

A REPORT ON EVALUATED $^{238}\text{U}(n,\gamma)$ CROSS SECTION

Y. Kanda

Kyushu University, Kasuga, Fukuoka 816, Japan

Y. Kikuchi and Y. Nakajima

Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-11, Japan

M. G. Sowerby and M. C. Moxon

Atomic Energy Research Establishment, Harwell, Oxon, OX11 0RA, U.K.

F. H. Fröhner

Kernforschungszentrum Karlsruhe, Karlsruhe, F. R. Germany

W. P. Poenitz

Argonne National Laboratory-West, Idaho Falls, ID 83403-2528, U.S.A.

L. W. Weston

Oak Ridge National Laboratory, Oak Ridge, TN 37830, U.S.A.

Abstract: A longstanding and difficult problem in nuclear data evaluation has been that ^{238}U capture cross sections in the unresolved resonance region evaluated on the basis of available experiments are larger than the ones expected from the reactor physics analysis. However, the new versions of the major files, ENDF/B-VI, JEF-2 and JENDL-3 have now adopted lower values than the respective previous versions. To be convinced that these new evaluations are correct, a subgroup in the NEACRP/NEANDC Working Group on International Evaluation Cooperation has studied the problem.

New resonance parameters deduced from capture and transmission data by the shape analysis method can be used to renormalise early capture cross section experiments. The average capture cross sections calculated from these then has high weight in a simultaneous evaluations which leads to lower evaluated capture values. Theoretical model fitting to available experiments gives similar values. Two recent measurement agree with the lower ones. Therefore, the subgroup concludes that the lower capture cross sections of ^{238}U recommended in ENDF/B-VI, JEF-2 and JENDL-3 are reasonable.

(^{238}U , capture cross section, shape analysis, neutron width, gamma width, simultaneous evaluation, ENDF/B-VI, JEF-2, JENDL-3)

Introduction

Neutron capture cross section of ^{238}U in unresolved resonance region is an important quantity for reactor calculation. There was, however, a longstanding difficulty: Earlier evaluations resulted in a higher capture cross sections than expected from reactor physics analysis. This was common in three major evaluated data files i.e. ENDF/B-V, JEF-1 and JENDL-2. The available differential measurements on which they were scattered by more than 15 % depending on the neutron energy region. As shown in Fig. 1 there were substantial discrepancies even in the careful experiments e.g. Moxon[1] and de Saussure *et al.* [2] which had been undertaken to solve the problem. Evaluators recommended mean values of experiments as the best cross section values as there was to modify the experimental results. Nevertheless, the new versions of the major files, ENDF/B-VI, JEF-2 and JENDL-3 have now adopted smaller capture cross sections in the unresolved region than the previous versions. In Fig. 1, as a typical example, JENDL-3 is shown in comparison with the experiments and the previous version JENDL-2 as a typical example. As can be seen in this figure JENDL-3 follows the lowest values of experimental data, while JENDL-2 follows the average values.

To have a full understanding of the smaller capture cross sections adopted in the new major files, the subgroup on ^{238}U capture and inelastic scattering cross sections was established by the NEACRP/NEANDC Working Group on International Evaluation Cooperation. The problems concerning on the capture cross sections have been intensively studied and resolved. The results are reported here. The project on the inelastic scattering cross section is in progress.

Validity of the New Versions of three Major Files

The Resolved Resonance Range

It is believed that measurements of the ^{238}U capture cross sections made with white neutron sources (e.g. Linacs) can be accurate. Normally these are normalised at very low energies using resonances where the neutron width Γ_n is much smaller than the capture width Γ_γ and the sample is "black" so that at the resonance peak the capture yield gives directly the normalisation constant. Therefore, the measurements with white neutron sources must be renormalised when it is found that incorrect values of Γ_n and Γ_γ were used in their original data procedures.

