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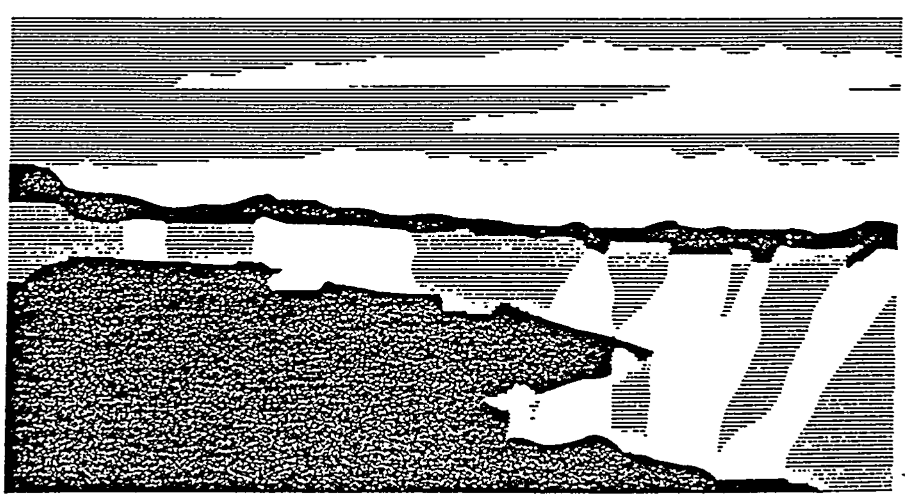

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MULTILEVEL FITTING OF ^{235}U RESONANCE DATA SENSITIVE TO BOHR- AND BROSA-FISSION CHANNELS

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ABSTRACT

The recent determination of the K, J dependence of the neutron induced fission cross section of ^{235}U by the Dubna group[1] has led to a renewed interest in the mechanism of fission from saddle to scission. The K quantum numbers designate the so-called Bohr fission channels[2], which describe the fission properties at the saddle point. Certain other fission properties, e.g., the fragment mass and kinetic-energy distribution, are related to the properties of the scission point. The neutron energy dependence of the fragment kinetic energies has been measured by Hambsch et al.[3], who analyzed their data according to a channel description of Brosa et al.[4] How these two channel descriptions, the saddle-point Bohr channels and the scission-point Brosa channels, relate to one another is an open question, and is the subject matter of the present paper. We use the correlation coefficient between various data sets, in which variations are reported from resonance to resonance, as a measure of both the statistical reliability of the data and of the degree to which different scission variables relate to different Bohr channels. Following the suggestion we made at the 1989 Berlin Conference on *Fifty Years Research in Nuclear Fission*,[5] we have carried out an adjustment of the ENDF/B-VI multilevel evaluation[6] of the fission cross section of ^{235}U, one that provides a reasonably good fit to the energy dependence of the fission, capture, and total cross sections below 100 eV, and to the Bohr-channel structure deduced from an earlier measurement by Pattenden and Postma.[7] We have also further explored the possibility of describing the data of Hambsch et al. in the Brosa-channel framework with the same set of fission-width vectors, only in a different reference system. While this approach shows promise, it is clear that better data are also needed for the neutron energy variation of the scission-point variables.

1. INTRODUCTION

The existence of resonance structure in the low-energy neutron cross sections of fissile target materials came as a surprise to many. If one considers each of the possible fission product pairs as a different fission channel, then the width-to-spacing ratio should preclude observation of resonances. However, the resonances are there, and there are also pronounced asymmetries in the resonance shapes, suggesting that fission is a few-channel process. At the 1955 Geneva Conference on *Peaceful Uses of Atomic Energy*, A. Bohr[2] provided the explanation that is still accepted: For excitations near threshold, the fissioning nucleus in passing over the saddle-point is "cold", i.e., not highly excited. The quantum states representing motion in the fission direction are widely separated and few in number. Bohr suggested that this model should have two observable consequences.

First, the nuclear angular momentum at the saddle point should be concentrated on a collective vibration or rotation leading to a characteristic angular distribution of the fragments. If the nuclear shape at the saddle point is axially symmetric, then the quantum number K, the projection of nuclear angular momentum on the nuclear symmetry axis, can be used to characterize the channel. Secondly, differences in the fission threshold for states of different spin and parity in the compound nucleus can lead to peculiar selection rules in the fission process. In particular, Bohr suggested that the symmetry properties of the wave function in the asymmetry coordinate at the saddle point could affect the mass distribution of the fragments for near-symmetric scission in a predictable way. Bohr went on to state, "If slow-neutron fission of aligned nuclei could be studied, large anisotropies of the fragments would be expected."

This first paper on the Channel Theory of Fission immediately stimulated two kinds of experiments. First, there were attempts to study relative variations in the symmetric fission yield. These were first done for neutron-induced fission of ^{235}U by the Los Alamos Radiochemistry Group[8] and G. A. Cowan et al.[9-11] The positive results of these experiments led to subsequent studies of the neutron energy dependence of very asymmetric cold fission,[12-14] of the average number of prompt neutrons emitted per fission, and of the fragment kinetic energies. The second class of experiments was the determination of K-states by measuring the angular distributions of fragments emitted in the slow neutron fission of aligned targets of ^{235}U. These experiments were first carried out by Roberts and Dabbs et al.,[15-17] somewhat later by Pattenden and Postma,[6] and, very recently, by the Dubna group.[1] One problem with these early measurements was that their interpretation was ambiguous because of a lack of knowledge of the resonance spins. The definitive measurements by Keyworth et al.[18], leading to the determination of spin-separated cross sections[19], was a crucial step in understanding of the K data.

The Brosa model and its application to fission has been discussed by Hambsch and Siegler[20] at the *Seminar on Fission, Pont d'Oye II*. The model has two parts, a multi-modal potential-energy calculation as a function of deformation, and a random neck rupture leading to a distribution of fragment pairs. For the compound nucleus ^{236}U, three modes or channels are found, referred to as Standard I, Standard II, (asymmetric splits) and Superlong, leading to symmetric fragment splits. At this same conference, Weigmann and Hambsch[21] suggested that the Bohr channels might play a role analogous to doorway states in the fission process; their analysis of the statistical properties of the Brosa channels and the correlation of Brosa partial widths led them to the conclusion that the Brosa channels must be fed by common doorway states operating in front of them.

