PHYSOR 2004 -The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments
Chicago, Illinois, April 25-29, 2004, on CD-ROM, American Nuclear Society, Lagrange Park, IL. (2004)

Status of a New Evaluation of the Neutron Resonance Parameters of ^{238}U at ORNL

H. Derrien,* L.C. Leal, and N.M. Larson
Oak Ridge National Laboratory
P. O. Box 2008
Oak Ridge, TN 37831 USA

Neutron resonance parameters were obtained in the energy range 0 keV to 20 keV from a sequential SAMMY analysis of high resolution neutron transmissions and capture cross sections measured at the Oak Ridge Electron Linear Accelerator (ORELA). In the energy range 0 keV to 10 keV the analysis used as prior values the resonance parameters of ENDF/B-VI evaluated file. In the energy range10 keV to 20 keV, where ENDF/B-VI uses average parameters for the description of the cross sections, this analysis resulted in the creation of a set of resolved resonance parameters which will allow more accurate calculation of the self shielding factors. The statistical properties of the parameters in the energy range 0 keV to 20 keV are given. The results of selected benchmark calculations show significant improvements compared to calculations using the ENDF/B-VI evaluation, particularly for the k_{eff} prediction in thermal benchmarks.

KEYWORDS: resonance parameters, neutron cross section, statistical properties, evaluation, benchmarks.

1. Introduction

In the framework of the U.S. Department of Energy Nuclear Criticality Safety Program, a new evaluation of the neutron resonance parameters of ^{238}U was undertaken at the Oak Ridge National Laboratory (ORNL, USA). The new evaluation was performed within the framework of the Working Party on International Nuclear Data Evaluation Cooperation (WPEC) in order to solve current k_{eff} prediction problems. In this paper we present the results of a new evaluation using the computer code SAMMY [1] with all the available ORELA data in the experimental data base. In Section 2, short descriptions of the experimental data base and the method of analysis are given. The properties of the resonance parameters are given in Section 3. Comparison between the cross sections calculated with ENDF/B-VI and the present resonance parameters, and the results of some benchmark calculations, are given in Section 4.

2. The experimental data base and the method of analysis

Since 1970 a large effort at ORELA was devoted to performing accurate neutron transmission and neutron capture measurements of ^{238}U, in order to improve the accuracy of the resonance parameters. The first series of transmission measurements was performed by Olsen *et al.*[2] for seven sample thicknesses using a 42 m flight path, in the energy range 5 eV to 10 keV(1977). The second series was also performed by Olsen *et al.* [3] for four sample

* Corresponding author, Tel. 865-574-7268, E-mail: derrienh@ornl.gov

thicknesses using a 150 m flight path in the neutron energy range 300 eV to 100 keV(1979). The third series was performed by Harvey *et al*. [4] for three sample thicknesses with a 200 m flight path in the neutron energy range 1 keV to several hundred keV(1988). Capture measurements were performed by de Saussure *et al*. [5] (1973) on a 40 m flight path, and by Macklin *et al.* [6] (1985-1988) on a 150 m flight path. All these data, except the 1988 neutron transmission of Harvey, were used in the evaluation of the resonance parameters for ENDF/B-VI and other nuclear data files (JEFF, JENDL). [7] In the present work all of the data of Olsen and Harvey, and the de Saussure capture data, i.e fourteen sets of experimental data, were gathered in the experimental data base for a sequential SAMMY Bayes analysis. The data of Macklin were not available.

The computer code SAMMY uses the Reich-Moore R-matrix formalism for the calculation of the cross sections, and the calculation of the neutron transmissions is straightforward for a given sample thickness. To make the experimental data corresponding to different transmission data sets consistent, SAMMY can adjust the normalization factors and the background to take into account the experimental errors. The calculation of the measured capture data (effective capture cross section) is much more difficult due to the self shielding and multiple scattering effects. The accuracy of the calculation of these experimental effects in the experimental capture cross section has been largely improved in the lastest version of SAMMY which was used in the present work.

