ANALYSIS OF THE ^{235}U NEUTRON CROSS SECTIONS IN THE RESOLVED RESONANCE RANGE

CONF-890406--12

DE89 010842

L. C. Leal, G. de Saussure, and R. B. Perez
Oak Ridge National Laboratory
Engineering Physics and Mathematics Division
P. O. Box 2008
Oak Ridge, Tennessee 37831-6356
and
The University of Tennessee
Nuclear Engineering Department
315 Pasqua Building
Knoxville, TN 37996-2300
(615) 574-6114, 574-6125

ABSTRACT

Using recent high-resolution measurements of the neutron transmission of ^{235}U and the spin-separated fission cross-section data of Moore et al., a multilevel analysis of the ^{235}U neutron cross sections was performed up to 300 eV. The Dyson Metha Δ_3 statistics were used to help locate small levels above 100 eV where resonances are not clearly resolved even in the best resolution measurements available. The statistical properties of the resonance parameters are discussed.

INTRODUCTION

An accurate resonance analysis of the ^{235}U neutron cross sections was recently completed for ENDF/B-VI.[1,2] In this analysis, the resolved resonance formalism is used up to 2250 eV. However, since the level spacing in ^{235}U is approximately 0.5 eV the resonances cannot be truly resolved over that range, and at the higher energies the goal of the analysis was mainly to provide pseudo-parameters that represented well the observed structures of the cross sections. Such a representation is expected to yield a better estimate of resonance self-shielding than the often-used unresolved formalism.[3,4]

As part of this analysis, an attempt was made to determine as accurately as possible the resonance energies up to 300 eV. Even at this lower energy it is not possible to resolve unambiguously all the levels. However, the availability of spin-separated fission cross-section data[5] and of high-resolution measurements done on samples cooled to the liquid nitrogen temperature[6,7] to reduce Doppler broadening of the resonances, allows resolving levels up to 300 eV with reasonable confidence. The Dyson Metha Δ_3 statistics[8] introduce strong correlations in the expected level spacings and help determine the energies of small resonances that cannot be unambiguously resolved.

METHOD OF ANALYSIS

The resonance parameter analysis code SAMMY[9] was used to perform a consistent R-matrix multilevel analysis of selected neutron cross section and transmission measurements. The computer code SAMMY uses the Reich-Moore formalism and a fitting procedure based on the Bayes' method which allows the successive incorporation of new data in a consistent manner. The code allows for searching not only resonance parameters but also experimental parameters such as sample thickness, residual backgrounds, local renormalization, effective temperature and the parameters of the resolution function, all consistent with predetermined uncertainty limits. A special feature of SAMMY, programmed for this analysis, allows the fitting of separated spin contributions to the fission cross section.

UTILIZATION OF THE Δ_3 STATISTICS

The Δ_3 statistics of Dyson and Metha[8] are particularly sensitive to long-range correlations within a set of levels. The mean-square deviation Δ_3 is defined by a sequence of n consecutive resonance energies in the range $(-L, +L)$ by:

$$\Delta_3 = \underset{A,B}{\text{Min}} \left\{ \left(\frac{1}{2L}\right) \int_{-L}^{+L} [N(E) - AE - B]^2 dE \right\} ,$$

where $N(E)$ is the cumulative number of levels versus neutron energy, and $AE + B$ is the line fitted to the histogram. The expected value of Δ_3 is $\frac{1}{\pi^2}(\ln n - 0.0686)$ with a variance of 0.012 where n is the total number of levels. Using the results of the high-resolution low Doppler-broadening transmission and fission measurements and the spin-separated fission cross-section data, essentially all the resonances can be resolved up to 60 eV. The Δ_3 statistics can then be used to determine precise values of the level spacings for each spin levels.

"The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes."

Above 60 eV, the Δ_3 statistics which constrain the number of levels per unit energy are used again to determine the probable spin of a level where the spin-separated fission cross-section data have large uncertainties or to decide where to place additional levels where the resolutions of the measurements do not permit an unambiguous interpretation of the resonance structure.