2. CORRELATIONS OF SCISSION-POINT VARIABLES.

When it was first noticed[22] that the variation of the Bohr channel K dependence from resonance to resonance in (^{235}U + n) from Pattenden and Postma[6] shows a definitive correlation with the valley-to-peak ratio in the mass distribution from Cowan et al.[11] (0.80 with 28 degrees of freedom, giving a significance level of 0.9999+), many researchers were convinced that the small variations in fragment mass distribution and kinetic energy, and in ν, the average number of prompt neutrons emitted, were to be explained as a K, J dependence of the modes of motion leading to fission. Further data showed, however, that the fission process is much more complex than had been thought. For example, the earliest measurements of the variation of ν in ^{235}U resonances,[23,24] those reported at the second *International Conference on the Physics and Chemistry of Fission,* were strongly anticorrelated, and it was obvious that one of them was incorrect. But the theorists were by no means unanimous about which one it was, or if a variation of ν existed or not. Later measurements[25,26] at least showed a significant positive correlation with each other, with a significance level of 0.95, from which it could be inferred that the experimenters were measuring the same effect and that the variation likely does exist, but the correlation with J, K, the Bohr-channel descriptors, was not significant. Again, early measurements[27] of the fragment kinetic-energy variation in (^{235}U+n) were suggestive but not conclusive; the data of Hambsch et al.[3] are the definitive work, showing that the effect is a real one, and giving the expected significant negative correlation[28] of kinetic energy with ν (-0.43±0.18 for 21 degrees of freedom, with, e.g., the data of Reed, for a significance level of 0.99+.) But again, Hambsch et al. found that there is a correlation of the Pattenden-Postma A_2 coefficients only with the symmetric fission yield, which they attributed to the Brosa Superlong Channel.

3. MULTILEVEL FITTING OF THE PATTENDEN-POSTMA A_2 COEFFICIENTS AND THE MASS-DISTRIBUTION RATIOS.

Several years ago, we proposed a re-evaluation of the low energy resonance cross sections of ^{235}U for the U.S. Evaluated Nuclear Data File ENDF/B-VI, and carried out a preliminary fit[29] to the spin-separated fission data that attempted to include the Pattenden-Postma angular anisotropies that give the variation of the Bohr fission channels. But this was not incorporated into the later work by Leal et al.[6] We did not ever consider any data on the variation of the average number of neutrons emitted per fission, or of any other of the scission point variables presently thought to be characteristic of the Brosa fission channels. It was first pointed out by Auchampaugh[30] that a two (or more) fission channel description of spin-dependent fission cross sections is not unique; there can be many solutions for the relative orientation of the fission-width vectors. Physically, however, the relative fission-width vectors must have a fixed orientation in channel space, i.e., only one of the many possible descriptions is physically the correct one. We assume that this correct solution is the Bohr-channel representation, the one that fits the measurements of Pattenden and Postma and the Dubna group. An open question is what kind of parametric representation will describe the energy dependence of the scission-point variables in the Brosa-channel representation.

The analysis by Leal et al[6]. of the total, fission, capture, and spin-separated fission cross sections of (^{235}U+n) adequately accounts for the fission-resonance asymmetries and observable interference effects. The approach in the present work is to preserve, insofar as is possible, the fit to the cross sections that Leal et al. obtained, and, at the same time, obtain a set of parameters that will describe the energy dependence of the Bohr-channel resonance structure as reflected in the Pattenden-Postma angular-distribution coefficients. In order to accomplish this, a modification to the SAMMY fitting code was provided by Nancy Larson of ORNL. This modification allows one to search only on the fission-vector directions in channel space. If we use the calculated Leal description of the spin-separated fission cross section as the data set to be fitted, and provide an initial guess parameterization of the fission-vector orientations that give the correct Bohr-channel components, then the SAMMY code will find a local solution that may be close to the vector orientations of the initial guess. We note that in general there are four different orientations in a two-dimensional channel space that give the same fission vector components for each resonance, so if we are fitting a region that has several resonances, a unique solution is clearly impossible unless the off-resonance energy dependence of the data is known.

The present study is an extension of the work we presented at the Berlin conference[5] *and corrects the error that appeared in that parameter set, where the certain of the K-values for the channels were mislabeled.* In this study, we have modified the ENDF/B-VI parameter set in such a way that the predicted cross sections are the same as those in our evaluation, and yet provide a reasonably good description of the Bohr-channel angular distributions. This same set of fission vectors also provides a description of the energy dependence of symmetric fission as measured by Cowan et al.; and, assuming the correlation of K with the symmetric yield ratios, we extended the fit to 80 eV. Finally, we confirm the conjecture in our earlier work that it is possible to obtain a reasonable fit to the energy dependence of the fragment kinetic-energy variation, in the framework of the two Brosa standard channels, by a simple rotation of the fission-vector coordinate system. The objective of the present exercise was to examine if it is possible to develop a predictive capability for the energy dependence of fission variables that are characteristic of the saddle-point configuration and of the scission-point configuration with the same basic fission-width parameters. Perhaps this objective has been met. One question remains open: Is there any physical significance to this result? Or is it simply a demonstration that with enough parameters, one can fit anything.

5. RESULTS AND CONCLUSIONS

Typical fits to the data, corresponding to the parameter set of Table 1, are shown in Figs. 1-12. The odd-numbered figures show the fitting of the A_2 coefficients reported by Pattenden and Postma. The even-numbered figures from 1 to 7 show the Hambsch et al. W_1/W_2 ratios; those from 9 to 11 the Cowan et al. and Hambsch et al. valley-to-peak mass-distribution ratios. Certain features of the results of this exercise should be pointed out. First, as Weigmann and Hambsch have noted, the correlation coefficient between the J=4 partial widths in the K=1 channel and the K=2 channel is consistent with a random orientation of width vectors. This is not the case for the J=3 partial widths, which strongly suggests that our neglect of the K=0 channel for J=3 (so that we can treat the problem as if it were a two-dimensional space) is not justified. Instead, we should consider the adoption of the formalism of Vogt[31], as was done in the recent work of Durston[32] in the multilevel fitting of the spin-separated fission cross sections of (^{235}U+n).

Perhaps it should be emphasized that all the data sets we used in this analysis share in common the assumption that the observed variations are considered to be a property of the resonances, and are reported as an average value for each resonance. This is in marked contrast to the data of Keyworth et al. on the J dependence of the fission cross section of ^{235}U, where the data had a high enough statistical accuracy that spin-separated cross sections as a function of neutron energy could be extracted over the resonances. Only in the case of the recent Dubna measurements of K is the statistical accuracy adequate for a similar analysis; such measurements for the scission-point variables is still lacking.

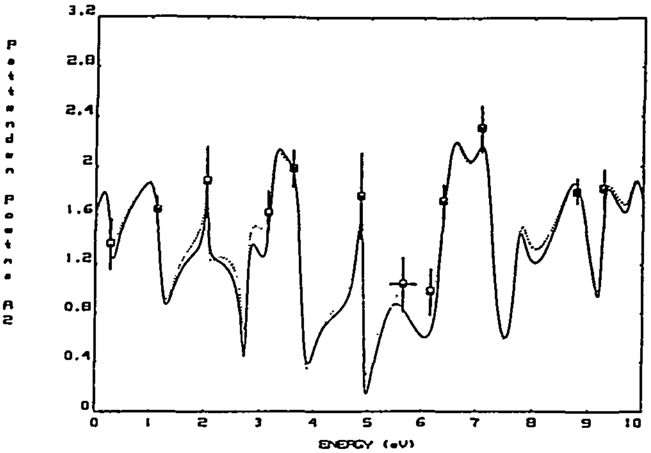

Fig. 1. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the energy range 0 to 10 eV.

