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EVALUATION OF THE FISSION CROSS SECTION FOR U-233 AND COMPARISON WITH THAT FOR U-235

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Abstract: The fission cross section for U-233 was reevaluated in the energy range from 10 keV to 20 MeV, as a part of works for JENDL-3. This revise was performed on the basis of the recent experimental data published after 1982 in which JENDL-2 was released, and using the fission cross section of U-235 which was obtained by simultaneous evaluation for JENDL-3. Especially, the data of fission cross section ratio of U-233 to U-235 which were measured in Tohoku University in 1985 and 1987, were taken into account in the energy range from 200 keV to 7 MeV.

(fission cross section, ratio data, absolute measurement, JENDL, simultaneous evaluation, integral test)

1. Introduction

U-233 is a main nuclide in thorium series fuel cycle, and the fission cross section plays an essential role in determination of the characteristics of reactors and fuel burn-up. Therefore, it is necessary to know the values of fission cross section as accurate as possible, in order to obtain the reliable characteristics by calculation. Measurements of the fission cross section for U-233 have been actively performed, and a number of data were accumulated up to the present. As to the measurement of fission cross section for U-233 after JENDL-2 which was released in December, 1982, two relative measurements were performed with the Dynamitron accelerater at Tohoku University in the energy ranges from 490 keV to 6.97 MeV and from 218 to 849 keV, and the ratio data to U-235 were published by Kanda et al./1/ in 1985 and by Manabe et al./2/ in 1987, respectively. In the high energy region around 14 MeV, the absolute data were published by Dushin et al./3/ in 1983 and by Zasadny et al./4/ in 1984, and the ratio data to U-235 were also presented by Meadows/5/ in 1987.

In the present work, the fission cross section of U-233 was reevaluated on the basis of the latest experimental data and the fission cross section of U-235 obtained by a simultaneous evaluation of heavy nuclides.

2. Comparison of the Recent Experimental Data

The relative measurements of U-233 below 8 MeV which are discussed in this paper, are shown with the evaluated data in Fig. 1 and Fig. 2. As seen in both figures, the data by Carlson and Behrens show good agreement with the data by Fursov et al. over the whole energy range except 250 to 800 keV and around 6 MeV. The maximum difference between both data is about 5% around 300 keV. Although the data by Kanda et al. show comparatively good agreement with the data by Carlson and Behrens in 500 keV to 1 MeV, their data are considerably higher than those by Carlson and Behrens above 1 MeV, and agree with the data by Meadows/7/. The maximum difference between the data by Kanda et al. and by Carlson and Behrens is abount 5% around 2.5 and 6 MeV. The data by Manabe et al. show somewhat higher values than those by Kanda et al., and distribute between the data by Meadows and by Carlson and Behrens in the energy region 350 to 850 keV. The data by Meadows show the highest values in the whole energy range except 1.25 to 2.5 MeV.

On the other hand, as seen in Fig. 1 and Fig. 2, the data of ENDF/B-IV are remarkably lower than the recent experimental data in the energy region 300 keV to 6.5 MeV. This means that the old experimental data which were adopted in preparation of ENDF/B-IV are much lower compared with the recent data. The data by White and Warner/10/ plotted in both figures are an example of the old data. Accordingly, this time change of the data suggests a rising tendency.

In the energy region around 14 MeV, three measurements were recently performed. The absolute data given by Dushin et al./3/ are 2.254 b(measured in Khlopin Radium Institute) and 2.244 b(measured in Technical University) at 14.7 MeV, and the weighted mean value of both data is 2.248 b. Next, the cross section measured by Zasadny et al./4/(University of Michigan) is 2.43 b at 14.62 MeV. This value is 8.1% higher than the mean value by Dushin et al. On the other hand, the ratio value measured by Meadows/5/ is 1.132 at 14.74 MeV, and is 3.7% higher than that(1.092) at 14.904 MeV measured by Carlson and Behrens/9/. The cross section derived from this ratio value and the fission cross section of U-235 at 14.74 MeV is 2.40 b and close to the data by Zasadny et al.