Sowerby *et al.* [3,4] and Moxon *et al.* [5,6]

The NEANDC Task Force on ^{238}U was set up to deal with two problems; the neutron widths of the resolved resonances above 1.4 keV and the capture cross section in the resolved and unresolved resonance regions. In the Task Force, the new evaluation was carried out over the whole energy range below 10 keV using the shape analysis code REFIT[7]. This code can simultaneously analyse both capture and transmission data. The shape analysis is able to identify errors in background and normalisation in both the measurements. It should be noted that previous evaluations are mainly based on area analysis.

The normalisation of capture data is no longer necessary to consider only very low energy resonances as in principle the experiments can be normalised at any resonance where both Γ_n and Γ_γ are well known. The peak height in a capture measurement and its capture area can be derived from the resonance parameters obtained from transmission measurements. For resonances which are isolated and do not overlap with others the derived quantity is accurate and hence can be used to normalise the experiment. As a result of this ability, it was found that the capture cross section of de Saussure *et al.* [2] were inconsistent with the parameters obtained from the transmission data and an assumed values of Γ_γ (23~23.5 meV) unless the capture data were renormalised by a factor of ~0.9 near 1.8 keV neutron energy. This renormalisation is correct for a wide range of resonances neutron widths from $\Gamma_n \ll \Gamma_\gamma$ to $\Gamma_n \gg \Gamma_\gamma$. The original normalisation is correct at the first resonance at 0.67 eV, where the measured data were normalised by the authors, but at higher resonance energies the capture yields calculated from transmission data increasingly deviate from the experimental values. The average capture cross sections published by de Saussure *et al.* [2] must be corrected by multiplying by the following correction factor F :

$$F = 0.845 \exp \left(\frac{0.38421}{\sqrt{E}} \right),$$

where E is in eV [8]. It is probable that this tendency will continue in the unresolved resonance region. This correction bring the data of de Saussure *et al.* into good broad agreement with the data of Moxon [1,9] as seen in Fig. 2. The reason for the above correction factor is uncertain. It is worth noting that the normalisation of the Moxon data [1] has also been checked by the same method and it was found that the normalisation was correct.

The Unresolved Resonance Range

Evaluation by Fröhner [10,11,12] The evaluation in the unresolved resonance region (~10 to 300 keV) is based on simultaneous fits with the FITACS code [13], which employs Hauser-Feshbach theory with width fluctuation and the generalized (Bayesian) least squares technique.

to a large body of total (5 sets), inelastic scattering (4 sets) and capture cross section data (27 sets), and on rigorous (Bayesian) inclusion of prior knowledge from resolved resonances and from optical model fits at higher energies. Multiple scattering corrections applied to capture yield data produced lower capture cross sections, consistent with the resolved-resonance analysis.

Utilisation of theory permits simultaneous description of all the observations in terms of average resonance parameters. Since this theory relates averaged cross sections for all reaction channels, a coherent evaluation of all information provides powerful physical constraints and reduces uncertainties.

Evaluation by Poenitz [14,15,16] The evaluation of the ^{238}U capture cross section was part of a simultaneous evaluation of ten cross sections and later combination with a R-matrix analysis of additional data for five of these cross sections [16]. For ^{238}U the average capture cross sections in the resolved resonance region as well as data above the unresolved resonance range were used in addition to the cross section for the unresolved region. The resulting evaluated cross section lies on the lower side of the bulk of the available measurements and is accurate to ~ ±2.5 % or better over most of the energy range between 10 keV and 500 keV as shown in Fig. 1.

Contents of three Major Libraries

ENDF/B-VI and JEF-2 These two files adopted the same evaluation in the resolved and unresolved resonance region [17]. For the resolved resonance region from 10^{-5} eV to 10 keV the evaluation by Moxon and

Sowerby [3,4,5,6] was used. Fröhner's evaluation [10,11] was adopted in the unresolved resonance region from 10 to 149 keV. The evaluation from 149 keV to 20 MeV is taken directly from the simultaneous standards evaluation [14,16].

