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CALCULATION OF NEUTRON CROSS SECTIONS FOR TUNGSTEN ISOTOPES

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[Neutron Cross-Section Calculations, ^{182,183,184,186}W, 0.2-20 MeV, σ(E), Hauser-Feshbach, Preequilibrium, Coupled-Channel Methods]

Neutron-induced cross sections on tungsten isotopes have been calculated in the energy range between 1 and 20 MeV using preequilibrium-statistical model techniques. The success of these calculations, which form part of an effort to improve the evaluated neutron and gamma-ray production cross sections for tungsten appearing in ENDF/B, depends strongly on the determination of consistent input parameter sets applicable over the entire range of interest. For example, neutron optical model parameters have been derived through a simultaneous analysis of total cross sections, resonance data, and angular distributions. These parameters, when used in multistep Hauser-Feshbach calculations, produce good agreement with varied experimental data such as neutron inelastic scattering excitation functions and (n,2n) cross sections. Likewise, gamma-ray strength functions have been determined through fits to neutron capture data that produce calculated results that compare well to measured gamma-ray production cross sections. A description of the techniques used in such parameter determinations as well as comparison of calculated results to experimental data will be presented.

Preliminary calculations of neutron-induced cross sections on tungsten isotopes have been made using preequilibrium statistical model techniques from 0.2 to 20 MeV. This effort comprises part of a new tungsten evaluation[1] which hopefully will correct problems in the present ENDF/B evaluation arising from energy imbalance at several energies.

The determination of neutron optical parameters plays an important role in the present calculations since parameters are needed which realistically describe low energy neutron emission such as in (n,2n) reactions while also producing reasonable values for compound nucleus formation cross sections at higher energies. To produce such parameters, we adopted the following approach. Since the tungsten isotopes are deformed, we determined the direct inelastic cross section from scattering off low lying collective states through use of coupled-channel calculations. This cross section was then subtracted from evaluated values of the experimental total cross section and an effort was made to fit this remainder using the spherical-optical model with realistic parameter values. By doing so, we sought to separate compound and direct reaction effects so that reaction cross sections determined from these optical parameters would in fact represent mainly the compound nucleus formation cross section. In this manner, Hauser-Feshbach calculations could be made without having to adjust the formation cross section to account for direct effects not included in the reaction mechanism.

To determine direct inelastic scattering cross sections from the 2^+ and 4^+ rotational states of the even tungsten isotopes, we used the JUPITOR[2] coupled channel program along with deformed neutron optical parameters and β_2, β_4 values determined by Delaroche.[3] We then took recent evaluations of the ^{182,184,186}W total cross sections based mainly on new measurements of Guenther[5] as well as those of Foster[6] and subtracted these calculated direct inelastic scattering contributions. For ^{183}W we used an average of the evaluated total cross sections for ^{182}W and ^{184}W and subtracted contributions from direct inelastic scattering to the $1/2^-$, $3/2^-$, $5/2^-$, and $7/2^-$ levels. As an example, the subsequent spherical optical parameters determined for ^{184}W are shown in Table I.

Along with this effort, we also extracted approximate gamma-ray strength functions from fits to ^{182,183,184,186}W(n,γ) cross sections. In doing so, we assumed a giant dipole resonance form consisting of one Lorentz shape whose width and location were adjusted to approximate the double Lorentz shape which exists because of deformation effects. We did not attempt, for these preliminary calculations, to include refinements such as the pygmy resonance and/or dip occuring for $\varepsilon_\gamma \sim 6$ MeV in the shape of the strength function. Our present gamma-ray strength functions enabled us to describe effectively gamma-ray competition to neutron emission, which is important especially around the (n,2n) reaction threshold.

To test our choice of neutron optical model and gamma-ray strength function parameters, we performed two sets of calculations, one for incident neutron energies below 5 MeV and one for energies from the (n,2n) threshold up to 15 MeV. The latter calculations also provided information concerning the suitability of the Gilbert-Cameron level density parameters[7] used throughout the calculations. Figure 1 illustrates results obtained for ^{184}W from optical model and width-fluctuation corrected Hauser-Feshbach calculations using the optical parameters of Table I. For the calculations of the total cross section and the excitation cross