3. Evaluation and Results

In the present work, the fission cross sections of U-235 obtained by simultaneous evaluation of the heavy nuclides for JENDL-3 were used to derive those of U-233 from the ratio data. This simultaneous evaluation was performed in the energy range from 50 keV to 20 MeV. Accordingly, the present evaluation in the energy range from 10 to 50 keV was performed on the basis of the data by Gwin et al./11/. Their data were adopted in order to keep the consistency with the simultaneous evaluation, because their data were used in the evaluation of Pu-239, and their ratio data agree well with the data by Carlson and Behrens around 50 keV. The fission cross section in the energy range from 50 to 200 keV were evaluated on the basis of the data by Carlson and Behrens and by Poenitz/11,12/. The data of absolute measurement by Poenitz/11/ show good agreement with the evaluated values derived from the ratio data by Manabe et al./2/ around 200 keV.

Next, the fission cross sections in the energy region from 200 keV to 7 MeV were evaluated on the basis of the latest data by Manabe et al./2/ and by Kanda et al./1/ taking account of the rising tendency of the experimental data mentioned in the previous section. The data by Fursov et al. were also used to determine the detailed shape of the ratio data, because their data points are abundant compared with those of Manabe et al. and Kanda et al. The results of evaluation in the energy region from 100 keV to 8 MeV are shown in Fig. 3 and Fig. 4 with the experimental data and previous evaluations(ENDF/B-IV and JENDL-2). The differences between the present and previous evaluations are considerably large in this energy region. This is due to the differences of the adopted ratio data and of the fission cross sections of U-235. This problem is discussed in the next section.

Finally, the fission cross section in the energy range above 7 MeV was evaluated on the basis of the ratio data by Carlson and Behrens/9/ except around 14 MeV. As mentioned in the previous section, large discrepancies exist between the absolute measurements by Dushin et al. /3/ and by Zasadny et al./4/, and also between the relative measurements by Carlson and Behrens and by Meadows/5/ around 14 MeV. The latest data by Meadows support the measurement by Zasadny et al., though the data by Carlson and Behrens lie between both absolute measurements. In addition, the accuracy of the data by Meadows is very good(0.7%). Therefore, in the present work, the data by Meadows at 14.74 MeV were adopted instead of the data by Carlson and Behrens at 14.180 and 14.904 MeV. The result of evaluation in the energy range from 8.0 to 20 MeV is shown in Fig. 5.

4. Comparison with the Fission Cross Section for U-235

As seen in Fig. 4, the present results show considerably high values compared with the data of JENDL-2 and the only absolute measurements by Poenitz/12/ in the energy region from 1 to 5.5 MeV. Although the differences between the present results and data by Poenitz are a few percents in the energy region below 1 MeV, the differences above 1 MeV are remarkably large. The maximum difference attains to 13.5% at 4 MeV. This situation is similar to the case of U-235. In the case of U-233, this difference is composed of two factors. The first factor is due to the fact that the ratio data adopted in the present work are higher than the ratio values calculated from the absolute data of U-233/12/ and U-235/13,14/ by Poenitz. The second factor is due to the fact that the fission cross sections of U-235 obtained by simultaneous evaluation are also higher than the absolute measurements of U-235 by Poenitz in the same energy region.

These relations are shown in Fig. 6 in the energy region from 1 to 7 MeV. In this figure, the thick solid line shows the ratios of the present results(JENDL-3T) to the data by Poenitz /12/. The thin solid line shows the ratios of the relative data by Kanda/1/(Tohoku Univ.) to those obtained from the data by Poenitz/12,13,14/. The thin broken line shows the ratios of the simultaneously evaluated fission cross sections (JENDL-3T) to the absolute measurements by Poenitz /13,14/ for U-235. As seen in this figure, the thin broken line(${}^{235}\sigma f(J\text{-}3T)/{}^{235}\sigma f(\text{Poenitz})$) shows the highest values in the energy region from 3 to 4.25 MeV. This is based on the following reason. Roughly speaking, the simultaneously evaluated data are the weighted averages of the recent experimental data which are most scattered in the above energy region, whereas the data by Poenitz belong to the lowest group of the experimental data in this region. This status is shown in Fig. 7*.

* quoted from the paper by Bhat/15/

The ratios of the relative data(R(Tohoku)/R (Poenitz)) are also large in the energy region from 3.5 to 5.25 MeV. Accordingly, the effect of product of the two factors has been strongly reflected in the present results.

