measurement details are available in another contribution to this conference [10].

An off-line analysis of the data was performed to subtract a small time-uncorrelated background, correct the fission rate spectra for the background resulting from high-energy ($E_n > 35$ MeV) neutron interactions in the steel backing and oxide content of the fission deposits, and to correct for neutron transmission through any upstream material in the chamber. The chamber was also disassembled and the fission foils were alpha counted to determine their thicknesses. The results of a mass spectroscopic analysis provided by ORNL was used to identify contaminant mass contributions in cases where individual alpha particle peaks could not be resolved. We measured fission cross section ratio data for all of the major actinide contaminants during this experiment and those data were used to correct the results shown here.

3. RESULTS AND DISCUSSION

The fission cross sections obtained for ^{235}Uand ^{238}U over the entire range of this discussion are shown in Figures 1 and 2. Above about thirty MeV, the data show a slow decrease and levelling off near 100 MeV. Other neutron [3,4] and proton [11,12,13] induced fission data available from published literature is shown as well.

We have taken a considerable amount of data for ^{232}Th, ^{233,234,236,238}U, ^{237}Np, ^{239}Pu fission ratios to ^{235}U as part of the present measurement program [7,8]. One feature of the fission systematics at intermediate energies is obvious from those data -- the ratios all reach constant, but different, values above about 20 MeV, extending to the upper limit of our ratio measurement, 400 MeV.

There have been some attempts to calculate the behaviour of the fission cross section at medium energies. Shown in Fig. 3 are the results of the GNASH pre-equilibrium-statistical model code calculation [14]. The code incorporates a Hauser-Feshbach statistical calculation, using level densities obtained from Gilbert and Cameron parameters. Fission widths are calculated using both barriers in the complete damping approximation. The user can supply an enhancement factor (due to nuclear shape deformations) to the level densities at the two saddle points. Those calculations reproduce proton-induced fission results reasonably well, but are significantly above the neutron data.

Additional calculations [15] using an intranuclear cascade (INC) model preceeding evaporation, include several treatments of the fission process. Figures 4 and 5 show the results of some of those calculations compared to both neutron and proton fission data. Although the data disagree with the calculations at lower energies, the agreement is good in the region starting at about 100 MeV where the INC model is believed applicable. Our fission data seem systematically higher than the (p,xf) data of Steiner and Jungerman [13], but within their quoted error.

The data presented here provide completely new information about the fission process, covering the broadest intermediate energy range to date. These results provide a challenge for theorists to develop a model that can describe the entire range. In addition, having data throughout the intermediate energy range allows a fission chamber to be used as a neutron flux monitor for medium-energy studies with confidence for the first time.

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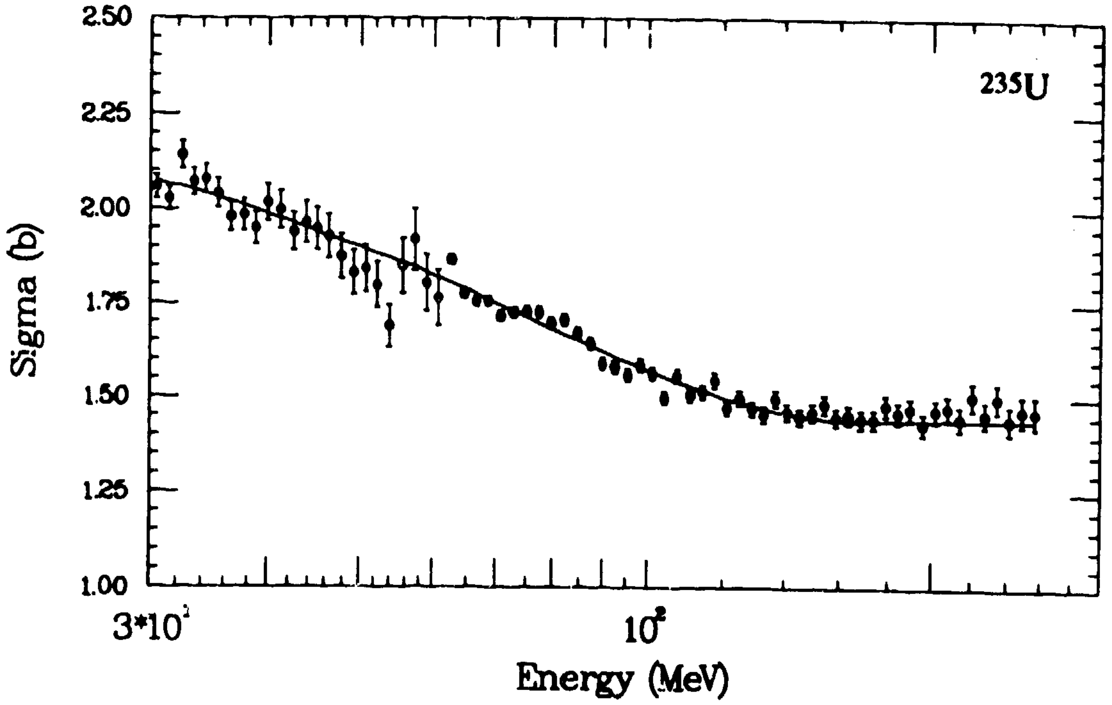