When performing a resonance analysis over a large neutron energy range (e.g., 0 eV to 20 keV) it is important to calculate accurate values of the contribution of the resonances pertaining to the external region (truncated resonances), i.e. those of the negative energy range and those of energies larger than 20 keV. The value of this contribution is strongly correlated to the value of the effective radius, R', which is related to the total cross section between resonances, and to the experimental normalization and background parameters used for possible experimental error corrections. In the present work preliminary SAMMY fits of the data were performed in order to find a consistent set of external resonance parameters, of experimental correction parameters, and the value of R'. The value obtained for R' was 9.45 fm, that is in agreement with the value obtained by Olsen. The corresponding normalization parameters were smaller than 1% , and agree with the published experimental errors. As regards to the capture cross section of de Saussure *et al*., an important correction of about 15% was needed, similar to the one used by Moxon and Sowerby [7] for their evaluation in the energy range 0 keV to 10 keV.

3. The resonance parameters

The fits to the experimental data in the energy range 0 eV to 20 keV were obtained by using 932 s-wave resonances ($J^{\pi}=1/2^{+}$) and 2354 p-wave resonances (814 of $J^{\pi}=1/2^{-}$ and 1540 of $J^{\pi}=1/2^{+}$). The identification of the largest s-wave resonances was possible from the asymmetry due to the potential-resonant interference effect. All of the resonances which cannot be identified as s-wave resonances from their shape had to be distributed among 3 families: small s-wave resonances, J=1/2 p-wave resonances and J=3/2 p-wave resonances. According to the 2J+1 law of the level density spin dependance, the number of the J=1/2 p-wave resonances should be roughly the same as the number of s-wave resonances and the number of the J=3/2 p-wave resonances should be twice this number. In the present work we tried to assign the spin according to the 2J+1 law. The variation of the number of resonances versus neutron energy is given in Fig. 1, for both the s-wave and p-wave resonances. The observed average s-wave and p-wave spacing is 21.5 eV and 8.50 eV, respectively.

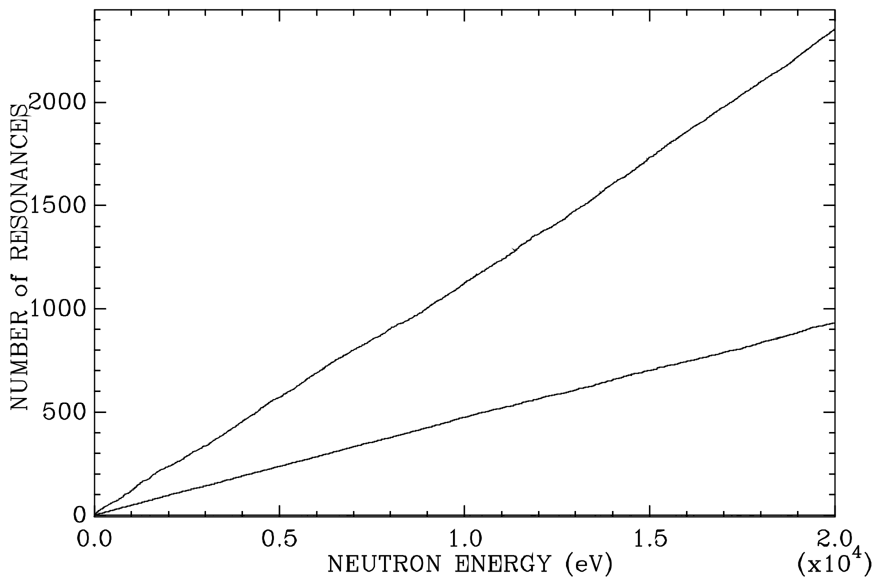

Figure 1. Number of resonances versus neutron energy. The upper line represents the p-wave resonances; the lower line represent the s-wave resonances.

The differential distributions of the s-wave and p-wave level spacings are shown in Fig. 2 and Fig. 3, respectively. The theoretical distribution in Fig. 3 is a superposition of two uncorrelated Wigner distributions in the ratio of the two p-wave spin populations. In both figures there is particularly good agreement between the experimental and the theoretical distribution. The Porter-Thomas distributions of the reduced neutron widths are shown in Fig. 4 and Fig. 5 for the s-wave and p-wave resonances, respectively. The agreement between the experimental and theoretical distributions is also good. However, the theoretical distribution in Fig. 5 takes into account a possible missing 15% of the p-wave resonances.

