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F. Emiliani
B. Becker
K. Guber
S. Kopecky
P. Schillebeeckx
R. Wynants

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Contact information
Peter Schillebeeckx
Address: Joint Research Centre, Retieseweg 111, B-2440 Geel, Belgium
E-mail: peter.schillebeeckx@ec.europa.eu
Tel.: +32 14 57 1475
Fax: +32 14 57 1862

http://irmm.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

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New resonance parameters for the stable tungsten isotopes from thermal to 1 keV

F. Emiliani[a], *B. Becker*[a], *K. Guber*[b], *S. Kopecky*[a], *P. Schillebeeckx*[a], *and R. Wynants*[a]
[a]European Commission, Joint Research Centre, Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium
[b]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Abstract
Neutron resonance parameters of the ^{182,183,184,186}W isotopes were obtained by a resonance shape analysis of experimental data measured at the time-of-flight facility GELINA using the REFIT code. In this document the analysis procedures of capture and transmission data are described. The deduced resonance parameters have been adopted in the new release of the Joint Evaluated Fusion and Fission file, *i.e.* JEFF-3.2, maintained by the Nuclear Energy Agency of the OECD.

1 Introduction

Accurate knowledge of neutron induced cross sections of tungsten is important in different fields such as nuclear astrophysics, neutron dosimetry, and fission and fusion technology. For instance, in fusion devices tungsten is used as a structural material of plasma facing components due to its high melting point, high thermal conductivity and high resistance to sputtering and erosion. Despite the importance of neutron induced cross sections of tungsten, the status of the nuclear data is not satisfactory [1]. In the last decade, several benchmark experiments have pointed out the deficiencies and discrepancies of evaluated data files of tungsten isotopes. A rather recent evaluation in the fast neutron range by Capote *et al.* [2] underlined that no significant improvement seems to be possible without new experimental data, in particular in the resonance region.

Measurements in the resonance region are best carried out with a pulsed white neutron source that is optimized for time-of-flight (TOF) measurements [3]. The TOF facility GELINA [4] has been designed and built for high-resolution cross section measurements in the resolved (RRR) and unresolved (URR) resonance region. It is a multi-user TOF facility, providing a white neutron source with a neutron energy range from 10 meV to 20 MeV. Up to 10 experiments can be performed simultaneously at measurement stations located between 10 m to 400 m from the neutron production target. The electron linear accelerator provides a pulsed electron beam with a maximum energy of 150 MeV, a peak current of 10 A and a repetition rate ranging from 50 Hz to 800 Hz. A compression magnet reduces the width of the electron pulses to less than 1 ns [5]. The electron beam hits a mercury-cooled uranium target producing Bremsstrahlung and subsequently neutrons via photonuclear reactions [6]. Two water-filled beryllium containers mounted above and below the neutron production target are used to moderate the neutrons. By applying different neutron beam collimation conditions, experiments can use either a fast or a thermalized neutron spectrum. The neutron production rate is constantly monitored by BF_3 proportional counters which are mounted in the ceiling of the target hall. The output of the monitors is used to normalize the time-of-flight spectra to the same neutron intensity. The measurement stations are equipped with air conditioning to reduce electronic drifts in the detection chains due to temperature changes.

To improve the quality of the neutron induced cross section data of tungsten, transmission and capture experiments on natural and enriched tungsten samples has been carried out at the GELINA time-of-flight (TOF) during the last years. A description of the experimental conditions is given in the JRC technical report JRC-78725 [7]. The data reduction procedures followed to produce the experimental transmission and capture yield are given in ref. [7] as well.

Table 1: Characteristics of the samples used for the transmission and capture measurements performed at GELINA. The first column is the reference number. The uncertainties are standard uncertainties at 1 standard deviation.