Fig. 1. Fission cross section of ^{235}U as a function of neutron energy. The smooth curve is a polynomial parameterization of the data.

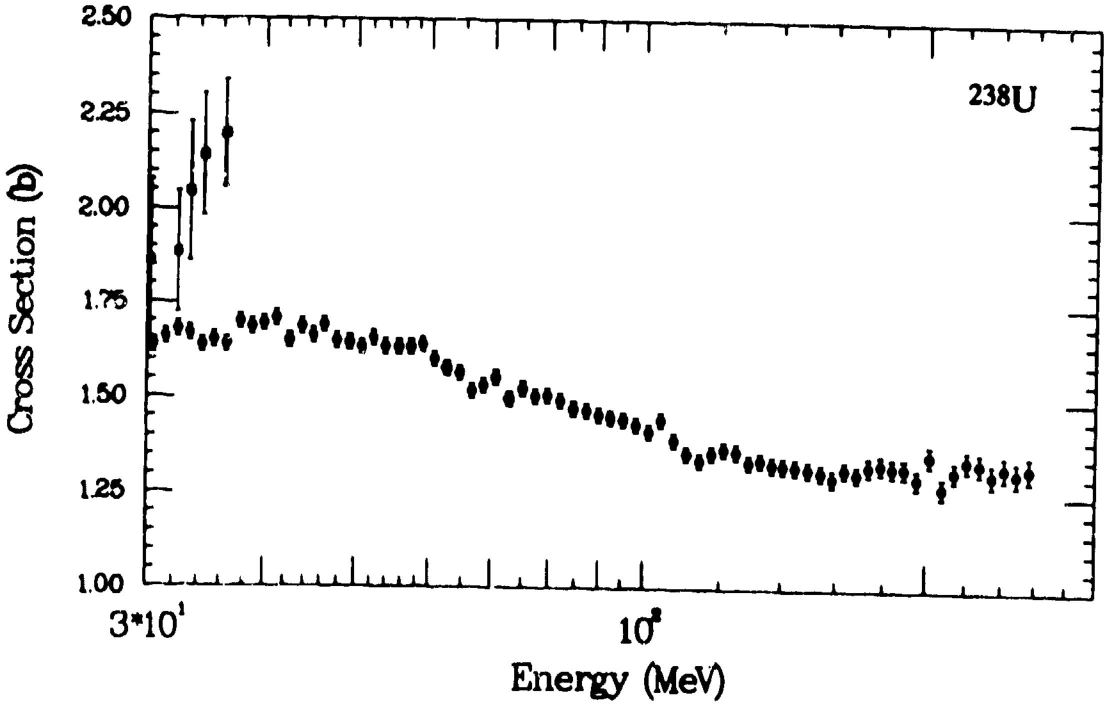

Fig. 2. Fission cross section of ^{238}U from the present measurements (filled circles) compared to the data of Ref. 3. (open boxes) as a function of neutron energy. The smooth curve is a polynomial parameterization of the data.