5. Discussion and Concluding Remarks

The fission cross section of U-233 was reevaluated in the energy range from 10 keV to 20 MeV. In the present work, the latest experimental data were used in the energy regions from 200 keV to 7 MeV and around 14 MeV. As the result of this work, the fission cross section of JENDL-2 was increased abount 1% on the average in the whole energy region. In particular, the increase in the energy region from 4 to 5 MeV attains to 8.5%.

Following this revise, the next subject is to examine the validity of the present work by the integral tests. In relation to this subject, three analyses have been performed by Watanabe et al.(1987)/16/, Kanda et al.(1988)(Kyushu Univ. and ANL)/17/, and Ganesan et al.(1987)/18/.

Watanabe et al. have measured the integral neutron fission cross section ratios to U-235 for seven heavy nuclides by using ^{9}Be-d neutron source. This neutron source is distributed in the energy range from 200 keV to 11.4 MeV, and the peak energy is 2 MeV. The experimental value of spectrum averaged fission cross section ratio for U-233 was 1.532, the calculated value using JENDL-2 was 1.459, and C/E-value was 0.9523. This result shows that the spectrum averaged value of fission cross section of JENDL-2 is about 5% lower than the experimental value.

Kanda et al./17/ have performed this integral test using the data of JENDL-3T and the same neutron spectrum. The ratio value obtained for U-233 was 1.5354 and C/E-value was 1.0022. This result means that the data of JENDL-3T are better than those of JENDL-2.

Ganesan et al. have analyzed the characteristics of the spherical U-233 JEZEBEL assembly and the U-233 irradiation performed in the RAPSODIE reactor. In this analysis, six nuclear data libraries including JENDL-2 were used. The keff-value obtained by using JENDL-2 for the JEZEBEL assembly was very close to the experimental value. However, the analysis of the integral fission cross section for U-233 in RAPSODIE reactor was not satisfactory. That is, the experimental and calculated values were 2.31 and 2.141 barns, respectively. This means that the data of JENDL-2 are 7% lower than those obtained by the experiment. This result is similar to that by Watanabe et al.

It seems that the validity of the fission cross section of JENDL-3T above 200 keV was roughly confirmed by the above analyses. However, it is necessary to carry out more detailed integral tests over the whole energy range in order to search for any defect of JENDL-3T library.

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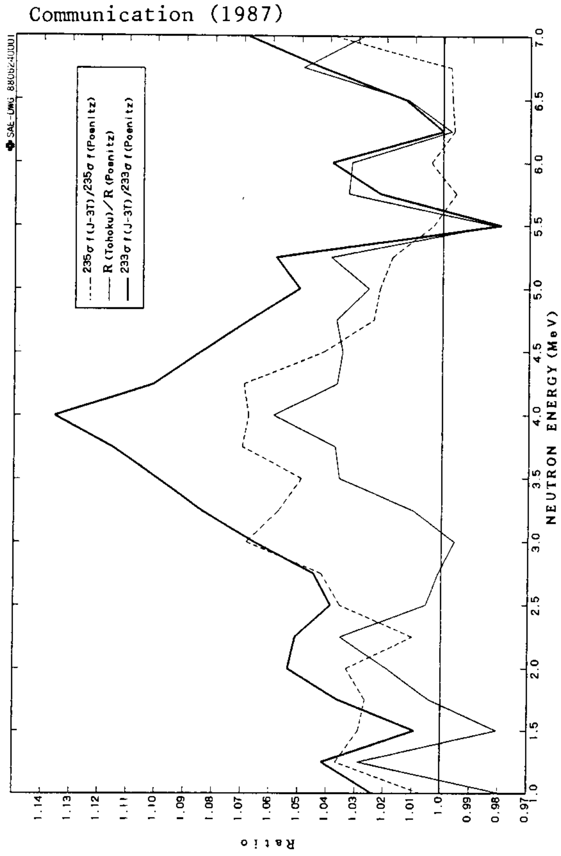
Fig.6 The Ratios of Fission Cross Sections for U-233 and U-235 to the Data by Poenitz in the Energy Range from 1 to 7 MeV