One of the reasons for a re-evaluation of the resonance parameters of ^{238}U was the underprediction of k_{eff} in the calculation of thermal assemblies. The first s-wave resonances play a major role in the calculation of the capture resonance integral. The accuracy of the parameters of these resonances could be affected by the model used for the Doppler broadening. In the present work the free gas model was used for the calculation of the Doppler broadening with an effective temperature of (300 ± 5) Kelvin. The parameters were obtained from the sequential SAMMY analysis of the 7 metallic sample transmission data of Olsen. From a preliminary SAMMY analysis of the Geel transmission data [8], obtained at different temperatures and using both metallic and oxide samples, A. Courcelle [9] found that the results of the analysis using the free gas model is not significantly different from results obtained using the crystal model. The parameters of the first s-wave resonances obtained in the present work are compared to the ENDF/B-VI values in Table 1. The capture width values are the same, since the values of Moxon and Sowerby were kept in the present evaluation; the values of the neutron widths are smaller than ENDF/B-VI values.

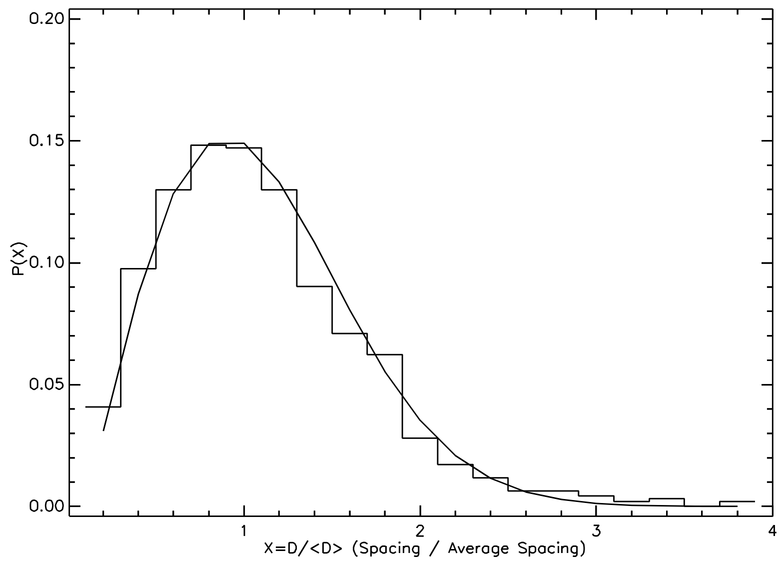

Figure 2. Differential distribution of the s-wave resonance spacings. The histogram represents the experimental data. The solid line represents the theoretical Wigner distribution.

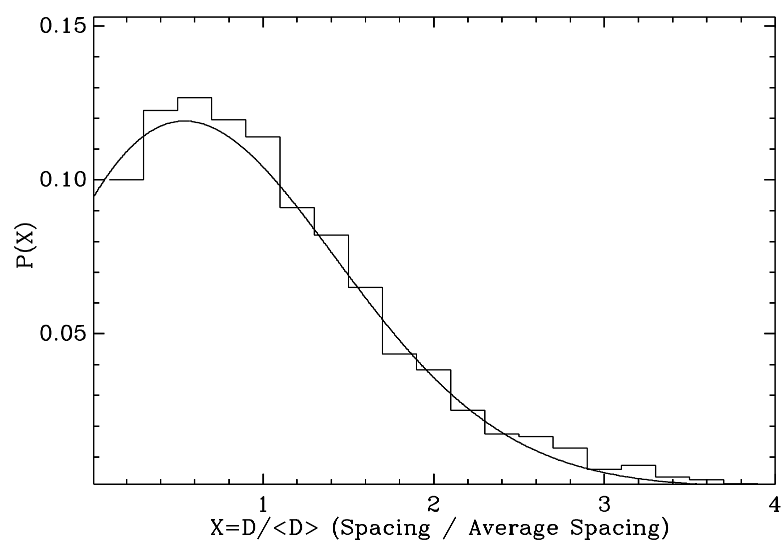

Figure 3. Differential distribution of the p-wave resonance spacings. The histogram shows the experimental distribution. The solid line represents the superposition of two Wigner distributions in the ratio of the population of the two p-wave spins.

