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LA-UR-88-3321



LA-UR--88-3321

DE89 002046

TITLE CALCULATED MEDIUM-ENERGY FISSION CROSS SECTIONS

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SUBMITTED TO The American Nuclear Society Conference, "Fifty Years with Nuclear Fission," April 26-28, National Bureau of Standards, Gaithersburg, Maryland

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FORM NO 836 R4
ST NO 2629 5/81

# CALCULATED MEDIUM ENERGY FISSION CROSS SECTIONS

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## ABSTRACT

Calculations were made of neutron-induced fission cross sections on $^{238}$U and $^{237}$Np to compare with new data available up to 100 MeV. This process also produced fission barrier parameters for neptunium and uranium compound systems required for calculation of p + $^{238}$U fission cross sections. To achieve reasonable agreement with higher energy neutron-induced fission data, a phenomenological enhancement to barrier heights based upon the average angular momentum of the compound system was required. These calculational procedures resulted in predictions of $^{238}$U(p,f) cross sections that agree well with available data.

# CALCULATED MEDIUM-ENERGY FISSION CROSS SECTIONS

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The GNASH[1] preequilibrium-statistical nuclear model code was used to calculate neutron-induced fission cross sections over the incident energy range from a few MeV to 100 Mev for $^{238}$U and $^{237}$Np. These calculations were compared with the new experimental results of Lisowski et al.2. This process also allowed determination of barrier parameters appropriate for theoretical investigation of $^{238}$U(p,f) cross sections over a similar range where little experimental data exists. As described in an accompanying paper to this conference[3] calculated compound system fission cross sections and excitation energies determined via this process were combined with models for fission fragment yields, excitation energies, and fragment de-excitation to produce fission neutron and gamma ray emission spectra.

Two versions of the GNASH code were utilized for the calculations described here. Both employ the exciton preequilibrium formalism of Kalbach[4]. Multistage preequilibrium emission processes were also included for higher incident energies The first version employs a complete Hauser-Feshbach compound nucleus treatment which was used for incident energies up to 32 MeV. The second version uses multi-step Weisskopf-Ewing evaporation theory and, because of the significantly faster computational times, was employed for $32<E_i<100$ MeV. Both versions include a fission model that allows specification of barrier parameters (height, curvature) for up to three uncoupled oscillators. At each barrier a spectrum of transition states are constructed using bandhead data above which a continuum of states are described using the Gilbert-Cameron[5] level density model. To account for symmetries existing at each barrier, an enhancement factor multiplies directly the calculated state density. More details concerning fission models can be found in Ref 1.

The initial step in the cross section calculations employed the ECIS[6] coupled-channel optical model code to calculate neutron and proton transmission coefficients as well as direct reaction cross sections. These results were used for both the Hauser-Feshbach and evaporation model GNASH calculations. Because of the complexity of calculations employing a double humped model at higher energies where 20-25 compound systems were involved, we utilized a single-barrier model throughout the calculations. Parameters for this model were then determined from adjustments required to fit the neutron fission cross section excitation function. As an indication of the agreement obtained via this procedure, Figure 1 compares our calculated results with the new Lisowski (n,f) measurements for $^{237}Np$. To duplicate the structure occurring in the cross section occurring for energies around 20-25 MeV significant enhancements (factor of 15) had to be applied to state densities calculated for the $^{235}Np$ compound system. The question of transition state density enhancements was an important aspect of the present calculational effort. From microscopic state density calculations (Jensen[7]) such enhancements are expected to die out at excitation energies above 20-30 MeV. However we found it necessary to have such enhancements disappear at much lower excitation energies (around 10 MeV) in order to match reasonably well the decrease in the fission cross section occurring at higher energies. Another problem encountered at high energies concerned barrier heights needed for neutron deficient compound systems of neptunium and uranium. Because of the number of compound systems contributing to the total fission cross section and because of the general trend of increasing neutron binding energies, calculated fission components using standard barrier heights resulted in significant overprediction when compared with these new data. To correct this situation required very high fission barrier heights and enhancement factors near unity. To circumvent this problem phenomenologically, we introduced a J(J+1) term in the fission barrier height determination. Here an average J was computed from the transmission coefficient data and this term was added to barrier heights obtained as input. The addition of this term is counter to angular-momentum corrections normally made, where such effects effectively reduce barrier heights. However as shown by the dotted line in Fig. 1, without such a purely empirical term , there would have been no possibly of reproducing these data within the context of the present calculations. As a final step in the fission cross section calculations, the barrier parameters obtained for uranium and neptunium compound systems via these analyses of $^{238}U(n,f)$ and $^{237}Np(n,f)$ data were used without further modification to calculate $^{238}U(p,f)$ cross sections . The results of this calculation are compared with data in Fig. 2 where reasonable agreement occurs.