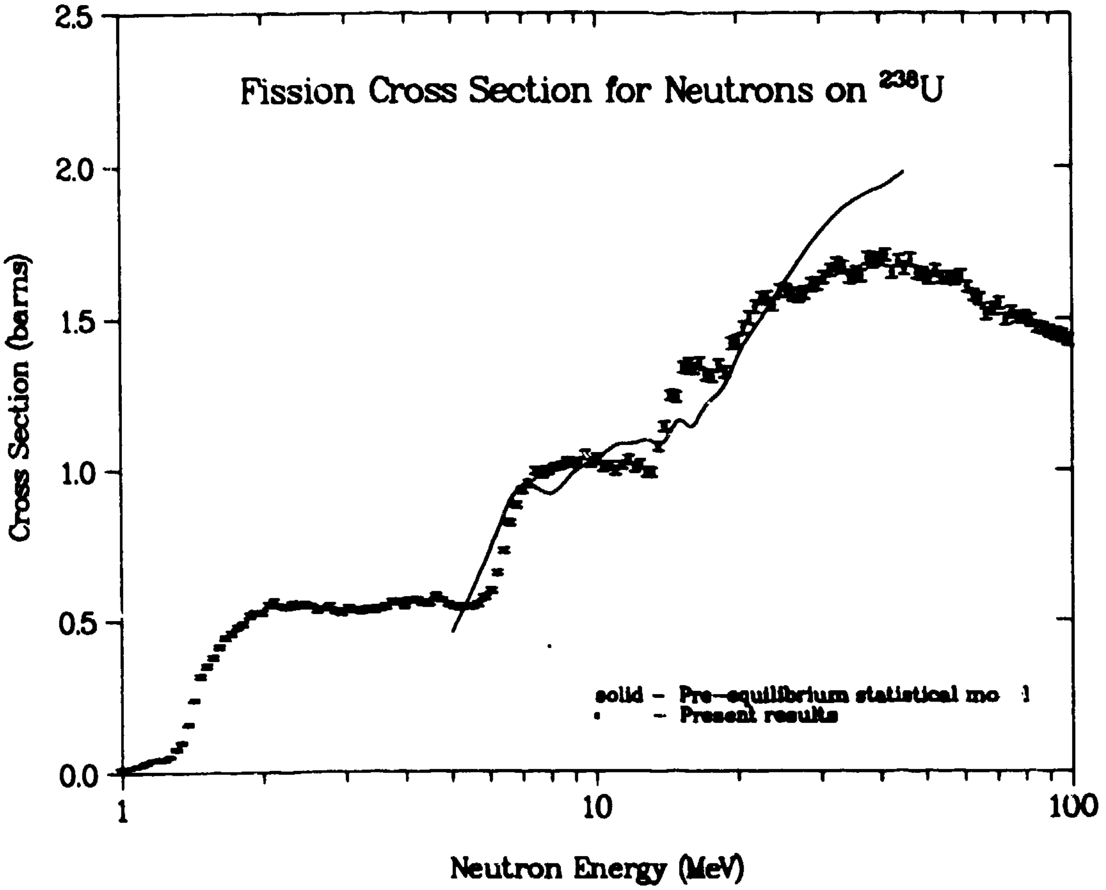

Fig. 3 A comparison of fission cross sections calculated with a pre-equilibrium-statistical model and the present results for ^{238}U.