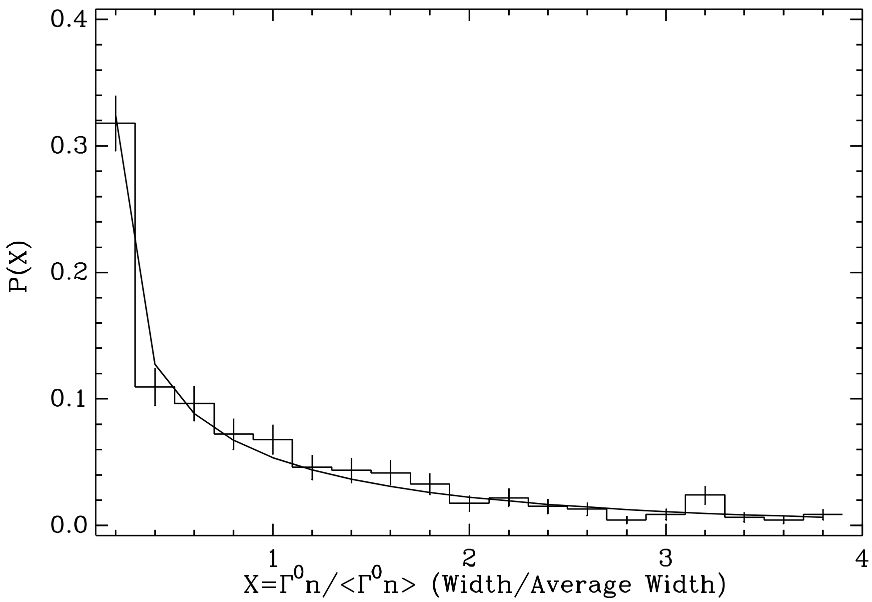

Figure 4. Differential distribution of the s-wave reduced neutron widths. The histogram represents the experimental distribution. The solid line is the Porter-Thomas distribution

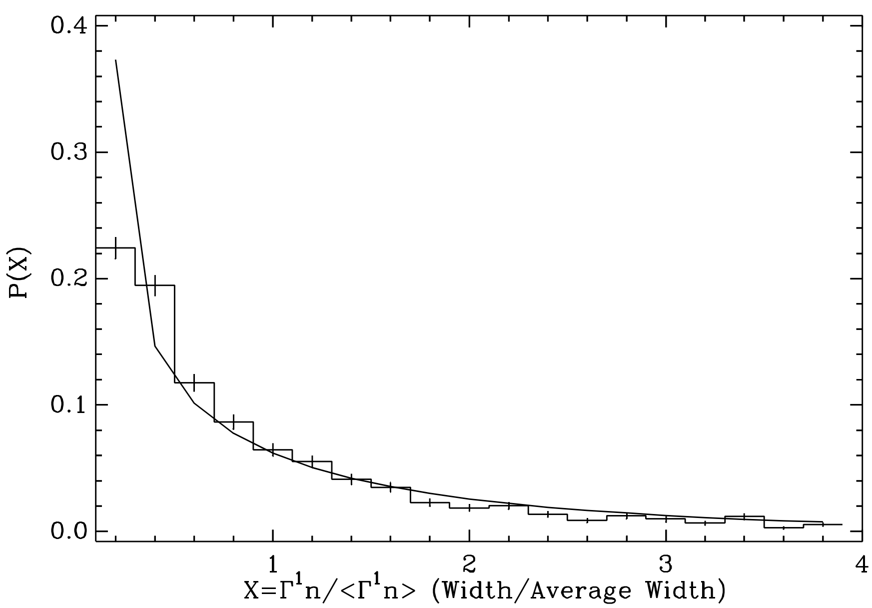

Figure 5. Differential distriburtion of the p-wave reduced neutron widths. The solid line is the Porter-Thomas distribution taking into account 15% of missing small neutron widths.

The values of the neutron strength functions obtained from the present resonance parameters are: (1.042±0.048) $\times 10^{-4}$ and (1.733±0.050) $\times$ 10^{-4} for the s-wave and p-wave neutron, respectively. The p-wave value could be underestimated due to the missing p-wave resonances.