RESULTS OF THE ANALYSIS

The results of the Δ_3 statistical test and the average values of the resonance parameters for each spin state are summarized in Table 1. Figure 1 shows histograms of the cumulative number of observed levels versus energy for each spin state as well as the lines fitted to these histograms. Figures 2 and 3 show the distributions of the reduced neutron widths for each spin state compared to an expected Porter-Thomas distribution.[10] In Figs. 4 and 5 the nearest neighbor level spacing distributions observed for each spin state are compared to theoretical Wigner distributions.[10] Finally, in Figs. 6 to 8 the transmission ratios and fission cross sections computed with our resonance parameters are compared to results of measurements. These figures illustrate how accurately the resonance parameters represent the experimental measurements. However, there are significant differences between observed and expected distributions of the spin 4 levels. These differences are under investigation. More extensive comparisons between cross sections computed with the resonance parameters and results of measurements are given in Refs. 1 and 2.

CONCLUSIONS

Recent high-resolution measurements and the spin-separated fission cross-section data permit resolving essentially all the levels in ^{235}U up to 60 eV. The use of the Δ_3 statistical test allows the extension of a multilevel analysis up to 300 eV. The resonance parameters obtained represent the available experimental data accurately. The observed distributions of the resonance parameters are consistent with the distribution predicted by R-matrix theory. Of course, the partial fission width is not unique since rotations and other transformations of the fission vectors leave the fission cross section invariant.[11,12] A discussion of the fission vectors orientations has been presented elsewhere.[13]

ACKNOWLEDGEMENTS

This research was sponsored by the Office of Energy Research, Nuclear Physics, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., and under contract DOE-DE-FG05-85ER-40188 with the University of Tennessee.

REFERENCES

1. L. C. LEAL, G. DE SAUSSURE, and R. B. PEREZ, "R-Matrix Analysis of the ^{235}U Neutron Cross Sections," *TANSAO* **56**, 587 (1988).

2. G. DE SAUSSURE, et al., "A New Resonance Region Evaluation of Neutron Cross Sections for ^{235}U," p. 293 in *Proc. International Reactor Physics Conference, Jackson Hole, Wyoming, Sept. 18-22, 1988*, Vol. 1. Also to be published in *Nucl. Sci. and Eng.*.

3. G. DE SAUSSURE and R. B. PEREZ, *Ann. Nucl. Energy* **9**, 79 (1982).

4. R. B. PEREZ et al., "On the Unresolved Resonance Region Representation of Neutron Induced Cross Sections," p. 183 in *Proc. International Reactor Physics Conference, Jackson Hole, Wyoming, Sept. 18-22, 1988*, Vol. 3.

5. M. S. MOORE et al., *Phys. Rev.* **C18**, 1328 (1978).

6. J. BLONS, *Nucl. Sci. Eng.* **51**, 130 (1973).

7. J. A. HARVEY et al., "High-Resolution Neutron Transmission Measurements on ^{235}U, ^{238}U, and ^{239}Pu," p. 115 in *Nuclear Data for Science and Technology, Proc. of International Conference, Mito, Japan, May 30 - June 3, 1988*, S. Igarasi, Ed.

8. P. G. DYSON and M. L. METHA, *J. Math. Phys* **4**, 701 (1963).

9. N. M. LARSON and F. G. PEREY, "Resonance Parameter Analysis with SAMMY," p. 573 in *Nuclear Data for Science and Technology, Proc. of International Conference, Mito, Japan, May 30 - June 3, 1988*, S. Igarasi, Ed.

10. C. F. PORTER and R. G. THOMAS, *Phys. Rev.* **104**, 483 (1956).

11. G. F. AUCHAMPAUGH, *Nucl. Phys.* **A175**, 65 (1971).

12. D. B. ADLER and F. T. ADLER, *Phys. Rev.* **C6**, 985 (1972).

13. M. S. MOORE et al. "Resonance Structure in the Fission of (^{235}U + n)," paper presented at the International Conference "Fifty Years Research in Nuclear Fission," Berlin, Germany, April 3-7, 1989.