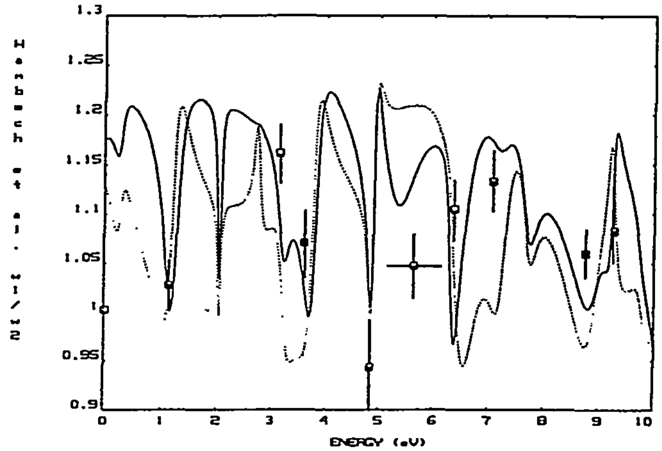

Fig. 2. Calculated and measured energy dependence of the ratio W_1/W_2 as a function of neutron energy for (235U+n) in the neutron energy range from 0 to 10 eV.

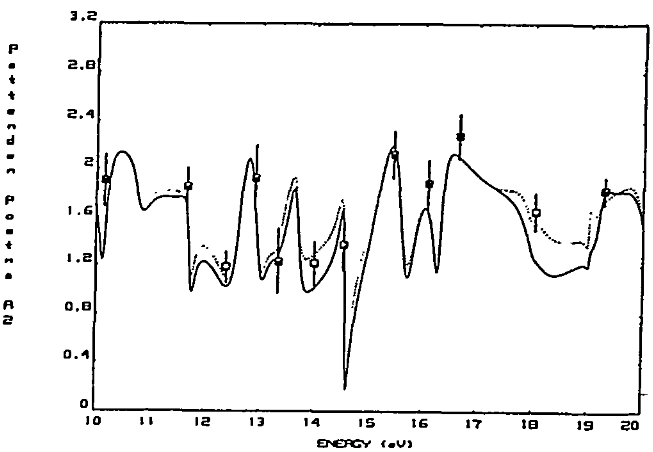

Fig. 3. Calculated and measured energy dependence of the angular distribution coefficient A_2 as a function of neutron energy for (235U+n) in the range from 10 to 20 eV.

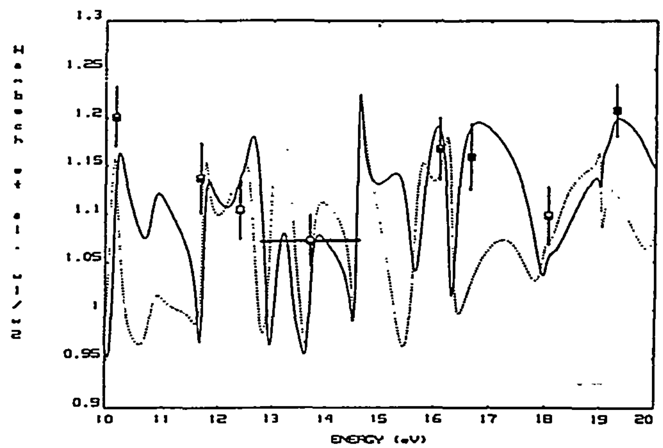

Fig. 4. Calculated and measured energy dependence of the ratio W_1/W_2 as a function of neutron energy for (^{235}U+n) in the neutron energy range from 10 to 20 eV.

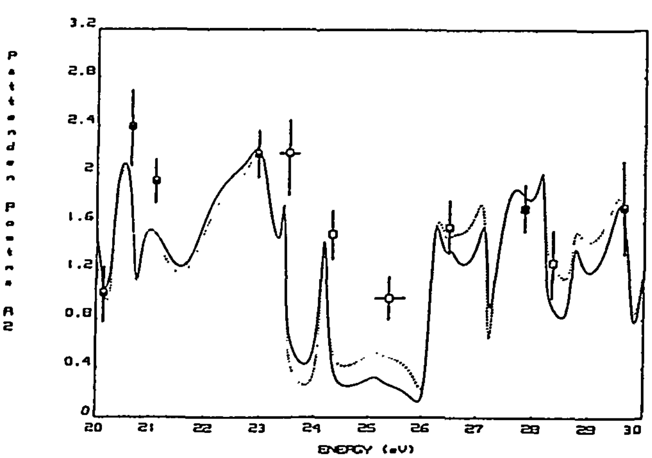

Fig. 5. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the energy range from 20 to 30 eV.

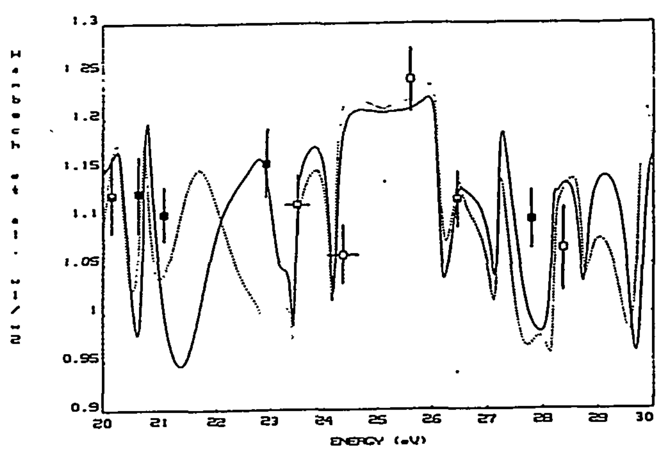

Fig. 6. Calculated and measured energy dependence of the ratio W_1/W_2, as a function of neutron energy for (^{235}U+n) in the neutron energy range from 20 to 30 eV.

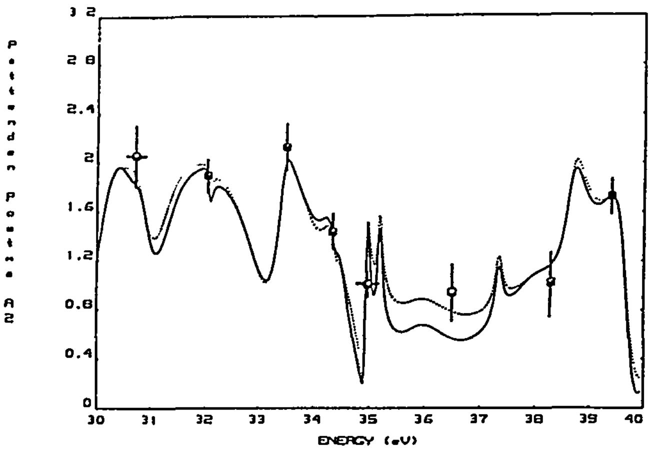

Fig. 7. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the energy range 30 to 40 eV.