Table 1 - The s-wave resonance parameters in low neutron energy range.

Energy eV	Radiative capture width meV	Neutron width meV	
		This work	ENDF/B-VI
6.674	23.00	1.485	1.493
20.871	22.91	10.022	10.260
36.682	22.89	33.552	34.130
66.033	23.36	23.972	24.600

4. The cross section

The average elastic cross section calculated with the present evaluation is 2%-3% larger than those calculated with ENDF/B-VI resonance parameters. In the energy range from thermal to 500 eV, the ENDF/B-VI average capture cross section is about 1.1% larger than the present value; at higher energies, up to 10 keV, the ENDF/B-VI capture values are generally smaller. In the energy range 10 keV to 20 keV, which is an unresolved energy range in ENDF/B-VI, the capture cross sections calculated with the present resonance parameters agree, on average, with the evaluation of Froehner [10].

The thermal capture cross section calculated in the present evaluation is 2.68 b compared to2.72 b in ENDF/B-VI. This value is the result of a measurement by Poenitz *et al*. [11] , and was included in the SAMMY experimental data base. This experimental value could easily be obtained by fitting the parameters of a resonance at -0.7 eV. In the thermal energy range, the capture cross section has a 1/v shape as shown in Fig. 6. The capture cross sections measured by Corvi *et al*. [12] are also shown in the figure. The present value of the capture resonance integral is 275.0 b which is about 1% smaller than the ENDF/B-VI value.

The results of the present evaluation are still preliminary. The Macklin *et al.* high resolution capture cross section has recently become available and will be added to the experimental data base in the next step of the evaluation. However, a preliminary resonance parameter file was distributed for testing purposes to the participants of the WPEC working group, for which the new ORNL resonance parameter file was merged with the new high energy evaluation performed at Los Alamos National Laboratory(LANL). Calculations of the eigenvalues of the 18 LEU-COMP-THERM-006 benchmarks (LCT6) [13] were recently performed by Weinman [14], using several evaluated data files including the new LANL-ORNL evaluation. The best values were obtained with the LANL-ORNL evaluation. The average eigenvalue with LANL-ORNL evaluation was 0.99816 compared to 0.99299 with ENDF/B-VI-5. The eigenvalues for the LCT6 benchmarks were also calculated by MacFarlane [15] showing large improvements when using the LANL-ORNL evaluation.

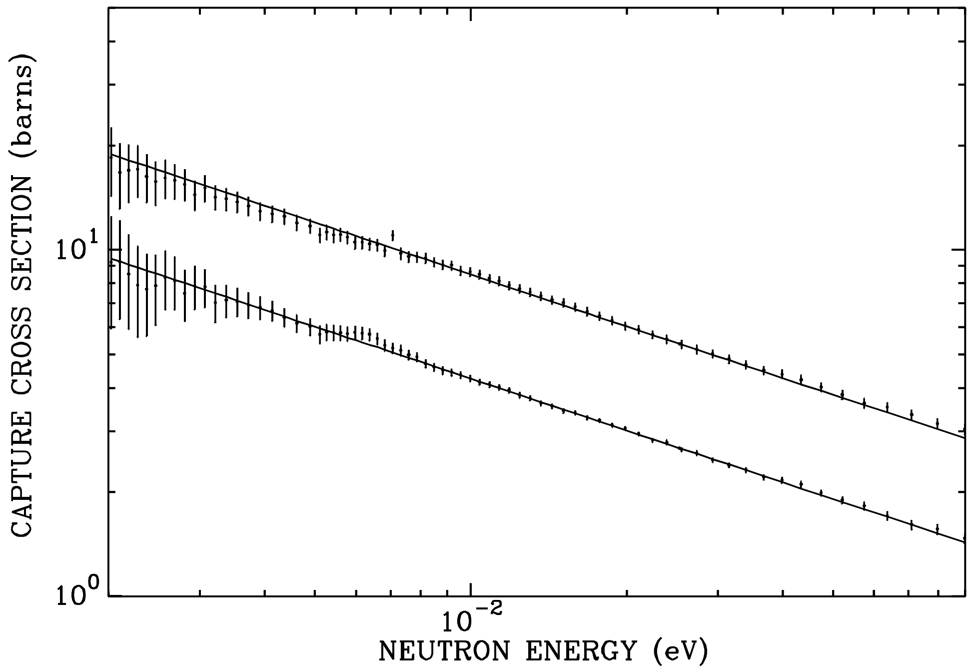

Figure 6. The capture cross section in the thermal energy range. The upper part of the figure represents the Corvi experimental data (multiplied by 2) obtained from the metallic sample; the lower part represents the data obtained from the oxide sample. The experimental data were normalized to 2.68 b at 0.0253 eV. The solid lines represent the cross sections calculated by SAMMY.