Sample ID	**Main isotope**	**Area** mm^2	**Weight** g	**Areal density** at/b
TP2013-005-001	^{nat}W	5026.55	5.17	0.00036
NP20120-12-08	^{nat}W	2827.72	544.66	0.063094
NP2012-12-08	^{nat}W	2836.44	276.34	0.031913
to be assigned	^{nat}W	6060.55	118.2	0.006389
TP-NP-08/08	^{nat}W	5030.12	20.5345	0.001337
ORNL W-182 n. 6	^{182}W	3421.19	48.2836	0.004670
ORNL W-182 n. 1	^{182}W	3421.19	47.6547	0.004608
ORNL W-182 n. 2	^{182}W	3421.19	45.4032	0.004391
ORNL W-182 n. 4	^{182}W	3421.19	47.1538	0.004561
ORNL W-183 n. 4	^{183}W	3959.19	45.645	0.003792
ORNL W-183 n. 1+5	^{183}W	3964.08	93.66	0.007771
ORNL W-184 n. 1	^{184}W	3919.88	45.2854	0.003781
ORNL W-184 n. 4	^{184}W	3780.88	45.6467	0.003951
ORNL W-184 n. 5	^{184}W	3615.22	44.7428	0.004051
ORNL W-184 n. 6	^{184}W	3657.06	44.9424	0.004022
ORNL W-186 n. 2	^{186}W	3801.82	44.9424	0.003828
ORNL W-186 n. 4	^{186}W	3760.99	44.7659	0.003854
ORNL W-186 n. 3	^{186}W	3758.24	45.8759	0.003952

This report summarize the resonance shape analysis which has been performed to deduce from the experimental transmissions and capture yields resonance parameters of the different tungsten isotopes. The experimental conditions are briefly recalled in section 2. In section 3 the resonance shape analysis procedures are discussed. The resonance parameters are reported in section 4.

2 Experimental conditions

The transmission and capture measurements were performed using a moderated neutron beam of GELINA. The measurement, data reduction and analysis procedures described in ref. [3] were followed.

Two different setups were used for the transmission measurements. The first one used the 50 m station of flight path 4 with a 6.35 mm thick and 101.6 mm diameter NE912 Li-glass scintillator enriched to 95% in ^{6}Li. The second one used the 25 m station of flight path 2 , which was equipped with a 12.7 mm and 101.6 mm diameter NE912 Li scintillator. The experimental transmission is given as the ratio of the background corrected sample-in and sample-out spectra. More details about the 50 m and 25 m measurement stations can be found in ref. [8] and [9], respectively.

The capture experiments were performed at the 12 m capture station of flight path 5 and the 60 m capture station of flight path 14. In both setups the prompt γ-rays created in the neutron induced capture events were detected by cylindrical C_6D_6 liquid scintillators. The detectors were mounted at 125° with respect to the direction of the incoming neutrons. The total energy detection principle in combination with the pulse height weighting technique was applied. The weighting functions were determined by Monte Carlo simulations as described in ref. [10]. The energy dependence of the neutron flux was measured with a ^{10}B ionisation chamber placed approximately 1 m before the sample.

The details of all the samples used in the experiments is given in table 1. The areal density was

Table 2: Coherent Scattering length and thermal capture cross section for the ^{182,183,184,186}W isotopes. The data were taken from refs. [22] and [23].

Isotope	$\mathbf{b}_{coh}$ fm	σ b
^{182}W	7.04 (0.04)	19.9 (0.3)
^{183}W	6.59 (0.04)	10.4 (0.2)
^{184}W	7.55 (0.06)	1.7 (0.1)
^{186}W	-0.73 (0.04)	38.1 (0.5)

based on a measurement of the weight and the area. The latter was determined by an optical surface inspection with a microscope measurement system from Mitutoyo. Both enriched and natural tungsten sample were used in the measurements.

In the data reduction procedure the AGS code [11] was used. This computer program, developed at the EC-JRC-IRMM, provides the full covariance matrix of the data reduction process, starting from the uncorrelated uncertainties estimated by counting statistics. Within AGS uncorrelated and correlated components of the covariance matrix are stored in vectorized form which allows for a very efficient storage of the full covariance matrix. This procedure has been endorsed by the Nuclear Data Section of the IAEA [12] for preparation and storing of experimental data in the EXFOR data library [13].