Table 1. Average value of observed ^{235}U resonance parameters up to 300 eV

	$J=3$	$J=4$
Level spacing (eV)	1.39 ± 0.09	0.90 ± 0.04
Reduced neutron width ($meV^{1/2}$)	0.12 ± 0.09	0.09 ± 0.08
s-wave strength function $\times 10^4$	0.89 ± 0.09	1.01 ± 0.08
Fission width (meV)	239	189
Capture width (meV)	38 ± 7	35 ± 3
Observed Δ_3	0.57	0.53
Expected Δ_3	0.54 ± 0.11	0.58 ± 0.11

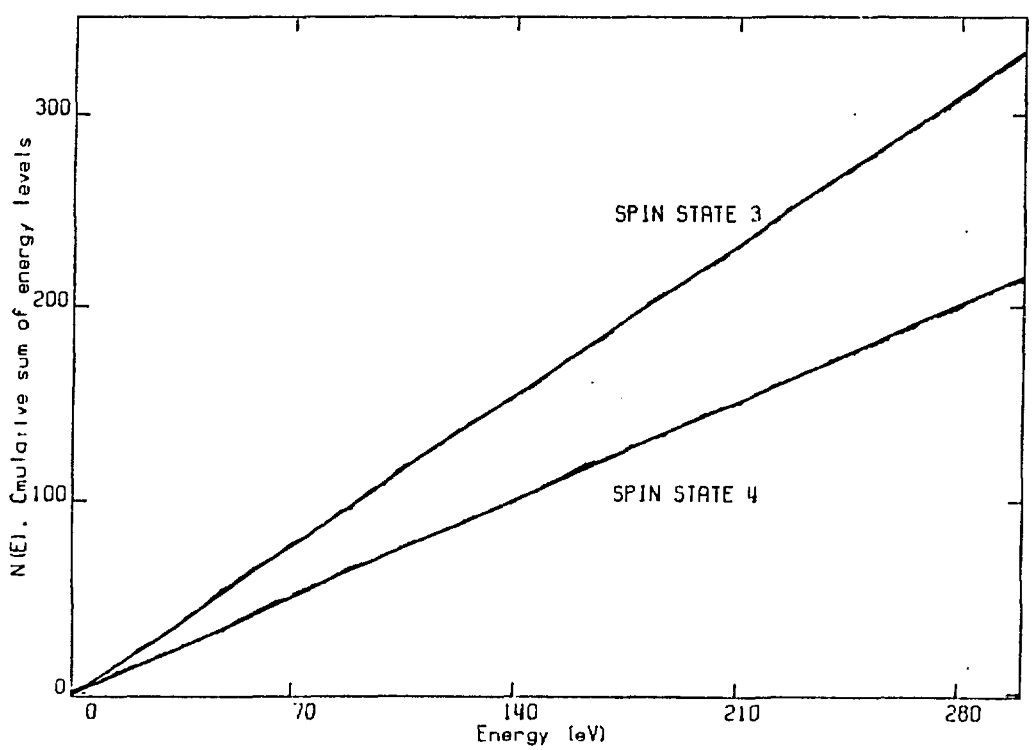

FIG. 1. CUMULATIVE SUM OF OBSERVED LEVELS

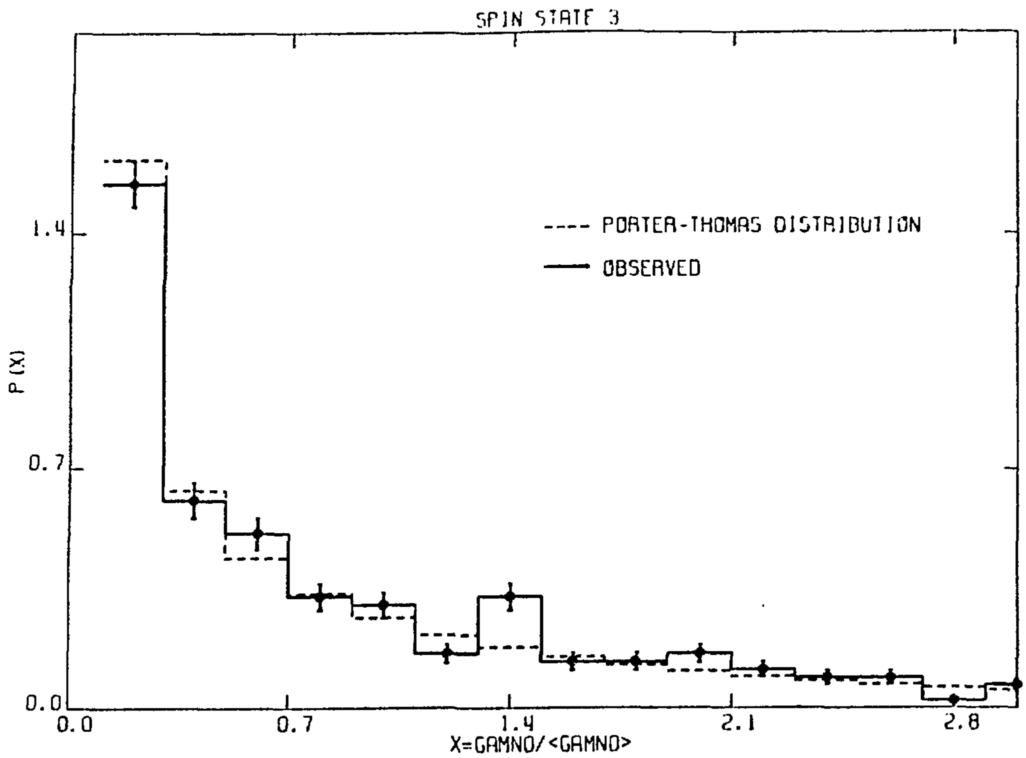

FIG. 2. DISTRIBUTION OF THE REDUCED NEUTRON WIDTH (SPIN STATE 3)