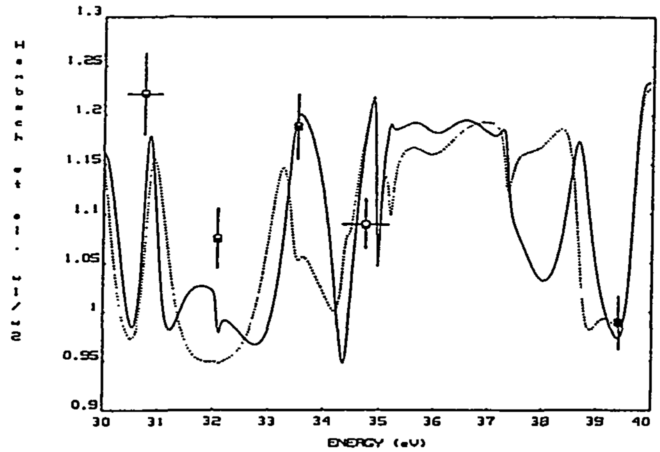

Fig. 8. Calculated and measured energy dependence of the ratio W_1/W_2 as a function of neutron energy for (^{235}U+n) in the neutron energy range from 30 to 40 eV.

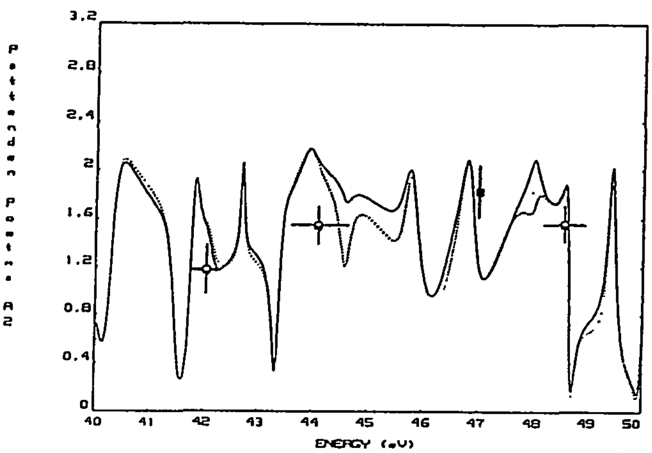

Fig. 9. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the energy range 40 to 50 eV.

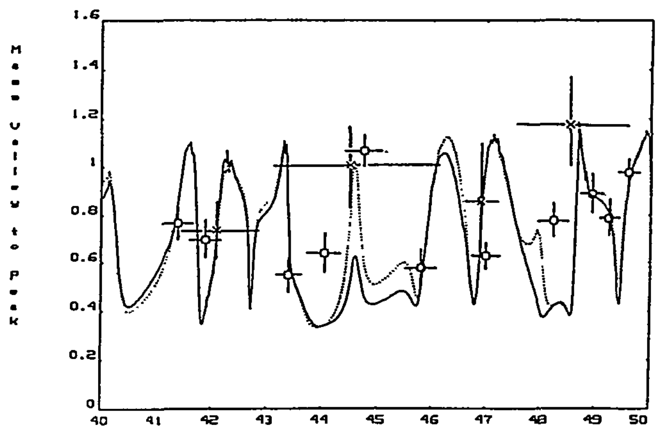

Fig. 10. Calculated and measured energy dependence of the mass distribution V/P ratio as a function of neutron energy for (^{235}U+n) in the energy range from 40 to 50 eV.

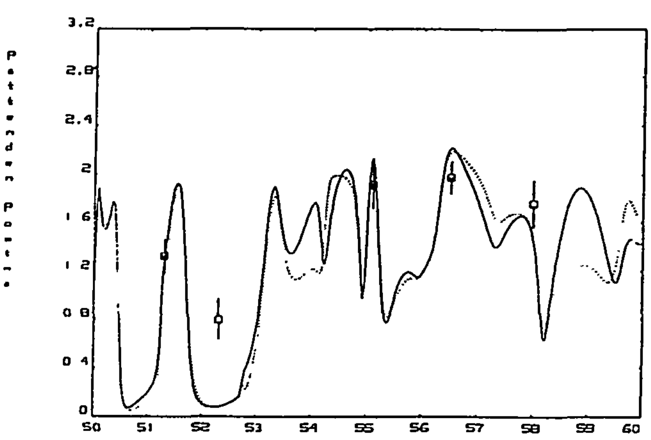

Fig. 11. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) from 50 to 60 eV.

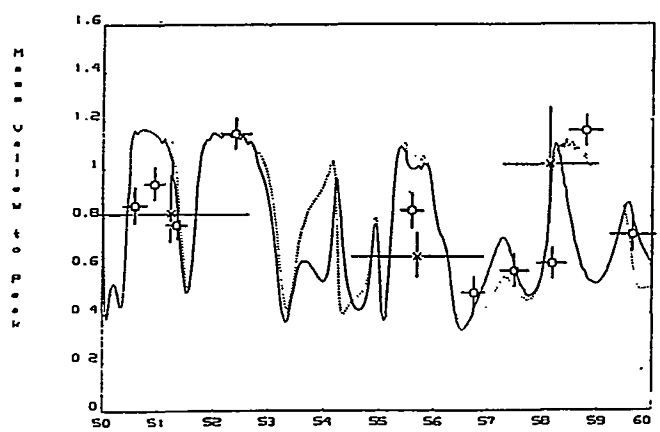

Fig. 12. Calculated and measured energy dependence of the mass distribution V/P ratio, as a function of neutron energy for (^{235}U+n) in the energy range from 50 to 60 eV.

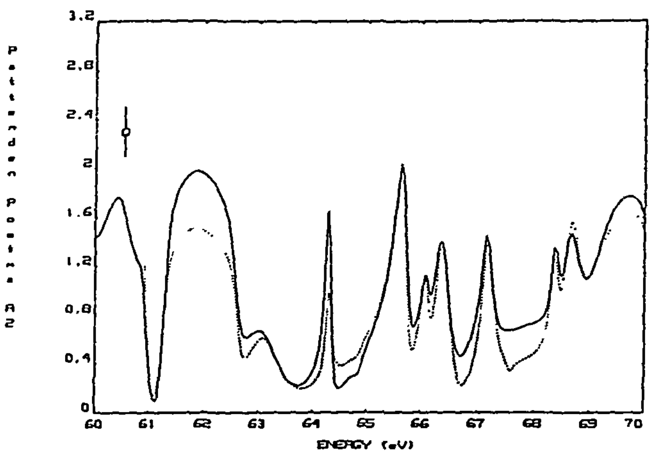

Fig. 13. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the range 60 to 70 eV.

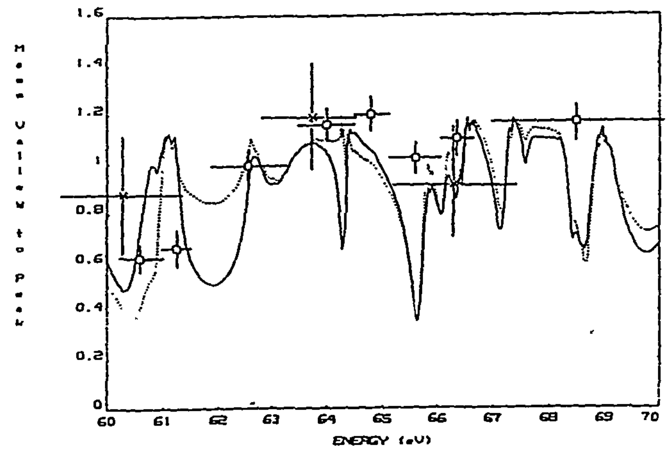

Fig. 14. Calculated and measured energy dependence of the mass distribution V/P ratio as a function of neutron energy for (^{235}U+n) in the energy range from 60 to 70 eV.