3 Resonance shape analysis

To extract the resonance parameters from the experimental data, the resonance shape analysis code REFIT [14] was used. In this code the the Reich-Moore [15] approximation of the R-matrix formalism [16] is used to derive resonance parameter from the experimental data. The code accounts for various experimental corrections, such as resolution broadening, Doppler broadening, multiple scattering interactions, γ-ray attenuation in the sample, sample inhomogeneity [17] etc. The least squares method is used to find the best model parameters. The numerical response function of the time-of-flight spectrometer has been calculated using MCNP5, following the description given in ref. [18].

Because of the rather poor agreement of calculations using the parameters in the evaluated data libraries with the experimental data, it was decided to create a completely new starting file. The procedure for this starting file has been established and tested already for the evaluation of the cadmium isotopes [9]. In ref. [19], a set of starting parameters was derived from combining the results of transmission measurements by Camarda *et al.* [20] and the capture measurement reported by Macklin *et al.* [21]. These data sets are in good agreement in the energy region where they overlap. Another constraint for the resonance analysis comes from the measured coherent scattering length [22] and the thermal capture cross section data [23]. In table 2 the values that were used for the present evaluation are given.

In the resonance shape analysis of the experimental data, an effective temperature and the free gas model were used to account for the the Doppler broadening. The functional relationship between effective temperature, room temperature and Debye temperature can be found in ref. [24]. According to ref. [25], the Debye temperature for a Tungsten metals is approximately 400 K. The exact flight path length of the transmission stations were fitted using transmission measurements of ^{238}U, which were analysed with the same response function as used for the tungsten measurements. The uncertainty of the resulting flight path lengths is dominated by the uncertainty on the energy of the 6.673 (0.001) eV resonance determined by Derrien *et al.* [26].

In a first step of the analysis procedure, the resonance energies and neutron widths Γ_n were adjusted in a fit to the transmission data only. Whenever possible, the capture widths Γ_γ were determined from the shape analysis of these data as well. In a second step, the energies of the resonances derived