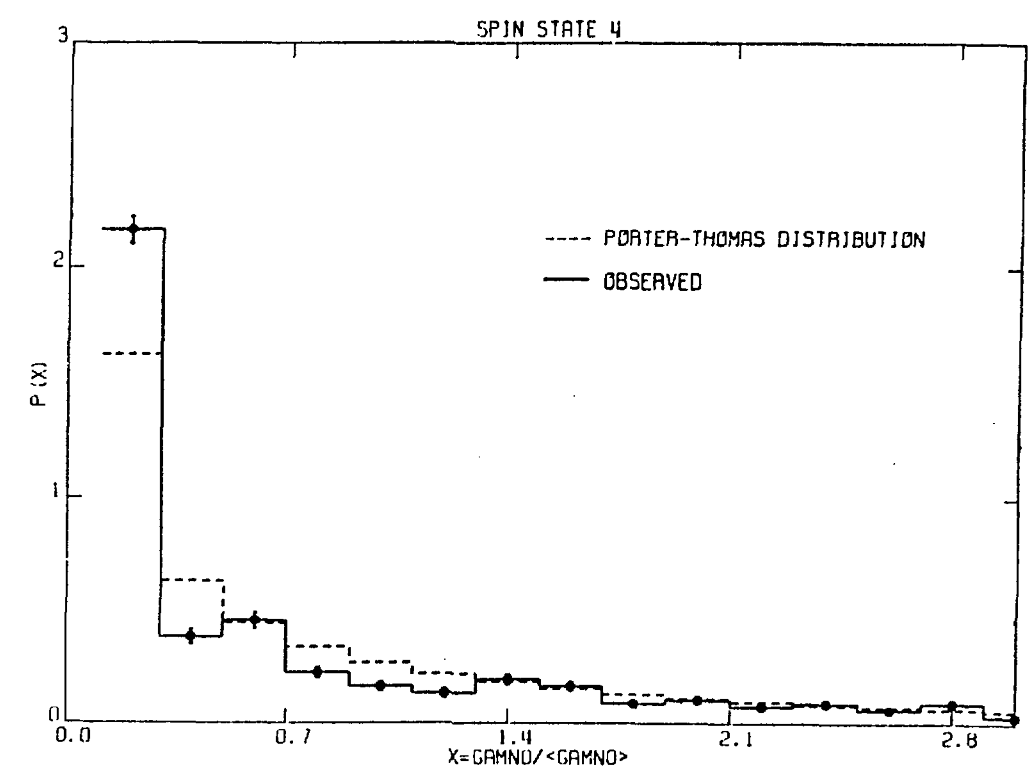

FIG. 3. DISTRIBUTION OF THE REDUCED NEUTRON WIDTH (SPIN STATE 4)

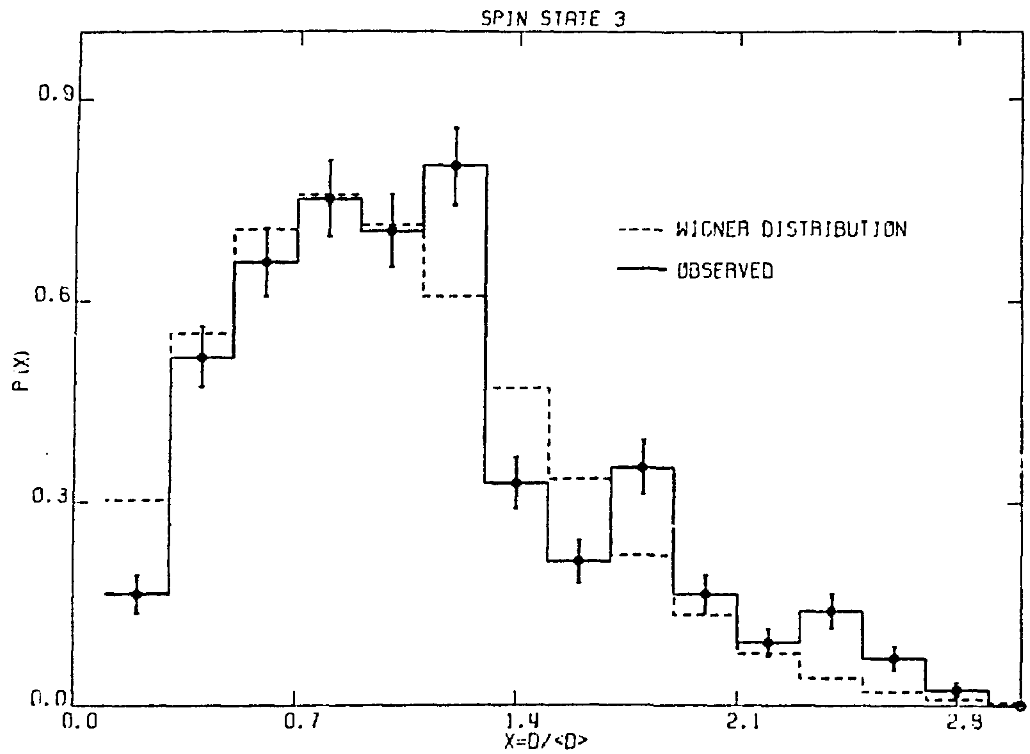

FIG. 4. LEVEL SPACING DISTRIBUTION (SPIN STATE 3)