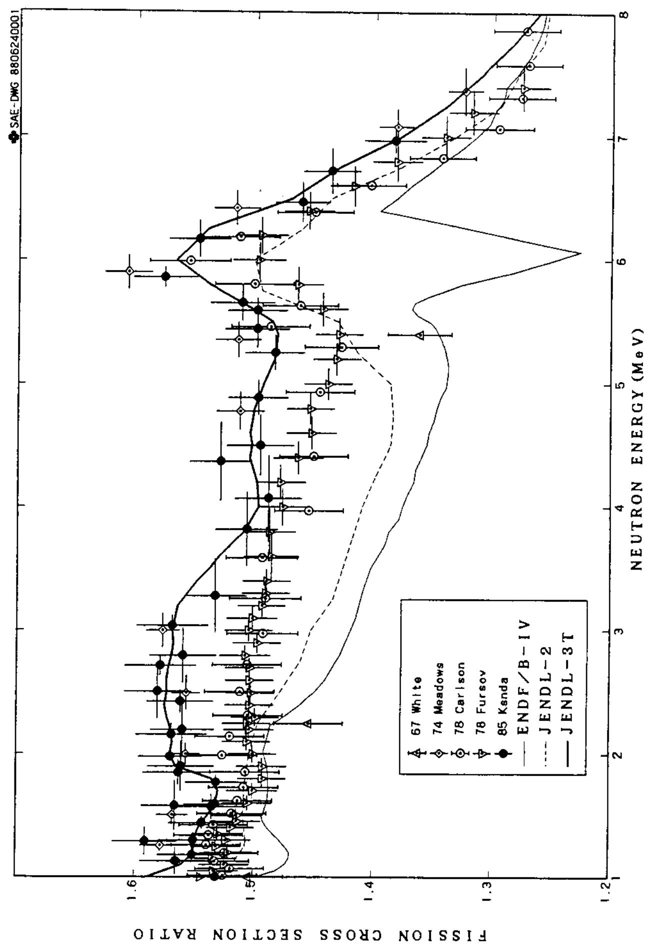

Fig.2 The Ratios of Fission Cross Section for U-233 to U-235 in the Energy Range from 1 to 8 MeV

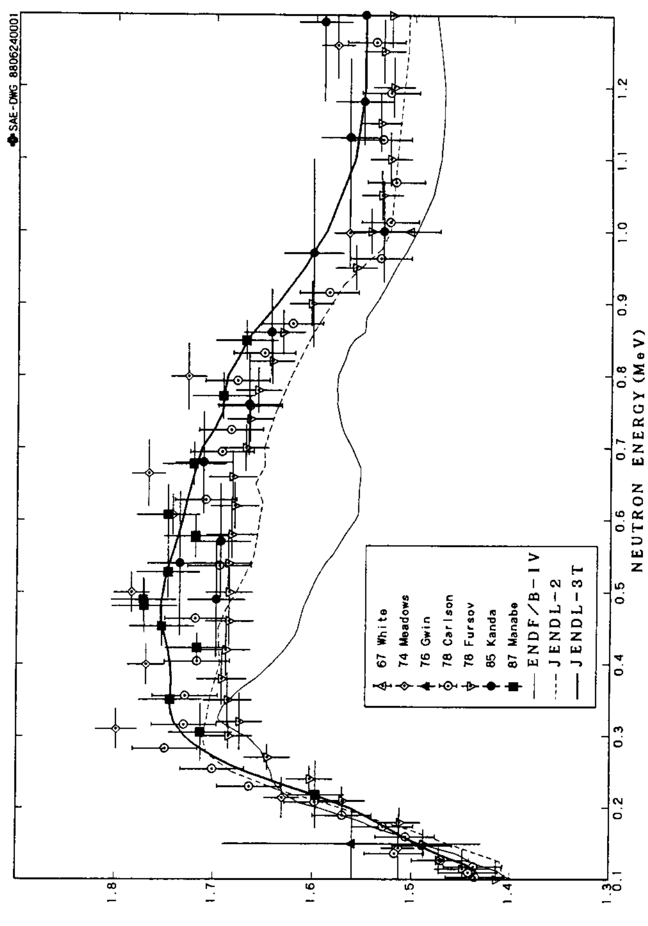

Fig.1 The Ratios of Fission Cross Section for U-233 to U-235 in the Energy Range from 100 keV to 1.3 MeV

