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TITLE PRELIMINARY CALCULATIONS OF MEDIUM-ENERGY FISSION CROSS SECTIONS AND SPECTRA

AUTHOR(S) M. Bozoian, T-2
E. D. Arthur, T-DO
D. C. George, T-2
D. G. Madland, T-2
P. G. Young, T-2

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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M. Bozoian, E. D. Arthur, D. C. George, D. G. Madland, and P. G. Young
Applied Nuclear Science Group
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

Nucleon-induced fission cross sections determined from a statistical preequilibrium model are used in conjunction with a new scission-point model of fission fragment mass, charge and excitation energy distributions to produce evaporation model calculations of particle and gamma spectra and multiplicities from fission. Comparisons are made to experiment for the 14.5-MeV neutron-induced fission of ^{238}U. In addition, calculated particle and gamma spectra will be compared with the ENDF/B library for 2- and 5-MeV neutron-induced fission of ^{235}U and ^{238}U, respectively. Initial predictions for these same quantities for proton-induced fission reactions at energies up to 100 MeV will be presented and discussed.

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INTRODUCTION

The GNASH[1] preequilibrium-statistical nuclear model code is used to calculate neutron-induced fission cross sections over the incident energies of a few MeV to 100 MeV for ^{238}U and ^{237}Np, as well as p + ^{238}U fission cross sections over a similar energy range. These calculated compound system fission cross sections and their excitation energies are then used as input to a scission-point model, which determines fission fragment masses, their yields, and excitation energies. The latter are used in an evaporation model version of GNASH to calculate neutron emission spectra resulting from de-excitation of the fragment masses.

DETERMINATION OF (n,f) and (p,f) CROSS SECTIONS

As described in an accompanying paper[2] to this conference, the GNASH preequilibrium-statistical model code was used to produce cross sections for fission of the respective compound nuclei that are involved in medium-energy nucleon-nucleus fission processes. Two versions, a multistep Hauser-Feshbach and Weisskopf-Ewing evaporation theory formulation, were used in this process. Both incorporate preequilibrium corrections and contain relatively sophisticated fission models. As described in Ref. 2, calculations were made to compare with new (n,f) data from which fission parameters required for neptunium and uranium compound systems occurring in p + ^{238}U fission were determined. From this procedure, fission cross-section components for the compound systems (up to 25-30 occurring for higher incident energies) appropriate for the neutron or proton-induced reaction process of interest were determined. Simultaneously, average excitation energies associated with each fissioning compound system were determined by weighting populations occurring during particle emission that produced systems that fissioned. As described below, these data were used with a scission point model to determine fission fragment excitation and kinetic energies.

THE SCISSION-POINT MODEL[3]

The basis of this model is the recovery of a fission fragment mass distribution from its given fission product mass distribution. The heavy fission product masses are augmented by half the total average neutron multiplicity, ν:

$$\bar{\nu}_H = \frac{1}{2}\,\bar{\nu} = \frac{1}{2}\;\frac{E^* - <E_\gamma^{tot}>}{<S_n> + <\eta>} \;, \tag{1}$$

where E^* is either the excitation energy or average excitation energy of a fragment pair at the scission point in first-chance or multiple-chance fission, respectively; $<E_\gamma^{tot}>$ is the Hoffmans' expression for average gamma-ray competition energy per fission fragment; $<S_n>$ is the average neutron separation energy; and $<\eta>$ is the average neutron kinetic energy. The recovery continues until the difference between the current $\bar{\nu}_H$, the average neutron multiplicity of the heavy fragment, and the previous $\bar{\nu}_H$ is less than 1. At all times the sum of the heavy and light fission fragment masses equals the mass of the fissioning nuclide.

The fission fragment charge distribution is described by a thin Gaussian and each fragment mass is associated with two charges on this Gaussian. These charges are determined from the Unchanged Charge Distribution (UCD) hypothesis, which assumes that the pre-fission and post-fission charge distributions are identical.