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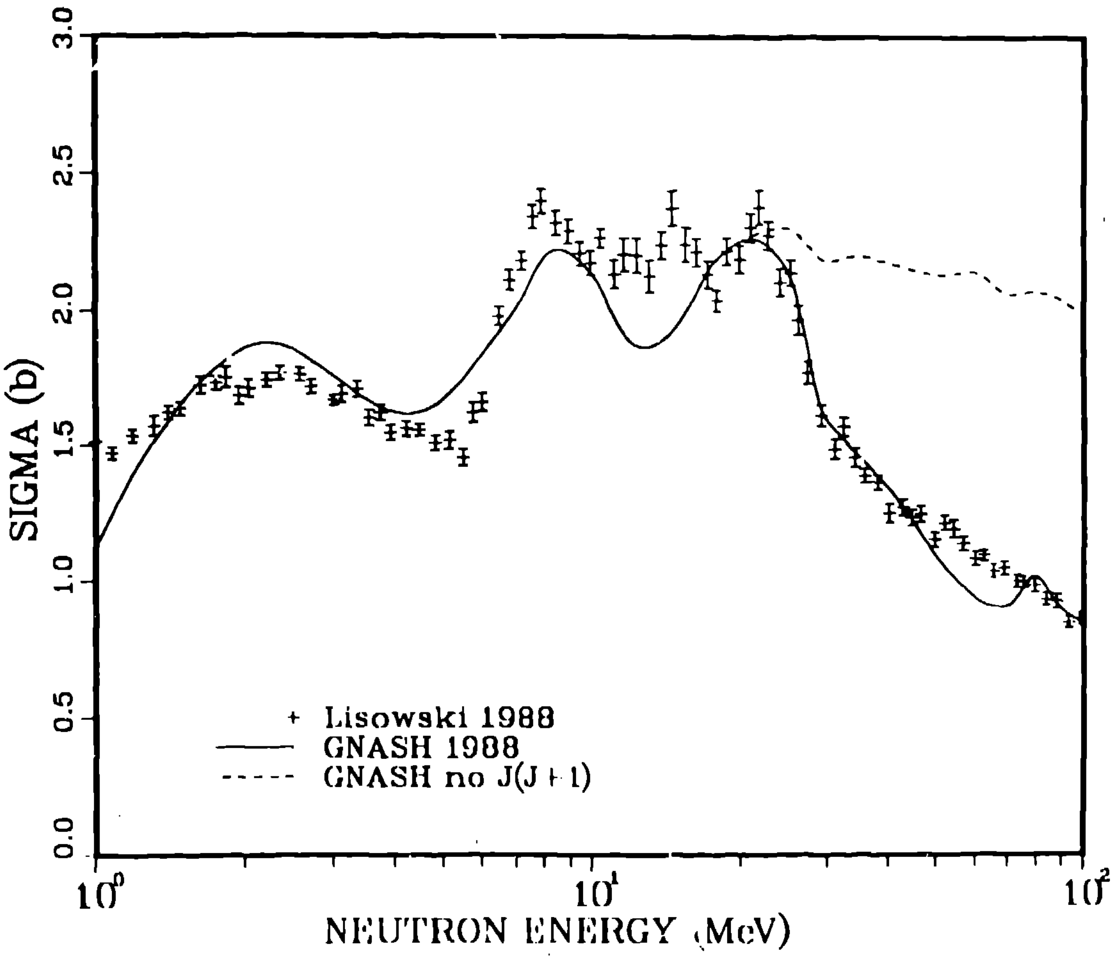


Fig 1. The results for calculated n + $^{237}Np$ cross sections are compared with the data of Lisowski. The dashed curve indicates values obtained without use of the J(J+1) term in the barrier heights.