Table I. Spherical Optical Model Parameters for n + ^{184}W

	r(fm)	a(fm)
V(MeV) = 55.2-0.13E	1.1	0.45
W_{SD}(MeV) = 5.2+0.23E	1.409	0.4
Above 6 MeV		
W_{SD}(MeV) = 6.6		
V_{SO}(MeV) = 6.2	1.01	0.75

sections for the 0.11 MeV (2^+) and the 0.365 MeV (4^+) states, we added the appropriate direct inelastic scattering contribution (as obtained from JUPITOR) to the Hauser-Feshbach or spherical optical model results. The elastic cross section includes both contributions from the shape elastic and compound elastic cross sections. Figure 2 compares calculated (n,2n) results to the experimental ^{182,183,184,186}W(n,2n) cross sections measured by Frehaut[8] from threshold to 14 MeV. Here the multistep Hauser-Feshbach code GNASH[9] was used along with preequilibrium corrections based on the Kalbach[10] exciton model. The agreement with these differing types of data confirms several things, particularly the low and high energy behavior of the neutron transmission coefficients as well as the value of the gamma-ray strength functions. Finally, in Figure 3 we compare our neutron emission spectrum obtained by a combination of calculated results from ^{182,183,184,186}W with measurements on natural tungsten by Hermsdorf et al.[11] This comparison provides a further check on our calculation, particularly with regard to preequilibrium corrections applied above 10 MeV.

Thus, our preliminary efforts to determine and verify neutron and gamma-ray parameters have led to values which appear to satisfactorily reproduce the majority of neutron-induced reaction data for tungsten isotopes.

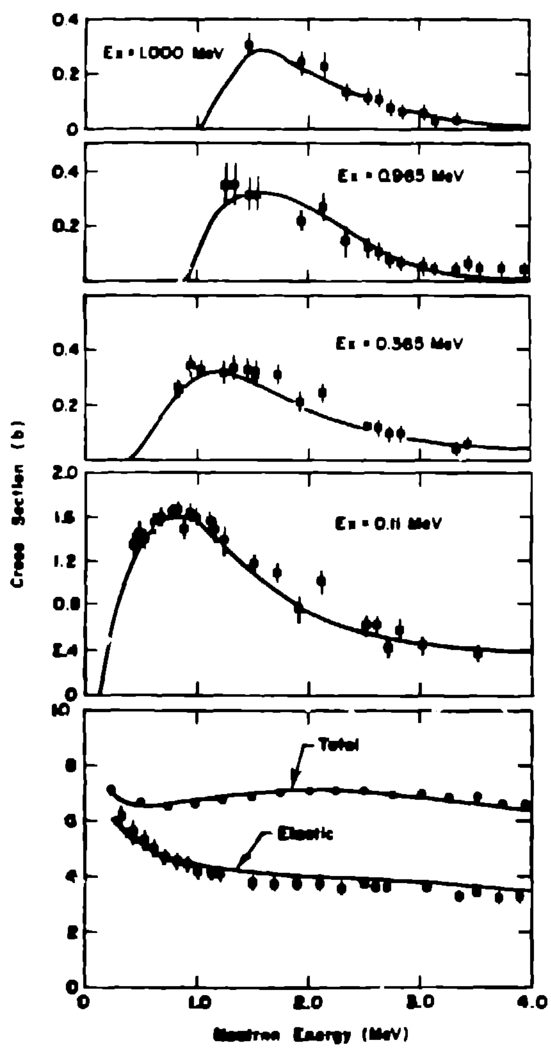

Fig. 1. Calculated values for the total, elastic, an certain inelastic scattering cross sections are compared to the Guenther (Ref. 5) data for ^{184}W.