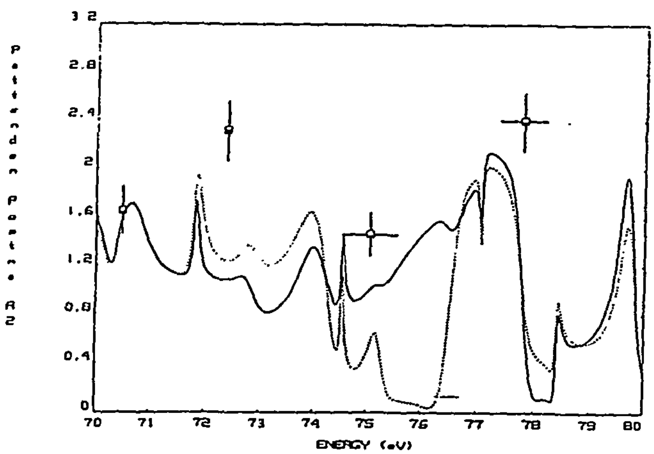

Fig. 15. Calculated and measured energy dependence of the angular distribution coefficient A_2 as a function of neutron energy for (^{235}U+n) in the range from 70 to 80 eV.

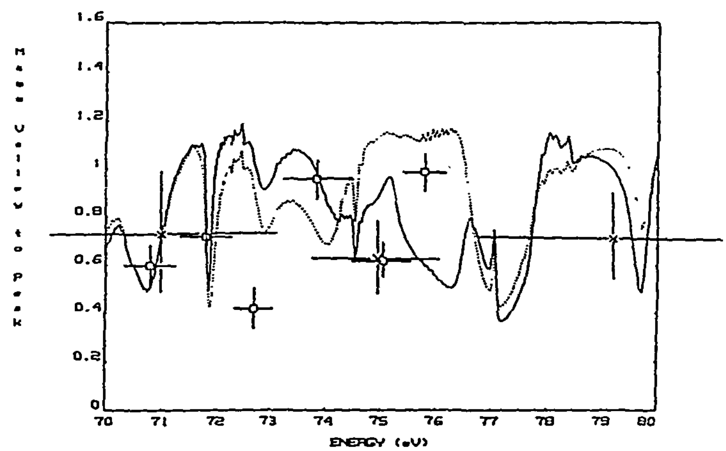

Fig. 16. Calculated and measured energy dependence of the mass distribution V/P ratio as a function of neutron energy for (^{235}U+n) in the energy range from 70 to 80 eV.

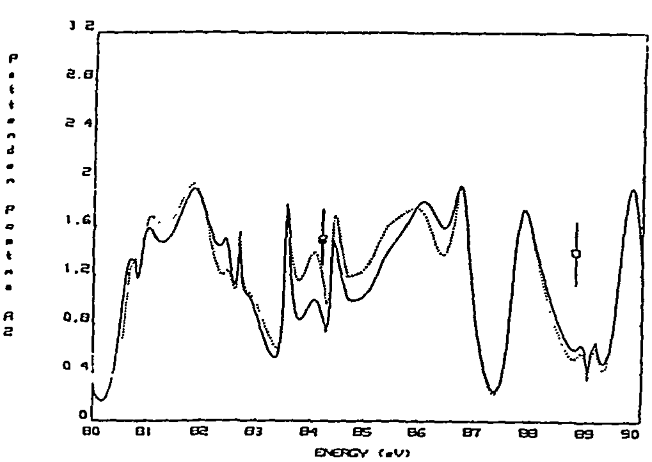

Fig. 17. Calculated and measured energy dependence of the angular distribution coefficient A_2, as a function of neutron energy for (^{235}U+n) in the range from 80 to 90 eV.

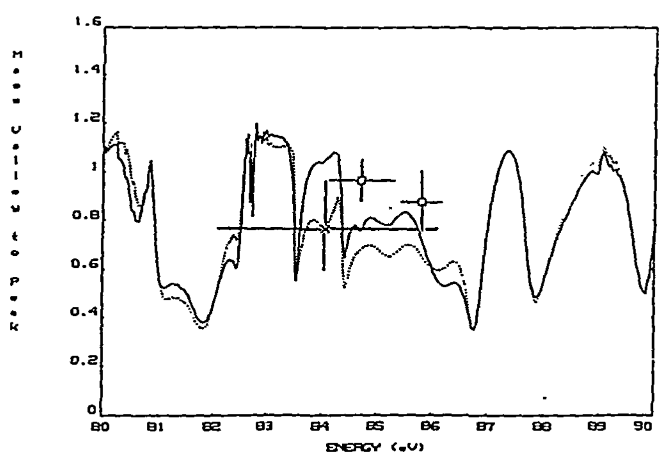

Fig. 18. Calculated and measured energy dependence of the mass distribution V/P ratio, as a function of neutron energy for (^{235}U+n) in the energy range from 80 to 90 eV.

Table 1. Resonance parameters for (^{235}U+n). The left column is for resonances of J=3, the right hand for resonances of J=4. This table is in SAMMY input/output format. The first column is the resonance energy in electron volts (eV); the second is the radiation width in milli-electron-volts (meV), the third is the reduced neutron width (divided by the square root of the neutron energy in eV) in meV, and the last two columns are the partial fission widths in meV. The signs in these columns are those that are associated with the square roots of the fission widths, or the fission-width vector components. See C. W. Reich and M. S. Moore, Phys. Rev. 111, 929 (1958).

Resonances with J = 3.