JENDL-3 The resolved resonance region from 10^{-5} eV to 4 keV. For the unresolved resonance region, the measurement by Kazakov *et al.* [18] was adopted because it was the recent experiment with good resolution and in addition it was consistent with reactor physics analysis. Although the ^{238}U capture cross section was included in the original simultaneous evaluation for JENDL-3 by Kanda *et al.* [19], the renormalisation of the average cross section in the resolved resonance region could not be utilized since the simultaneous evaluation was made only on the basis of the data above 50 keV. The recent measurement of Quang and Knoll [20] agrees also with the new evaluations.

Impact on Integral Parameters

The lower capture cross section of ^{238}U has been required from the reactor analysis. Hence it is interesting to know how the present change to lower values impacts on various integral characteristics of reactors. Some results of sensitivity analysis on JENDL-3 are presented here as an example. The sensitivity coefficients were calculated for ZPPR-9 critical assembly, which is a clean homogeneous physical mock-up core of large demonstration fast breeder reactor.

The sensitivity coefficients of ^{238}U capture cross section in the energy range from 1 keV to 500 keV are particularly significant to k-eff and the reaction rate of ^{238}U capture to ^{239}Pu fission (or ^{238}U fission). The differences of ^{238}U capture cross section from JENDL-2 to JENDL-3 causes increase of k-eff by 0.4 % and decrease of ^{238}U capture to ^{239}Pu fission rate ratio by 1.3 %. Contributions from the other energy regions are negligible.

Conclusion

The subgroup has studied the reason why the recent evaluated data of the ^{238}U capture cross section are lower than the average of the available measured data. Sowerby and Moxon found in their shape analysis of resolved resonances that some of the measured capture data should be renormalised. After the renormalisation, the measured data converge to the lower values, with which the recent evaluated data agree. The lower values could be reproduced with fitting the theoretical model to available experiments by Fröhner. From the multiple-scattering effect it is understood why many of the old capture data sets were too high: This confirms and explains Poenitz' renormalisation based on the resolved-resonance analysis. Furthermore, the lower capture cross section of ^{238}U has significant influence on the integral parameters of fast reactors, whose direction has been predicted by reactor physicists. Thus the subgroup concludes that the lower capture cross section of ^{238}U in the unresolved resonance region, which was adopted in three of the recent major files, i.e. ENDF/B-VI, JEF-2 and JENDL-3, are reasonable and that the earlier evaluations should be superseded.

The authors are indebted to Mr. Y. Nakagawa of JAERI for preparing the figures.

REFERENCES

1. M.C. Moxon, The Neutron Capture Cross Section of ^{238}U in the Energy Region 0.5 to 100 keV, AERE-R 6074, Atomic Energy Research Establishment (1967)
2. G. de Saussure *et al.*, Nucl. Sci. Eng. 51, 385 (1973)
3. M. Sowerby *et al.*, in Proc. Int. Conf on Nuclear Data for Basic and Applied Science, May 1985, Santa Fe, USA (Edited by P.G. Young *et al.*), Vol. 2, p.1511, Gordon and Breach, New York (1986)
4. M. Sowerby and F. Corvi, in Proc. Int. Conf. on Nuclear Data for Science and Technology, May/June 1988, Mito, Japan (Edited by S. Igarasi), p.37, Saikon, Tokyo (1988)
5. M.C. Moxon *et al.*, in Proc. 1988 Int. Reactor Physics Conf., Sept., Jackson Hole, USA, p. 1-281 (1988)
6. M.C. Moxon *et al.*, in Proc. 1990 Int. Reactor Physics Conf., PHYSOR'90, April, Marseille, France, p.III-41 (1990)
7. M.C. Moxon, in Neutron Data of Structural Materials for Fast Reactors, Pergamon Press, Oxford, p.644 (1979)
8. M.G. Sowerby and M.C. Moxon, Private Communication (1990)
9. M.C. Moxon, Private Communication (1991)
10. F.H. Fröhner, in Ref. 5, p.III-171 (1988)
11. F.H. Fröhner, Nucl. Sci. Eng., 103, p. 119 (1989)
12. F.H. Fröhner, Private Communication (1991)
13. F.H. Fröhner *et al.*, in Proc. Mtg. Fast Neutron Capture Cross Sections, Sept. 1982, Argonne, USA, ANL-83-4, p.116, Argonne National Laboratory (1983)
14. W.P. Poenitz, Private Communication to S. Igarasi (1989)
15. W.P. Poenitz, in Proc. Conf. on Nuclear Data Evaluation Methods and procedures, Sept. 1980, Brookhaven, USA, BNL-NCS-51363, Vol. 1, p.249, Brookhaven National Laboratory (1981)
16. A.D. Carlson *et al.*, in Ref. 3, Vol. 2, p.1429, Gordon and Breach, New York (1986)
17. L.W. Weston, Private Communication (1991)
18. L.E. Kazakov *et al.*, Yad. Const., 3, p. 37, (1986) (in Russian) and Report, INDC(CCP)-319/L, p.45 (1990) (in English)
19. Y. Kanda *et al.*, in Ref. 3, Vol. 2, p.1567