The excitation energy of the fission fragment pair, E^*, is found in terms of ε, the excitation energy of the compound nucleus formed from the incident nucleon prior to fission; E_r, the energy release per fission; and E_f^{tot}, the total fission fragment kinetic energy:

$$E^{*\uparrow\downarrow} = \varepsilon + E_r^{\uparrow\downarrow} - E_f^{tot\uparrow\downarrow} \quad . \tag{2}$$

The superscript up-and-down arrows differentiate between the two charges associated with each fragment mass. The sum of the charges of each fission fragment pair always equals the charge of the fissioning compound nucleus.

The excitation energy, $E^{*\uparrow\downarrow}$, is partitioned between the two fragment masses according to the Gilbert-Cameron[5] level density formula, *e.g.*,

$$E_H^{*\uparrow} = E^{*\uparrow} \Big/ \left(1 + \frac{a_L^{\downarrow}}{a_H^{\uparrow}}\right) \;, \tag{3a}$$

$$E_L^{*\uparrow} = E^{*\uparrow} / \left(1 + \frac{a_H^\uparrow}{a_L^\downarrow}\right) , \qquad (3b)$$

where the subscripts H and L refer to heavy and light members of each fission fragment pair and the a's are the Fermi gas parameters based upon Gilbert-Cameron. Similar expressions hold for $E_H^*\downarrow$ and $E_L^*\downarrow$ for the fragment mass pair in question.

The fission fragment yield for each mass pair is obtained from the binary fission hypothesis that assumes identity of the heavy and light distributions. The fission fragment yield is then partitioned between the two charges for each mass according to the previously mentioned charge distribution Gaussian.

The GNASH evaporation model is provided with these calculated fission fragment masses, their excitation energies, and yields and kinetic energies per nucleon. The de-excitation of the fragments allows calculation of multiplicities as well as neutron and gamma-ray emission spectra.

COMPARISONS TO EXPERIMENT AND INITIAL PREDICTIONS

The medium-energy fission model is compared with neutron emission, mass distribution and energy data for 14.5-MeV neutron-induced fission of ^{238}U.[6] Our expression for average total fragment kinetic energy agrees with Ref. 6's experimental value to within 0.06%. The average total fragment kinetic energy formula as a function of pre-neutron emission fragment mass tracks the data reasonably well (see Fig. 1). We also obtain good agreement with the data for average number of emitted neutrons as a function of pre-neutron emission fragment mass (the so-called "saw-tooth curve") except for the highest fission fragment masses, ≥ 150 amu. We obtain $\bar{\nu} \approx 2.5$, whereas the data is $\bar{\nu} \approx 3.5$. For the light fragment mass complements of these heavy masses, we find $\bar{\nu} \approx 1.25$, whereas the data is $\bar{\nu} \approx 0.75$. We're exploring possibilities of more refined level parameters for these very neutron-rich fragments, modifying the initial recovery criterion of $\bar{\nu}_H = 1/2\bar{\nu}$, refining the iterative procedure to recover the fragment mass distribution, or some combination of these latter three.

After conversion from the center-of-mass frame calculations done in GNASH to the Lab frame, neutron spectra for 2 MeV n + ^{235}U are compared with ENDF/B library data, Fig. 2. We conclude this summary with a composite figure, Fig. 3, showing neutron spectra for 5 MeV n + ^{238}U compared with ENDF/B data, and predictions of neutron spectra for 15 MeV n + ^{238}U and 70 MeV p + ^{238}U.