E_λ(eV)	$\Gamma_{\lambda\gamma}$(meV)	$\Gamma_{\lambda n}^{\circ}$(meV)	$\Gamma_{\lambda f1}$(meV)	$\Gamma_{\lambda f2}$(meV)
-9.9976E+01	3.9800E+01	3.6240E+00	4.4908E+02	1.8678E+02
-2.7231E+00	3.9799E+01	1.7494E-01	8.7900E+02	-5.4723E+02
2.7594E-01	3.7359E+01	4.1967E-03	-6.1337E+01	-5.7200E+01
2.0359E+00	3.9952E+01	9.0494E-03	8.6216E+00	-2.3679E-02
3.1472E+00	3.4964E+01	2.5220E-02	6.8124E+01	3.5960E+01
6.1988E+00	3.9608E+01	6.5088E-02	5.4984E+01	1.2085E+02
7.6606E+00	3.9999E+01	4.0043E-03	-1.1293E+02	1.5641E+02
8.9669E+00	3.9785E+01	1.3813E-01	6.5023E+01	4.9653E+02
9.7530E+00	3.3103E+01	3.9308E-02	-1.6070E+02	-4.2863E+01
1.0800E+01	3.4340E+01	1.0993E-02	1.1147E+02	-1.4073E+02
1.2390E+01	3.9942E+01	1.2154E+00	2.0207E+01	1.8844E+01
1.3677E+01	2.9999E+01	4.3043E-02	6.5466E+01	-8.0436E+01
1.3966E+01	3.7082E+01	5.9738E-01	2.0780E+02	2.7498E+02
1.4550E+01	3.9990E+01	1.1189E-01	-1.3013E+01	2.5796E+00
1.8038E+01	3.2763E+01	3.2877E-01	-8.1915E+01	-4.6516E+01
1.9185E+01	3.1550E+01	2.9645E-01	9.2354E+01	1.5498E+02
2.0165E+01	3.9996E+01	1.0029E-01	-5.8650E+01	-5.8651E+01
2.3598E+01	3.0947E+01	8.5339E-01	4.8535E+01	-1.4313E+02
2.4232E+01	4.0046E+01	3.6529E-01	-3.5416E+01	-2.3224E+01
2.5573E+01	3.0004E+01	1.3355E+00	6.8511E+01	5.5335E+02
2.6445E+01	3.0091E+01	4.5455E-01	2.4384E+02	1.2871E+02
2.7167E+01	3.8698E+01	6.5068E-02	-5.2034E+01	2.6832E+00
2.8331E+01	3.8342E+01	2.2185E-01	5.3593E+01	6.1631E+01
3.0587E+01	3.0055E+01	2.2179E-01	1.0784E+02	4.8198E+00
3.2088E+01	3.0854E+01	9.4131E-01	2.2920E+01	-7.1536E+00
3.4448E+01	3.5000E+01	3.4424E-01	-2.3347E+02	-5.9165E+00
3.4876E+01	3.0094E+01	1.4483E+00	6.7454E-01	8.6578E+01
3.5129E+01	3.9794E+01	3.2185E+00	6.7594E+01	1.6563E+02
3.8353E+01	3.8300E+01	5.1449E-03	8.8984E+01	-1.5336E+03
3.9947E+01	3.1948E+01	3.3023E-01	2.0225E+00	-2.2221E+02
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4.1862E+01	4.0002E+01	1.5034E+00	1.7401E+01	4.5091E-01
4.3378E+01	3.0042E+01	6.9342E-01	5.4377E+00	-9.8045E+00
4.4941E+01	3.9998E+01	1.2955E+00	-6.1884E+02	-6.2854E+01
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4.8755E+01	3.0014E+01	8.6461E-01	-9.8397E+00	-5.3160E+01
5.0084E+01	3.4367E+01	3.3119E-01	-3.3314E+01	-1.3305E+00
5.0441E+01	3.3325E+01	9.8380E-01	2.0937E+01	-1.8948E+01
5.1189E+01	3.6576E+01	1.4506E+00	1.3661E+01	1.0312E+02
5.2211E+01	3.4965E+01	3.0974E+00	-1.2836E+01	3.7599E+02
5.3411E+01	3.4940E+01	6.1036E-01	8.8010E+01	1.1774E+01
5.4931E+01	3.4951E+01	5.3155E-01	-1.0410E+01	7.6231E+01
5.6068E+01	3.4997E+01	1.4809E+00	-1.4093E+02	-7.5641E+01
5.7762E+01	3.4920E+01	1.2271E+00	1.6920E+02	3.1031E+01
5.8072E+01	3.4935E+01	1.4541E+00	-2.4870E+01	-2.0318E+01
6.0163E+01	3.4901E+01	1.2443E+00	-1.8618E+02	5.1556E+01
6.1078E+01	3.4969E+01	4.8779E-01	3.8279E+00	1.2210E+02
6.3143E+01	3.4999E+01	5.6929E-02	-5.6480E+02	-1.8117E+01
6.3605E+01	3.4982E+01	1.3259E+00	-3.0635E-10	7.4848E+02
6.5767E+01	3.4872E+01	3.9285E-01	1.5081E+01	1.5081E+01
6.8558E+01	3.4991E+01	9.6020E-02	-5.9343E+01	-3.7855E+01
7.0207E+01	3.4978E+01	4.9970E-01	-1.9518E-01	-4.3473E+02
7.0408E+01	3.4987E+01	1.3198E+00	-1.0116E+02	1.1615E+02
7.0790E+01	3.4884E+01	1.9630E+00	1.4677E+02	2.3015E+01
7.2902E+01	3.4981E+01	2.7281E-01	-1.2762E+02	1.5535E+02
7.4486E+01	3.4737E+01	1.9426E+00	4.5057E+01	7.7932E+01
7.5560E+01	3.4822E+01	1.7657E+00	-1.6148E+02	-1.0293E+02
7.8071E+01	3.5007E+01	1.2990E+00	-4.8516E+00	1.2160E+02
8.0346E+01	3.1257E+01	9.1251E-01	-2.2169E+01	-1.2036E+02
8.1411E+01	3.4922E+01	1.1672E+00	9.5652E+01	-2.9101E+01
8.2452E+01	3.4999E+01	1.8494E-01	-9.5351E+01	-1.2446E+01
8.3651E+01	3.4929E+01	1.4570E+00	5.1755E+01	-1.0697E+03
8.4364E+01	3.4676E+01	6.5182E-01	4.7211E+01	1.9125E+01
8.5136E+01	3.4969E+01	1.4046E+00	-2.5530E+02	2.5067E+02
8.6802E+01	3.4990E+01	4.9732E-01	9.2582E+01	-6.7615E+00
8.7597E+01	3.5002E+01	5.2920E-01	6.8775E+01	1.9425E+02
8.8752E+01	3.4504E+01	2.7991E+00	-1.0928E+02	3.4937E+02
9.1235E+01	3.4994E+01	3.0557E+00	-2.6705E+02	4.1373E-04

Resonances with J = 4.