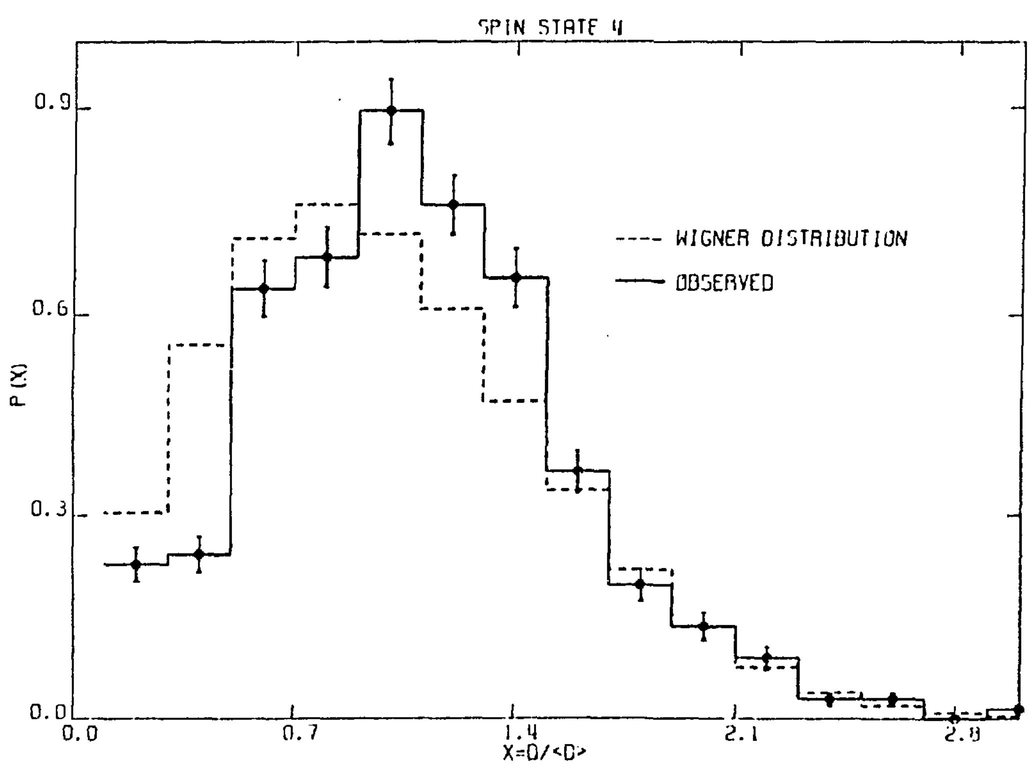

FIG. 5. LEVEL SPACING DISTRIBUTION (SPIN STATE 4)