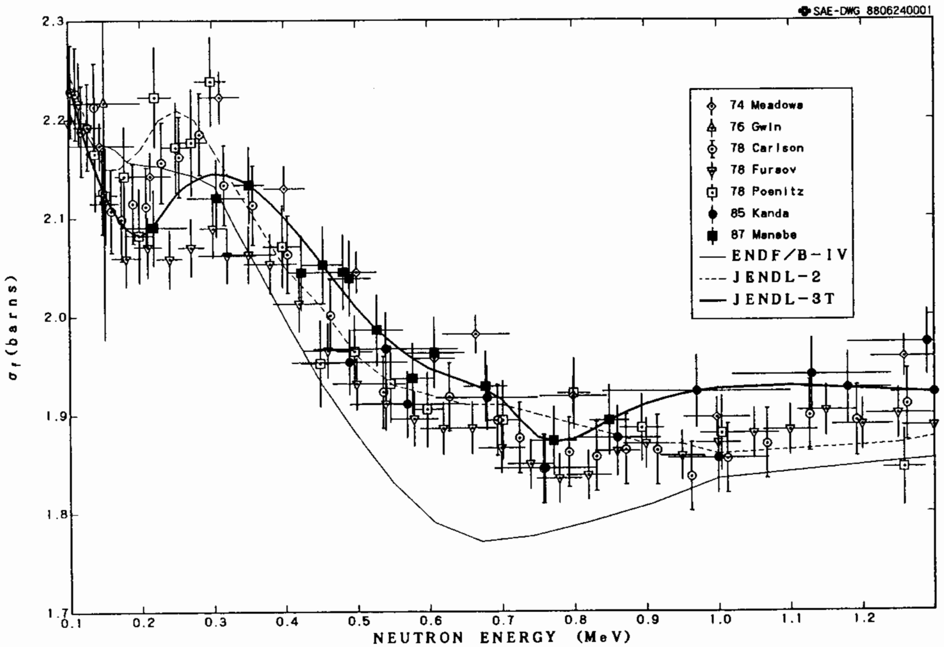

Fig.3 The Evaluated and Experimental Fission Cross Sections for U-233 in the Energy Range from 100 keV to 1.3 MeV

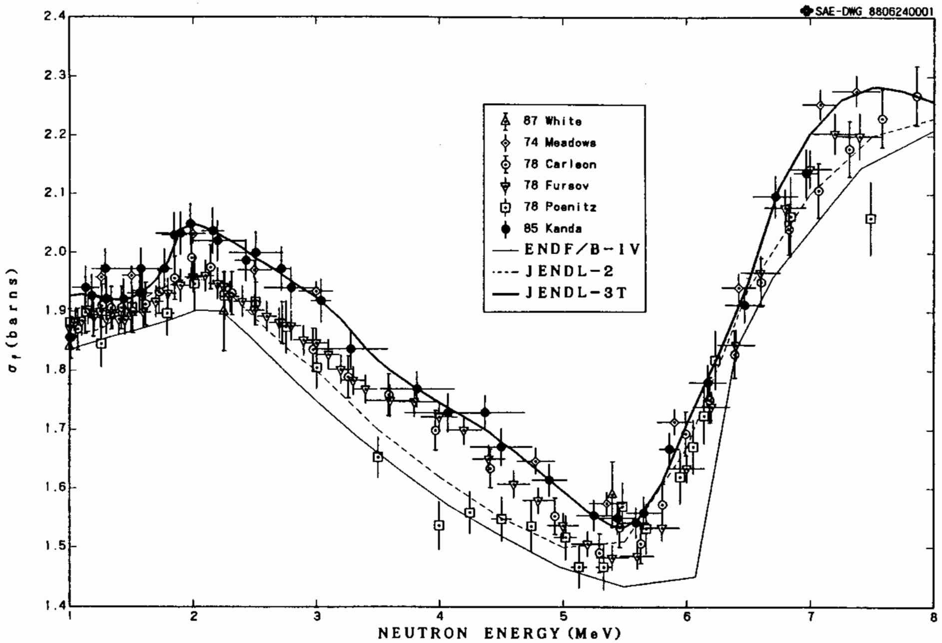

Fig.4 The Evaluated and Experimental Fission Cross Sections for U-233 in the Energy Range from 1 to 8 MeV