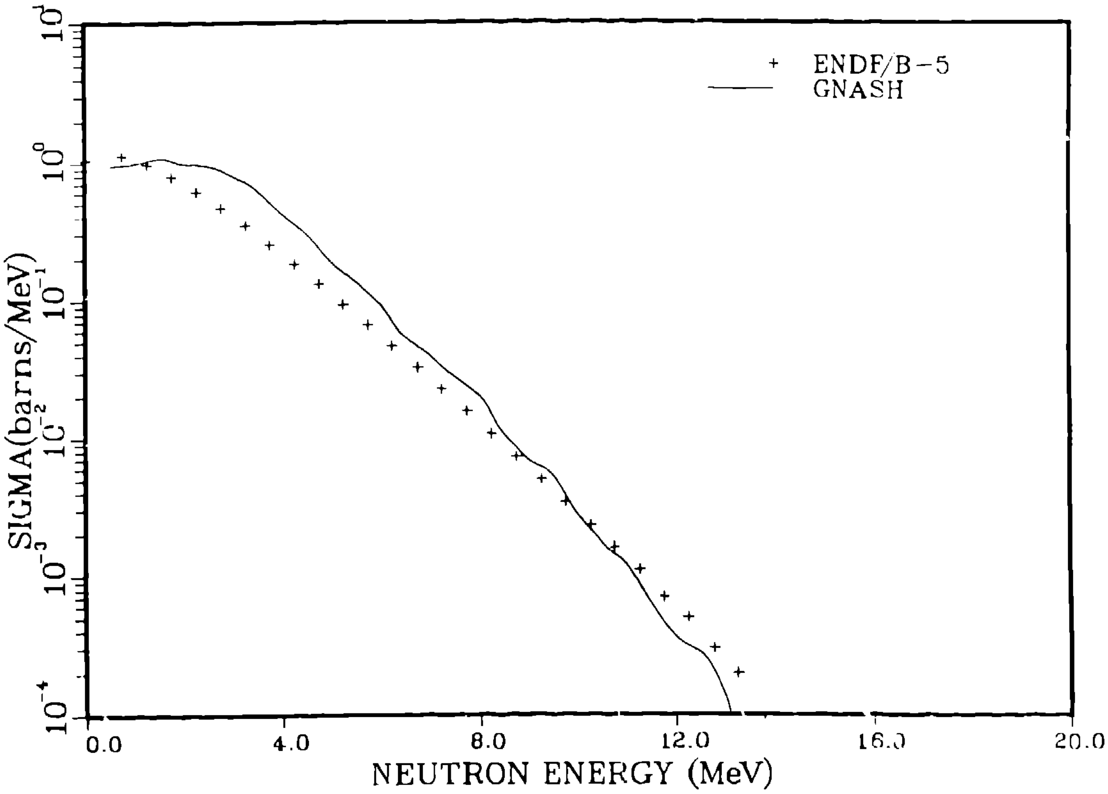

Fig. 2. 2 MeV n + ^{235}U fission neutron spectrum.