E_λ(eV)	$\Gamma_{\lambda\gamma}$(meV)	$\Gamma_{\lambda n}^{\circ}$(meV)	$\Gamma_{\lambda f1}$(meV)	$\Gamma_{\lambda f2}$(meV)
-4.7746E+00	3.9796E+01	7.8870E+00	3.4873E+02	4.0156E+00
-5.0673E-01	3.2554E+01	1.8284E-01	7.2204E+00	-1.7240E+02
1.1330E+00	3.4841E+01	1.4511E-02	-6.2453E+01	-6.2453E+01
2.7676E+00	3.5199E+01	8.8895E-04	1.0322E+02	-1.6068E+01
3.6162E+00	3.6043E+01	4.2944E-02	-4.0635E+01	-1.3545E+01
4.8507E+00	3.9213E+01	5.0147E-02	-2.8246E+00	-1.9887E+00
5.4236E+00	3.5003E+01	2.0367E-02	2.2968E+01	-4.3091E+02
6.3864E+00	3.9994E+01	2.2757E-01	5.0771E+00	7.7424E+00
7.0856E+00	3.8534E+01	1.1034E-01	-3.3377E+01	1.0377E+00
8.7606E+00	3.4974E+01	9.3914E-01	7.3895E+01	2.8853E+01
9.2791E+00	3.7054E+01	1.1114E-01	2.8302E+01	-3.2546E+01
1.0167E+01	3.3541E+01	4.9239E-02	1.5650E+01	-4.5874E+01
1.1666E+01	3.9910E+01	4.8865E-01	-3.1223E+00	-2.9117E+00
1.2358E+01	3.9996E+01	3.4581E-02	-4.4967E+00	-1.3302E+02
1.2856E+01	3.0000E+01	6.3985E-02	-9.3739E+01	-2.0383E+01
1.3263E+01	2.9996E+01	5.0179E-02	-5.7476E+00	1.5212E+02
1.4053E+01	3.0472E+01	1.6275E-02	-5.2068E+02	-2.6424E+02
1.5417E+01	4.0004E+01	2.0778E-01	-5.6205E+01	-1.5437E-01
1.6087E+01	3.9900E+01	3.3099E-01	-1.0816E+01	1.0087E+01
1.6647E+01	3.5169E+01	2.4445E-01	-1.0128E+02	9.4670E+00
1.7973E+01	3.9991E+01	5.3933E-02	2.9311E+01	1.0185E+02
1.8996E+01	4.0000E+01	5.2976E-02	1.8972E-01	-1.9122E+01
1.9294E+01	3.7728E+01	2.5631E+00	4.3732E+01	-1.9896E+01
2.0176E+01	3.5000E+01	5.0364E-03	-2.9074E+02	-2.3614E+01
2.0643E+01	3.9966E+01	1.3085E-01	-3.6065E+01	1.2407E+01
2.1068E+01	3.9873E+01	1.3287E+00	-1.2131E+01	-1.7630E+01
2.2933E+01	3.9931E+01	3.9759E-01	-4.3178E+01	8.5970E-03
2.3417E+01	3.9429E+01	6.8505E-01	6.9982E+00	2.1178E+00
2.5157E+01	3.0066E+01	1.6622E-02	-3.2563E+02	4.6282E+01
2.6482E+01	3.9999E+01	2.3069E-01	4.7989E+01	-7.9472E+01
2.7782E+01	2.9997E+01	5.8064E-01	-6.3688E+01	-2.8975E+01
2.8142E+01	3.1060E+01	4.8698E-02	6.9704E+01	7.3887E+00
2.8724E+01	3.9999E+01	2.8998E-02	4.8105E+01	4.6436E+01
2.9644E+01	3.9968E+01	1.4686E-01	-1.0767E+01	-1.1546E+01
3.0866E+01	3.9785E+01	4.6807E-01	-9.3636E+00	1.0957E+01
3.2029E+01	3.0061E+01	9.2566E-01	-8.0735E+01	-1.9206E+01
3.3415E+01	3.5000E+01	5.9626E-02	5.3540E+01	2.8619E+02
3.3511E+01	3.3425E+01	1.5837E+00	-2.5177E+01	7.8277E-01
3.4343E+01	3.0093E+01	1.6398E+00	1.0231E+01	2.4259E+01
3.5177E+01	3.0063E+01	1.5751E+00	3.9236E+01	-6.8082E+00
3.5653E+01	3.5000E+01	1.3756E-03	1.2232E+00	7.0784E+02
3.6199E+01	3.9800E+01	4.9970E-02	-9.2804E+02	-1.7525E+02
3.7373E+01	3.5000E+01	1.4296E-02	1.4870E+02	1.5238E+01
3.8355E+01	3.9794E+01	2.9805E-01	9.3727E+00	-3.0146E+02
3.9402E+01	3.9831E+01	2.3129E+00	-3.5428E+01	-2.4945E+01
4.0475E+01	3.5207E+01	3.2777E-01	1.8438E+02	-6.4336E-01
4.1339E+01	4.0000E+01	3.3209E-01	-1.6753E+02	-1.1042E+02
4.2193E+01	3.0007E+01	3.1209E-01	-3.6759E+01	-6.1572E+01
4.2696E+01	3.0028E+01	2.3906E-01	-2.9275E+00	4.4864E+00
4.3535E+01	3.5000E+01	6.5541E-02	8.2638E+01	5.9609E+02
4.3935E+01	3.1578E+01	3.2586E-01	8.8673E+01	-2.3151E+01
4.4594E+01	3.2029E+01	5.2173E-01	-2.9811E-11	7.2836E+01
4.5790E+01	3.4627E+01	1.6243E-01	-6.8476E+01	1.4650E+01
4.6772E+01	2.9989E+01	6.1178E-01	-9.6621E+01	-2.3224E+00
4.7004E+01	3.8041E+01	8.1911E-01	5.9262E+00	-9.7031E+01
4.7958E+01	3.1352E+01	7.3493E-01	2.2233E+01	2.4016E+01
4.9429E+01	3.7271E+01	8.3822E-01	-7.7724E+00	-3.7822E+00
5.1292E+01	3.1845E+01	1.8491E+00	1.5339E+01	4.6016E+01
5.1607E+01	3.4041E+01	5.0590E-01	-9.1706E+01	1.1807E+01
5.2678E+01	3.4966E+01	5.5895E-05	-7.4945E+01	3.1651E+02
5.2792E+01	3.4070E+01	3.3559E-03	-8.0382E+01	-1.5513E+02
5.4177E+01	3.2854E+01	9.8777E-02	1.3850E-01	-8.8557E+01
5.5087E+01	3.4810E+01	2.2514E+00	-4.1421E+01	-2.0661E-01
5.5829E+01	3.4850E+01	1.8661E+00	-9.0358E+00	-2.1660E+02
5.6467E+01	3.4853E+01	4.1783E+00	-8.6166E+01	3.7016E+00
5.7388E+01	3.4999E+01	1.6346E-04	-4.1168E+02	1.4719E+02
5.8655E+01	3.4858E+01	1.1768E+00	-4.0011E+00	-1.2869E+02
5.9676E+01	3.4969E+01	1.6525E-01	-3.1967E+01	-1.7796E+02
6.0829E+01	3.4935E+01	3.6915E-01	7.4682E+01	-2.4894E+01
6.1406E+01	3.5000E+01	1.9392E-01	-5.0402E-01	-5.3942E+02
6.2538E+01	3.5000E+01	7.5739E-02	5.7888E+01	1.7287E+02
6.4291E+01	3.5016E+01	9.9142E-01	-3.6568E-12	6.3482E+00
6.4825E+01	3.5000E+01	2.3891E-05	1.8174E+01	-1.8055E+02
6.6117E+01	3.5002E+01	1.3829E-02	1.0172E+02	-2.1038E+01
6.6392E+01	3.5016E+01	3.4714E-01	9.7251E+00	2.3981E+01
6.7212E+01	3.4974E+01	5.8527E-02	1.4866E+01	3.8991E+01
6.7576E+01	3.5000E+01	1.9907E-05	-3.6172E+01	-6.4708E+01
6.8366E+01	3.5000E+01	3.1035E-02	-4.0062E+01	-2.1325E+01
6.9218E+01	3.4960E+01	5.5578E-01	-1.0885E+02	-4.9250E+01
7.0429E+01	3.4903E+01	1.1332E+00	1.5938E+02	1.9492E+02
7.1684E+01	3.4921E+01	2.2587E-01	3.8292E+00	-1.8146E+02
7 2375E+01	3.4752E+01	2.5059E+00	-3.2326E+01	-8.1214E+01
7.4538E+01	3.4894E+01	8.6514E-01	-4.9776E+00	2.2799E+01
7.5176E+01	3.1658E+01	4.1571E-01	1.8488E+02	-1.1574E+00
7.6713E+01	3.2367E+01	1.0228E-01	4.2196E+01	1.2433E+02
7.7067E+01	3.4927E+01	9.9098E-05	-7.8687E+01	1.9447E-01
7.7504E+01	3.3053E+01	7.2815E-01	-1.0210E+02	3.5740E+00
7.8434E+01	3.4990E+01	6.7306E-02	6.7374E-01	4.6766E+01
7.9670E+01	3.4932E+01	5.5983E-01	1.8806E+00	-6.0454E+01
8.0783E+01	3.3646E+01	1.1247E-04	1.6993E+01	1.4460E+01
8.0820E+01	3.4968E+01	1.3285E-01	1.7423E+01	-7.2224E+01
8.2626E+01	3.4963E+01	1.0216E+00	6.5454E-01	-1.0436E+01
8.2796E+01	3.5865E+01	4.4393E-01	1.6250E+01	-6.4896E+01
8.3532E+01	3.4914E+01	6.7342E-02	-2.6648E+01	5.6861E-04
8.4048E+01	3.4939E+01	2.0112E+00	8.0028E+01	2.2419E+02
8.4684E+01	3.4913E+01	1.9634E-04	-5.7392E+01	-7.9889E+01
8.5706E+01	3.4960E+01	6.2506E-01	-1.1869E+02	-3.4741E+02
8.8873E+01	3.5000E+01	3.3219E-01	7.6042E+01	-1.5710E+02
8.9094E+01	3.5011E+01	2.0002E-01	4.0113E+00	-2.6914E+01
8.9783E+01	3.4990E+01	6.0390E-01	-8.4922E+01	-2.8854E+01
9.0346E+01	3.4952E+01	3.9413E+00	9.3362E+00	-1.5068E+02
9.0382E+01	3.5000E+01	1.8357E-01	-1.1369E+02	4.7040E+02