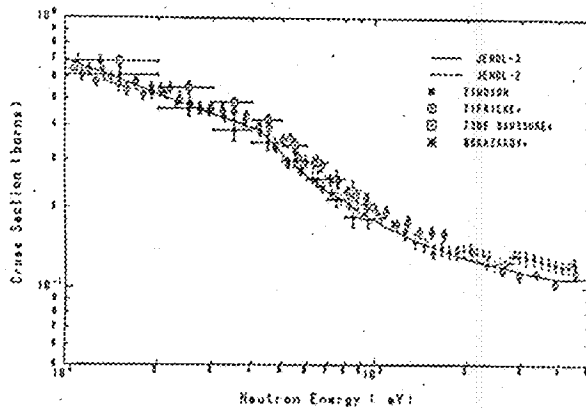


Fig.1

Comparison of evaluated data with experiments for ^{238}U capture cross sections in unresolved resonance region. JENDL-3 and JENDL-2 are shown as the typical examples of a new version and previous one of the major files, respectively. There are also typical experiments in available ones.

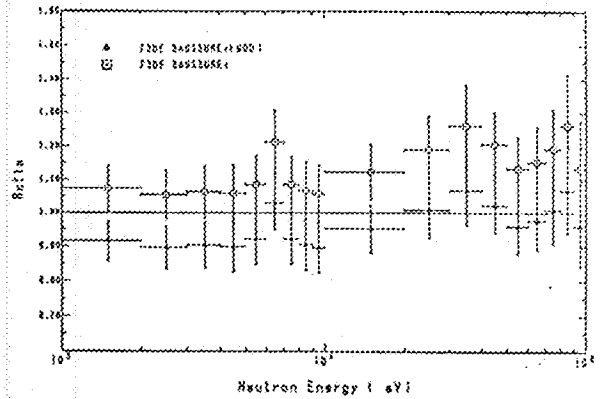


Fig.2

Comparison of ratios of the original de Saussure *et al.* data[2] and the de Saussure *et al.* ones renormalised by Moxon[9] to the Moxon measurement[1].

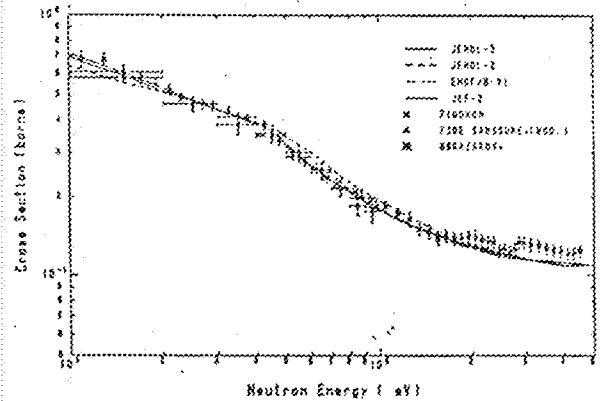


Fig.3

Comparison of the new versions of the major files with the experiments of Moxon, renormalised de Saussure *et al.* and Kazakov *et al.*