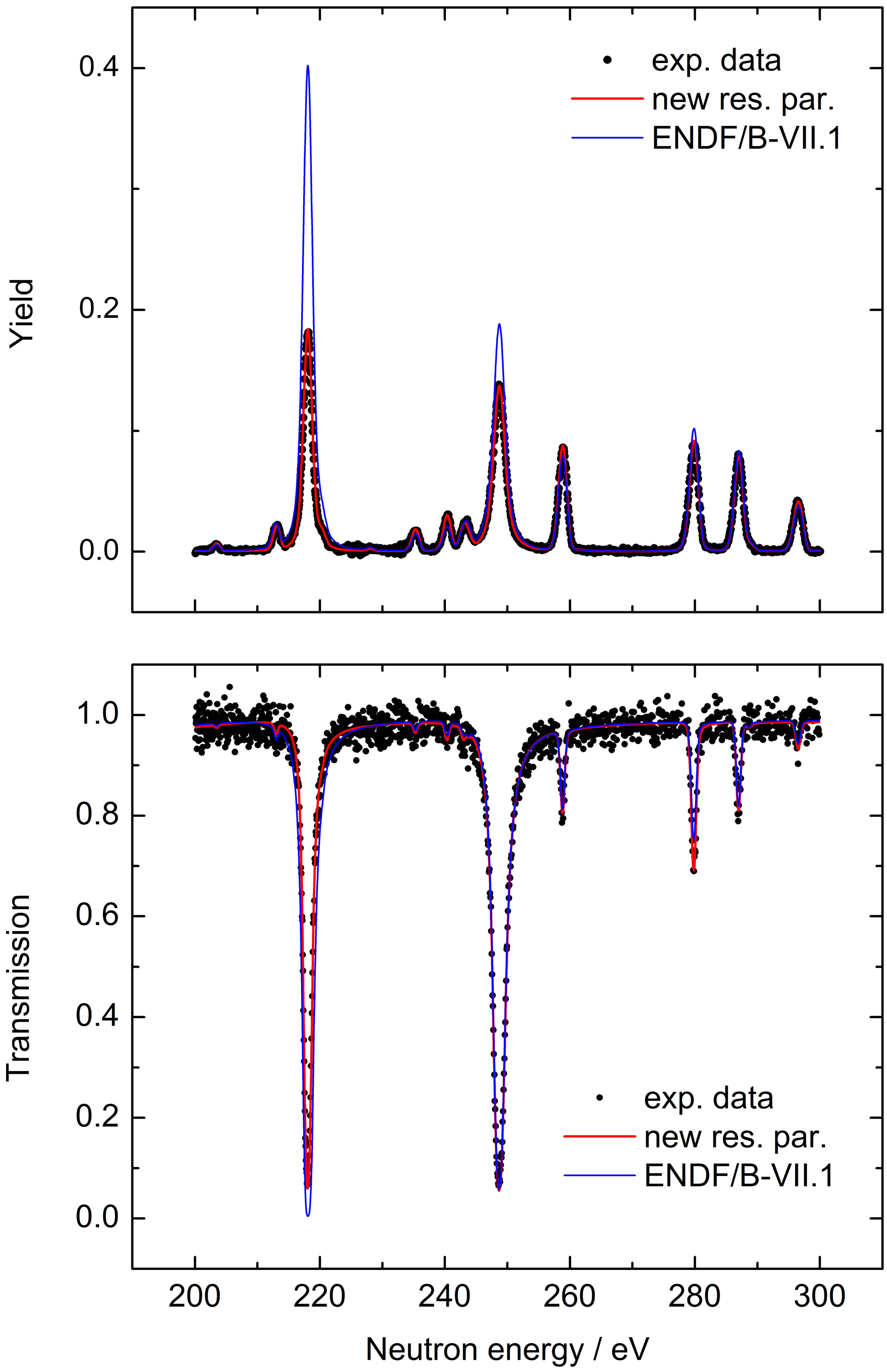

Fig. 1: Experimental capture yield (top) and transmission (bottom) resulting from measurements at GELINA compared to calculations using the resonance parameters presented in this report and the ones adopted in ENDF/B-VII.1 library.

from the transmission data were used to determine the flight paths of the capture stations. Then the normalization factors of the capture measurements were determined by using small resonances for which the resonance parameters were uniquely determined in the analysis of the transmission data. These obtained normalization factors were verified by additional measurements with Au, Ag and Fe samples. Finally, the resonance parameters and their uncertainties were determined in simultaneous fits to the capture and transmission data. Whenever possible the spin assignment of the resonance was checked. More details on the analysis procedures and results will be available in the thesis of F. Emiliani [28].

4 Results

The result of a simultaneous least squares adjustment using REFIT to the transmission and capture data is shown in fig. 1. The capture data were obtained at flight path 5 using sample TP2013-005-001. The transmission data were obtained at flight path 4 using sample W-nat TPNP08-08. The experimental transmission and capture yield are compared with the ones calculated with the parameters obtained in this work and the parameters adopted in the ENDF/B-VII.1 library [29].

The resulting resonance parameters from a simultaneous analysis of all data are listed in tables 3-6 for the ^{182,183,184,186}W isotopes. The quoted uncertainties are standard uncertainties at one standard deviation which result from only propagating the uncorrelated uncertainties due to counting statistics. The average capture widths were calculated from the fitted values. The derived average values for all the isotopes were then assigned to the resonances for which the experimental data were not sensitive enough. Finally, the contribution of the resonances below approximately 1000 eV to the thermal capture cross section and the coherent scattering lengths were determined. To match the literature values at thermal energies (table 2) resonance at negative energies were introduced when required. The final resonance parameters have been adopted in the new release of the Joint Evaluated Fusion and Fission file, *i.e.* JEFF-3.2, maintained by the Nuclear Energy Agency of the OECD.