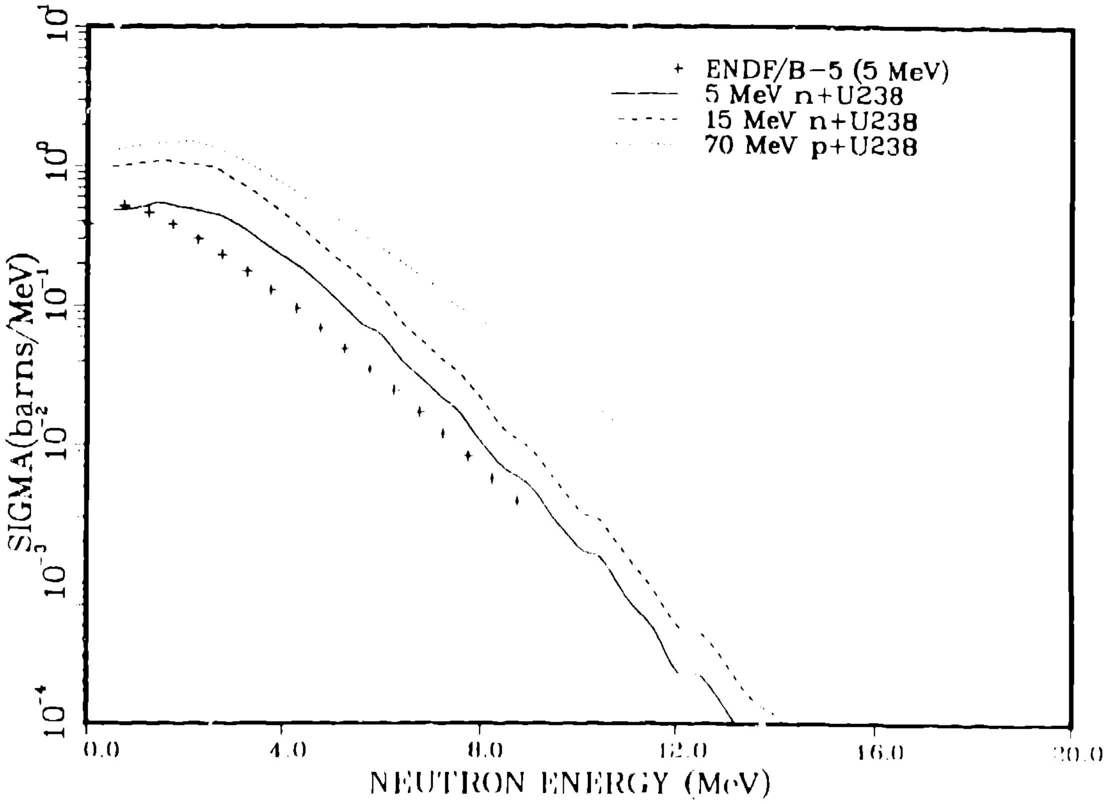

Fig. 3. Neutron spectra from fission of ^{238}U.

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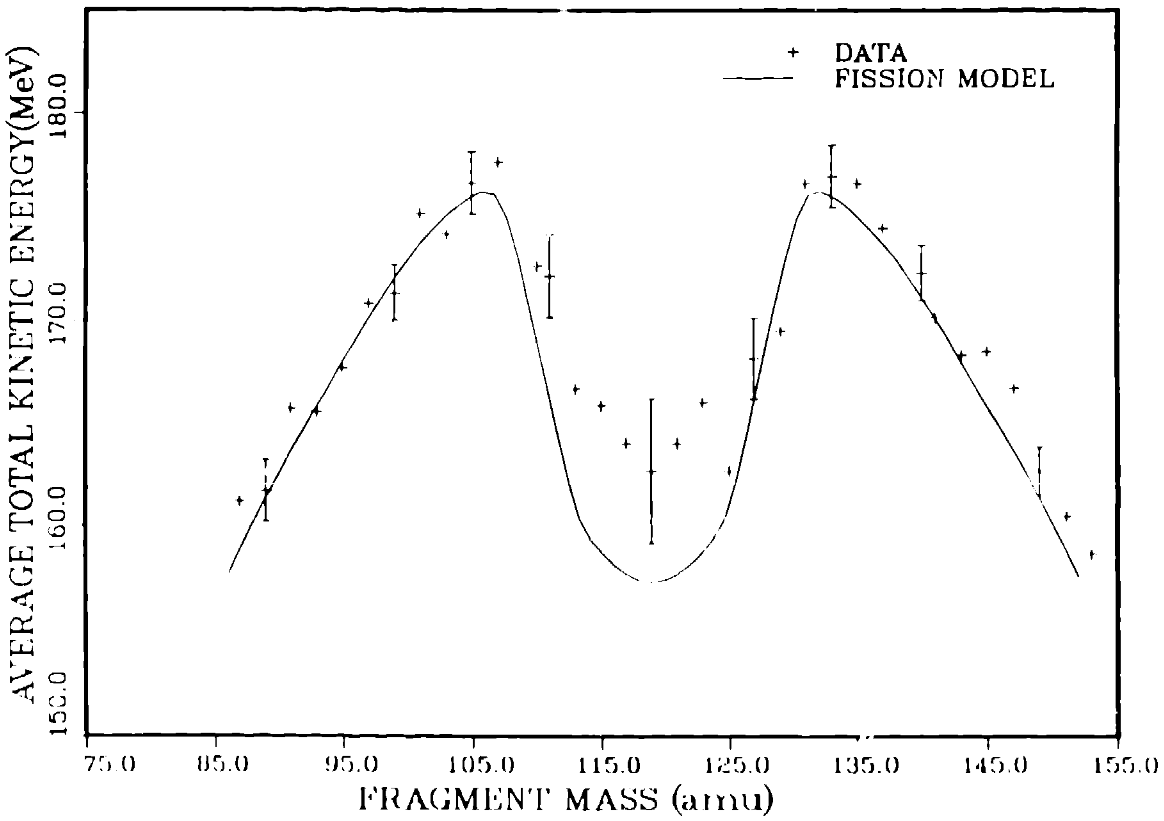

Fig. 1. Average total fragment kinetic energy as a function of pre-neutron emission fragment mass (data is from Ref. 6).