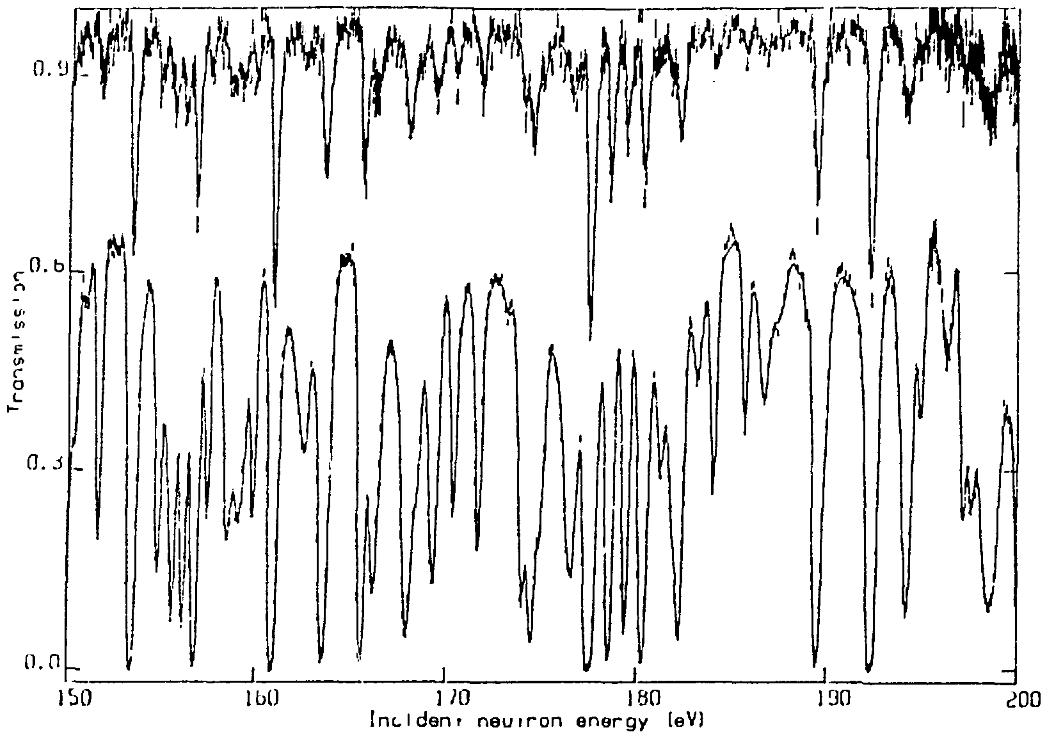

FIG. 6. COMPARISON OF COMPUTED AND MEASURED TRANSMISSION RATIOS.
(0.00234 atm/b, 0.03269 atm/b)