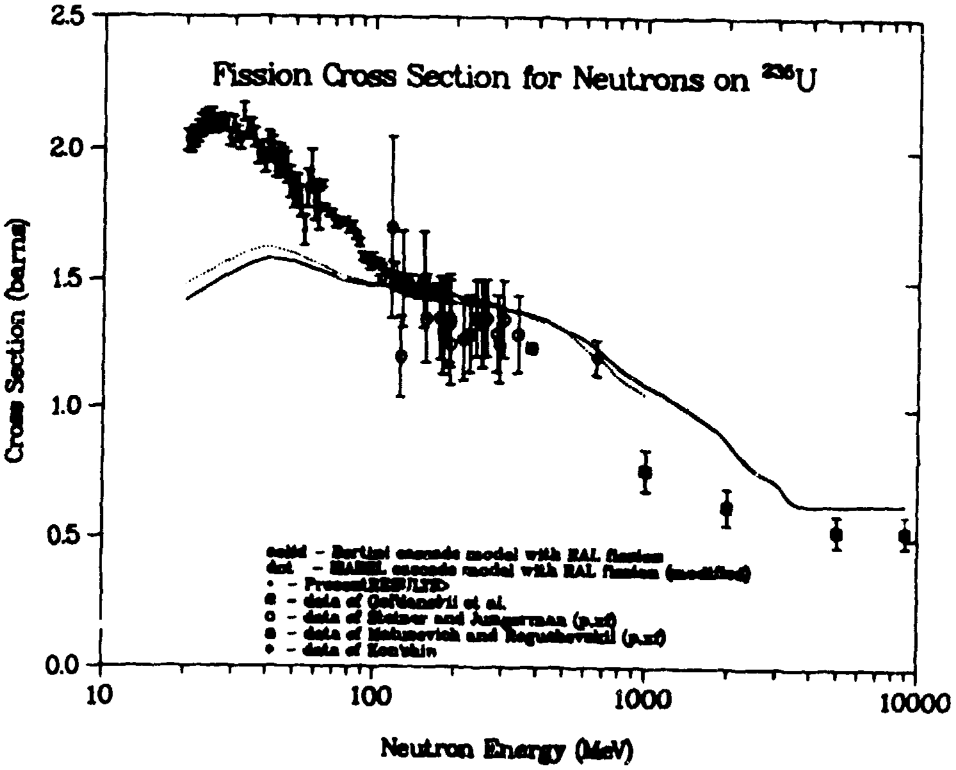

Fig. 4. A comparison of fission cross sections calculated with intranuclear cascade models, the present results for ^{235}U, and other data for neutron and proton-induced fission.

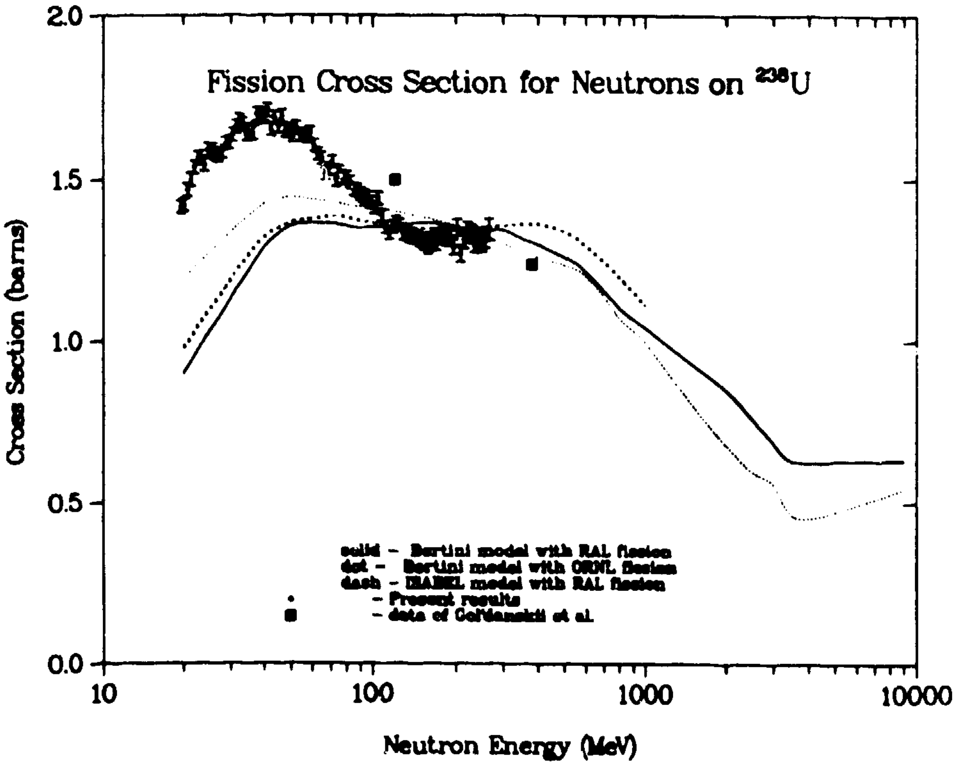

Fig. 5. A comparison of fission cross sections calculated with intranuclear cascade models, the present results for ^{238}U, and other data for neutron.