5. Conclusion

One of the goals of the present evaluation was to create a set of resonance parameters in the energy range 10 keV to 20 keV by taking advantage of the very high resolution of the experimental neutron transmission of Harvey *et al*. It was also expected that a new evaluation in the energy range thermal to 10 keV could help solve the systematic and unexplained k_{eff} underprediction when using the most recent nuclear data libraries. The resonance parameters were obtained in the energy range 10 keV to 20 keV. The new resonance parameter file obtained in the energy range thermal to 20 keV significantly improve the k_{eff} calculations in several thermal benchmarks.

Acknowledgments

The evaluation was performed in the framework of the U.S. Department of Energy Nuclear Criticality Safety Program at the Oak Ridge National Laboratory. The authors are grateful to J. A. Harvey for fruitful discussions concerning the experimental conditions of the transmission experiments. The work was sponsored by the Office of Research, Development and Simulation (NA-11), National Nuclear Security Administration, U.S. Department of Energy under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

References

1) N. M. Larson, *Updated Users' Guide for SAMMY*, Oak Ridge National Laboratory report ORNL/TM-9179/R6 (2003).
2) D. K. Olsen, *et al.*, "Precise Measurements and Analysis of Neutron Transmission Through Uranium-238," *Nucl Sci. Eng*. **62**, 479(1977).
3) D. K. Olsen, *et al.* "Measurement and Resonance Analysis of Neutron Transmission Through Uranium-238," *Nucl. Sci. Eng.* **69**, 202(1979).
4) J. A. Harvey, N. W. Hill, F. G. Perey, G. L. Tweed, and L. Leal, "High Resolution Transmission Measurements on ^{235}U, ^{239}Pu, and ^{238}U,"Nuclear Data for Science and Technology, May 30-June 3, 1988, Mito, Japan (1988).
5) G. de Saussure, E. G. Silver, R. B. Perez, R. Ingle, H. Weaver, *Measurements of the ^{238}U Capture Cross Section for Incident Neutron Energy up to 100 keV*, ORNL/TM-4059 (1973).
6) R. L. Macklin, R. B. Perez, G. de Saussure, and R. W. Ingle, "High Energy Resolution Measurement of the ^{238}U Neutron Capture Yield from 1 to 100 keV," *Ann. Nucl. Energy*, Vol. **18**, No 10, 567 (1991).
7) M. G. Sowerby, "Summary of the work of the NEANDC task force on ^{238}U, NEANDC-313U," (1994).
8) A. Meister, *et al,* "Experimental Study of the Doppler Broadening of Neutron Resonances at GELINA," pp 435 - 439 in *Conference on Nuclear Data for Science and Technology, Trieste, May 19-24, 1997* (1998).
9) A. Courcelle, Private Communication (2004).
10) F. H. Froehner, "Evaluation of the Unresolved Resonance Range of ^{238}U," *Nucl. Sci. Eng.* **103**, 119 (1989).
11) W. P . Poenitz, L. R. Fawcett, D. L. Smith,"Measurements of the ^{238}U(n,γ) Cross Section at Thermal and Fast Neutron Energies," *Nucl. Sci. Eng*. **78**, 239 (1981).
12) F. Corvi, G. Fioni, "Shape of the ^{238}U Capture Cross Section in the Range 0.00200.1 eV," *Nuclear Data for Science and Technology*, May 30-June 3, 1988, Mito, Japan (1988).
13) S. F. Steven Van Der Marck and A. Hogenbirk, JEFDOC-955.
14) J. P. Weinman, Private Communication to NEA/WPEC working group (2004).
15) R. E. MacFarlane, Private Communication to NEA/WEPC working group (2004).