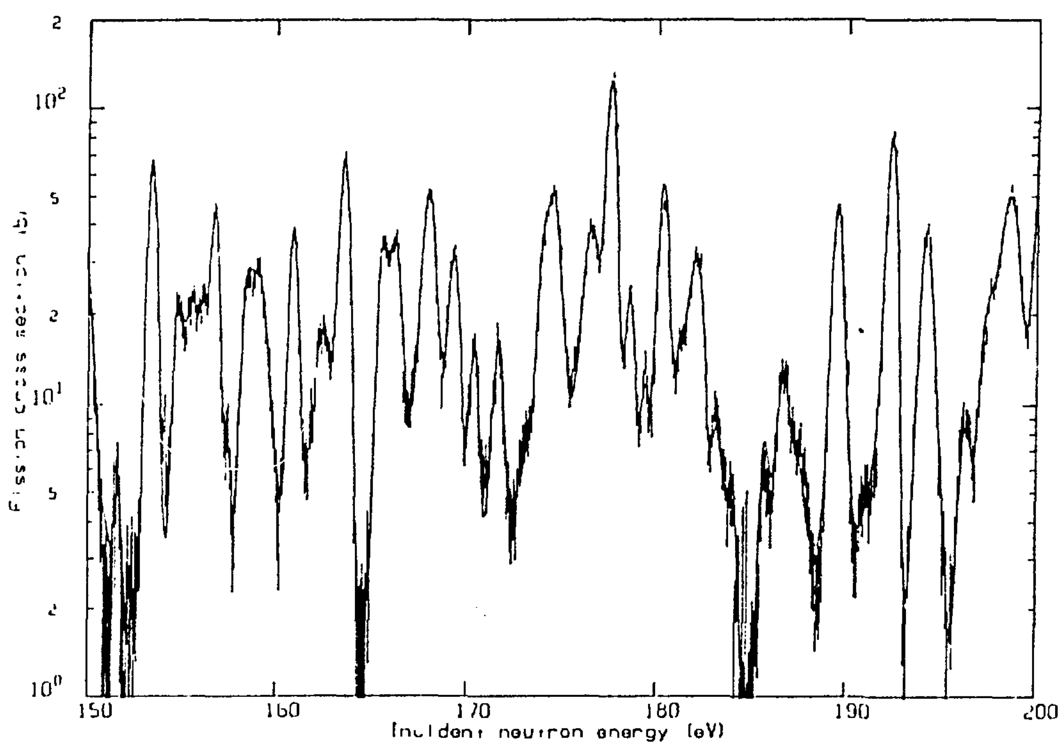

FIG. 7. COMPARISON OF COMPUTED AND MEASURED FISSION CROSS SECTIONS