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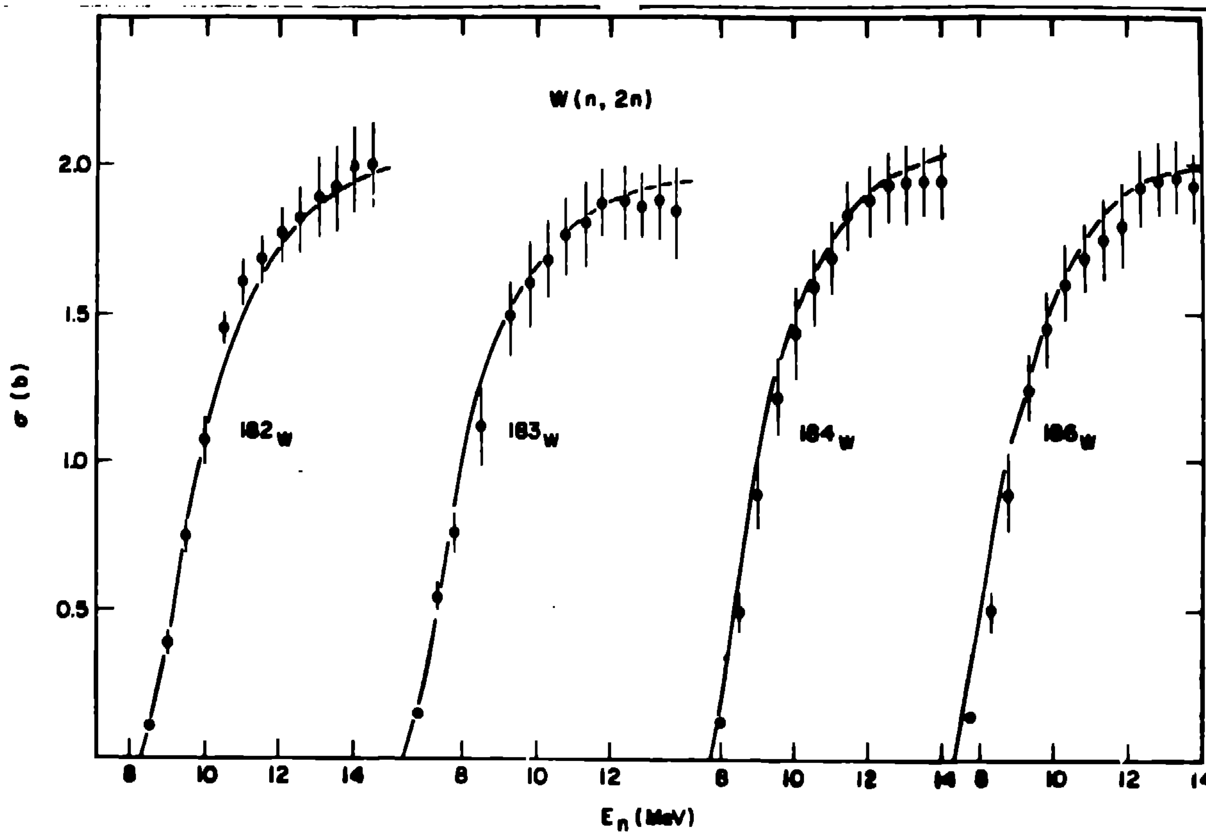

Fig. 2. Calculated 182,183,184,186W(n,2n) cross sections are compared to the Frehaut (Ref. 8) results.

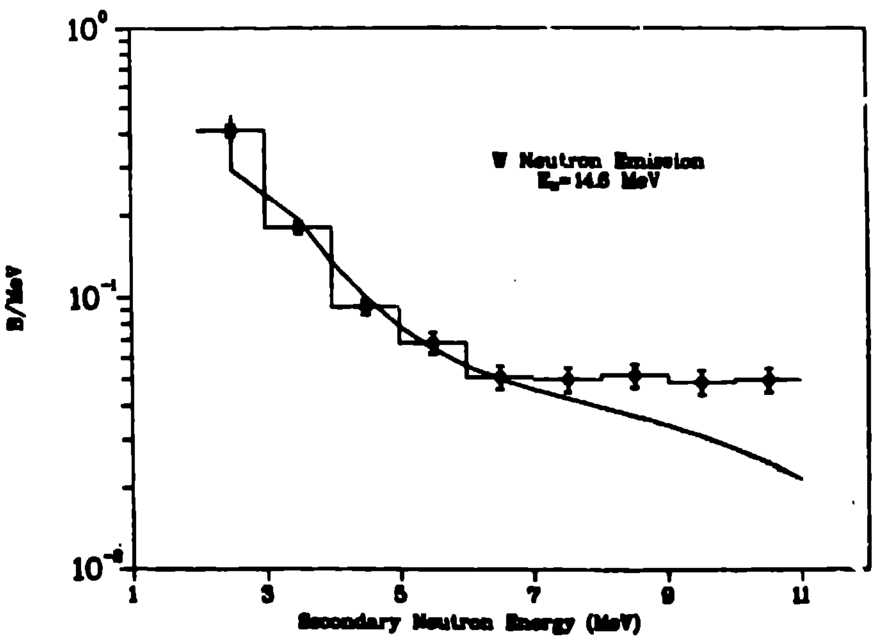

Fig. 3. A comparison of calculated and experimental (Ref. 11) values for the neutron emission spectra induced by 14.5 MeV neutrons.