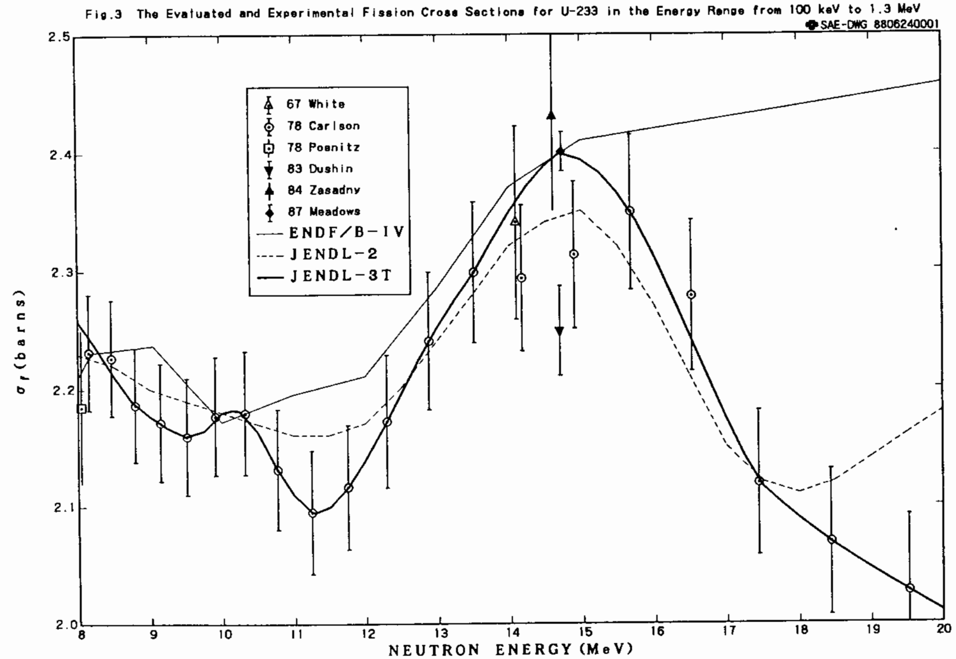

Fig.5 The Evaluated and Experimental Fission Cross Sections for U-233 in the Energy Range from 8 to 20 MeV

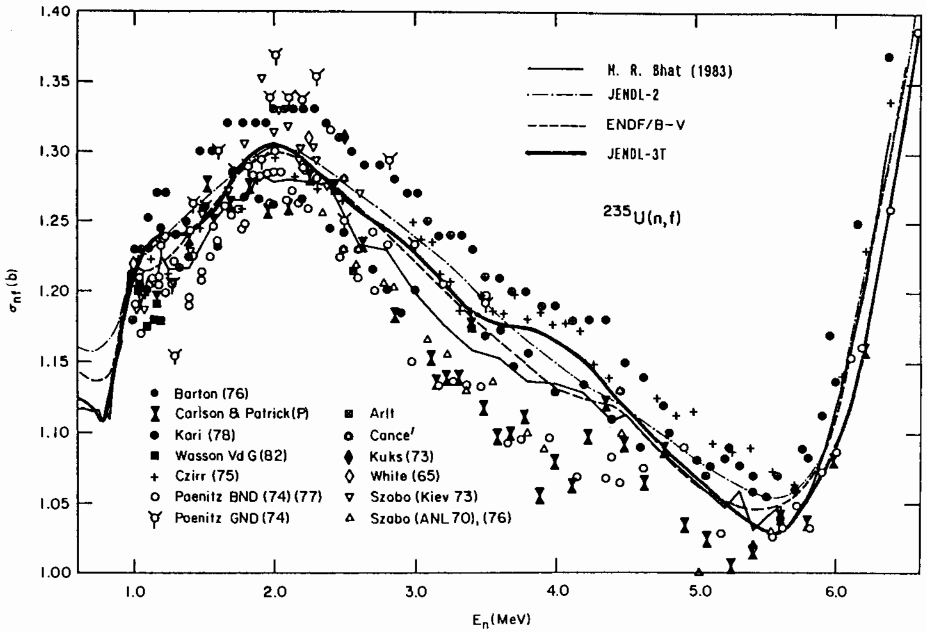

Fig. 7 Comparison of Eperimental and Evaluated Data in the Energy Range from 0.6 to 6.6 MeV