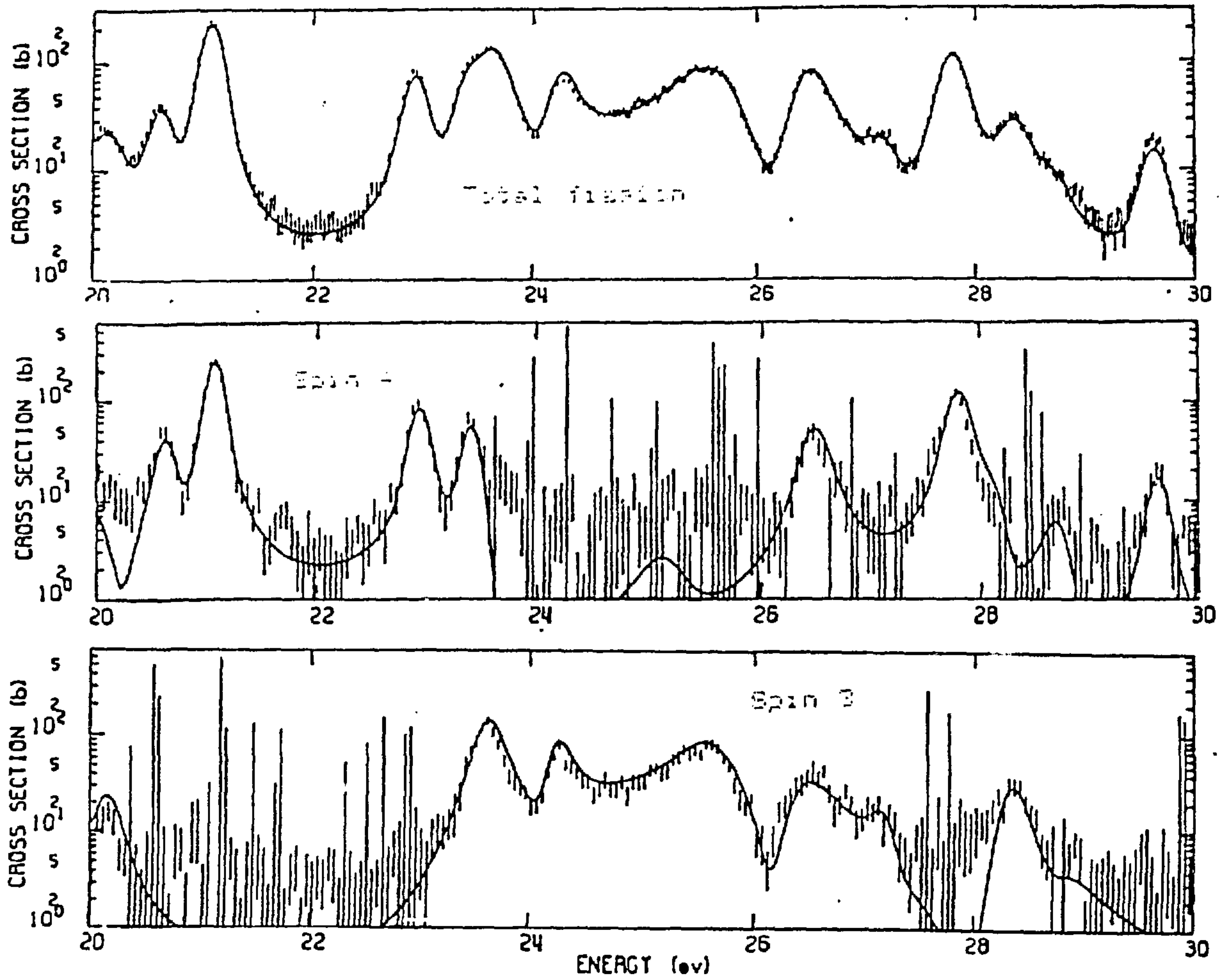

FIG. 8. TOTAL AND SPIN SEPARATED FISSION CROSS SECTION