5. REFERENCES

[1]W. I. Furman, in a seminar given at Los Alamos National Laboratory, Los Alamos, N.M., May 1994.
[2]A. Bohr, *Peaceful Uses of Atomic Energy*, **2**, 151, (1955).
[3]F.-J. Hambsch, H.-H.Knitter, C. Budtz-Jørgensen, and J. P. Theobald, Nuc. Phys. **A491**, 56 (1989).
[4]U. Brosa, S. Grossmann, and A. Müller, Z. Naturforschung **41A**, 1341 (1986).
[5]M. S. Moore, L. C. Leal, G. de Saussure, R. B. Perez, and N. M. Larson, in *Fifty Years Research in Nuclear Fission, Berlin*, Nuc. Phys. **A502**, 443c (1989).
[6]L. C. Leal, G. de Saussure, and R. B. Perez, Nuc. Sci. Eng. **109**, 1 (1991).
[7]N.J. Pattenden and H. Postma, Nuc. Phys. **A167**, 225 (1971).
[8]Los Alamos Radiochemistry Group, Phys. Rev. **107**, 325 (1957).
[9]G. A. Cowan, B. P. Bayhurst, and R. J. Prestwood, Phys. Rev. **130**, 2380 (1963).
[10]G. A. Cowan, B.P. Bayhurst, R. J. Prestwood, J. S. Gilmore, and G. W. Knobeloch, Phys Rev. **144**, 979 (1966).
[11]G. A. Cowan, B. P. Bayhurst, R. J. Prestwood, J. S. Gilmore, and G. W. Knobeloch, Phys. Rev. **C2**, 615 (1970).
[12]M. S. Moore and L. G. Miller, in *Physics and Chemistry of Fission, Salzburg*, Vol. I, p. 87 (1965).
[13]L. G. Miller and M. S. Moore, Phys. Rev. **157**, 1055 (1967).
[14]M. S. Moore and L. G. Miller, Phys. Rev. **157**, 1049 (1967).
[15]L. D. Roberts and J. W. T. Dabbs, Ann. Rev. Nuc. Sci. **11**, 175 (1961).
[16]J. W. T. Dabbs, F. J. Walter, and G. W. Parker, in *Physics and Chemistry of Fission, Salzburg*, Vol. I, p. 39 (1965).
[17]J. W. T. Dabbs, C. Eggerman, B. Cauvin, A. Michaudon, and M. Sanche, in *Physics and Chemistry of Fission II, Vienna*, p.321 (1970).
[18]G. A. Keyworth, C. E. Olsen, F. T. Seibel, J. W. T. Dabbs, and N. W. Hill, Phys. Rev. Lett. **31**, 1077 (1973).
[19]M. S. Moore, J. D. Moses, G. A. Keyworth, J. W. T. Dabbs, and N. W. Hill, Phys. Rev. **C18**, 1328 (1978).
[20]F.-J. Hambsch and P. Siegler, in *Seminar on Fission, Pont d'Oye II*, p. 32 (1991).
[21]H. Weigmann and F.-J. Hambsch, in *Seminar on Fission, Pont d'Oye II*, p. 50 (1991).
[22]M.S. Moore, in *Statistical Properties of Nuclei, Albany*, p. 55 (1972).
[23]S. Weinstein, R. Reed, and R. C. Block, in *Physics and Chemistry of Fission II. Vienna*, p. 477 (1970).
[24]Yu. V. Ryabov, in *Physics and Chemistry of Fission II, Vienna*, p. 486 (1970). See also
[25]Raymond L. Reed, Ph.D. Thesis, Nuc. Eng. Dept., Rensselaer Polytechnic Institute, Troy, N. Y. (1973).
[26]R. E. Howe, T. W. Phillips, and C. W. Bowman, Phys. Rev. **C13**, 195 (1976).
[27]J. P. Felvinci and E. Melkonian, in *Neutron Cross Sections and Technology*, Vol.II, 855 (1971).
[28]F.-J. Hambsch, H. -H. Knitter, C. Budtz-Jørgensen, and J. P. Theobald, in *Nuclear Data for Science and Technology*, and *IAEA Consultants' Meeting on Physics of Neutron Emission in Fission, Mito, Japan*, (1988).
[29]M. S. Moore, J. R. Smith, and G. de Saussure, in *Uranium and Plutonium Resonance Parameters*, INDC(NDS) - 129/GJ, p. 74 (1981).
[30]G. F. Auchampaugh, Nuc. Phys. **A175**, 65 (1971).
[31]E. Vogt, Phys. Rev. **112**, 203 (1958).
[32]C. Durston, as presented to the Oak Ridge, TN, meeting of the U. S. Cross Sections Evaluation Working Group, October, 1994.