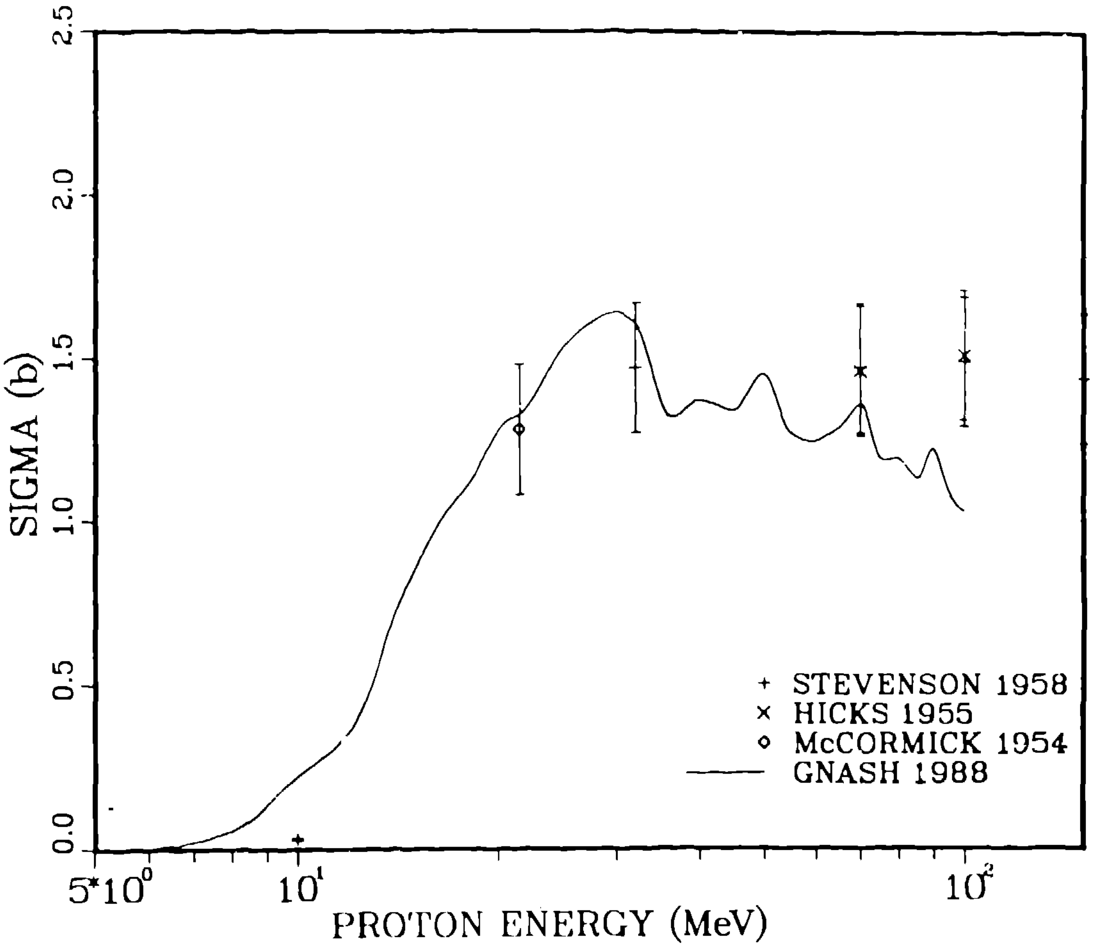


Fig 2. Calculations of the p + $^{238}U$ cross sections made using parameters determined via the (n,f) analysis described in the text are compared with available data.