References

[1] C . Lampoudis, S. Kopecky, P. Schillebeeckx, P. Siegler, K. Guber, J. Korean Phys. Soc. **59**, 1860 – 1863 (2012). DOI: 10.3938/jkps.59.1860

[2] R. Capote, A Trkov, I. Kodeli, E. Soukhovitskii, L.C. Leal, M. Herman, D.W. Muir, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22-27, Nice, France, pp. 690 – 692 (2007).

[3] P. Schillebeeckx, B. Becker, Y. Danon, K. Guber, H. Harada, J. Heyse, A.R. Junghans, S. Kopecky, C. Massimi, M. Moxon, N. Otuka, I. Sirakov, K. Volev, Nuclear Data Sheets **113**, 3054 (2012). DOI: 10.1016/j.nds.2012.11.005

[4] W. Mondelaers, P. Schillebeeckx, Notiziario Neutroni e Luce di Sincrotrone **11 no.2**, 19 (2006).

[5] D. Tronc, J.M. Salomé, K.H. Böckhoff, Nucl. Inst. Meth. A **228**, 217 (1985). DOI: 10.1016/0168-9002(85)90263-3

[6] A. Bensussan, J.M.Salomé, Nucl. Instr. Meth. **155**, 11 (1978). DOI: 10.1016/0029-554X(78)90181-73

[7] F. Emiliani, J.C. Drohe, K. Guber, S. Kopecky, A. Moens, P. Schillebeeckx, R. Wynants, JRC Technical Report, JRC 78725 (2013).

[8] I. Sirakov, B. Becker, R. Capote, E. Dupont, S. Kopecky, C. Massimi, P. Schillebeeckx, Eur. Phys. J. A **49** 144, 1 – 10, (2013) DOI: 10.1140/epja/i2013-13144-2

[9] K. Volev, A. Borella, S. Kopecky, C. Lampoudis, C. Massimi, A. Moens, M. Moxon, P. Schillebeeckx, P. Siegler, I. Sirakov, A. Trkov, R. Wynants, Nucl. Instrum. Meth B **399** 11-29 (2013) DOI: 10.1016/j.nimb.2013.01.030

[10] A. Borella, G. Aerts, F. Gunsing, M. Moxon, P. Schillebeeckx and R. Wynants, Nucl. Instr. Meth. A **577**, 626 – 640 (2007). DOI: 10.1016/j.nima.2007.03.034

[11] B. Becker, C. Bastian, F. Emiliani, F. Gunsing, J. Heyse, K. Kauwenberghs, S. Kopecky, C. Lampoudis, C. Massimi, N. Otuka, P. Schillebeeckx, I. Sirakov, JINST **7**, P11002 (2012). DOI: 10.1088/1748-0221/7/11/P11002

[12] N. Otuka, A. Borella, S. Kopecky, C. Lampoudis, P. Schillebeeckx, J. Korean Phys. Soc. **59**, 1314 - 1317 (2011). DOI: 10.3938/jkps.59.1314

[13] N. Otuka, S. Dunaeva, E. Dupont, O. Schwerer, A. Blokhin, J. Korean Phys. Soc., **59**, 1292 - 1297, (2011) . DOI: 10.3938/jkps.59.1292

[14] M.C. Moxon, J.B. Brisland, GEEL REFIT, A least squares fitting program for resonance analysis of neutron transmission and capture data computer code, AEA-InTec-0630, AEA Technology (1991).

[15] C. W. Reich, M. S. Moore, Phys. Rev. **111**, 929 – 933, (1958). DOI: 10.1103/PhysRev.111.929

[16] A.M. Lane, R.G. Thomas, Rev. Mod. Phys. **30**, 257 – 353, (1958). DOI: 10.1103/RevModPhys.30.257

[17] B. Becker, S. Kopecky, H. Harada, P. Schillebeeckx, Measurement of the direct particle transport through stochastic media using neutron resonance transmission analysis, submitted to EPJ Plus (2013).

[18] M. Flaska, A. Borella, D. Lathouwers, L.C. Mihailescu, W. Mondelaers, A.J.M. Plompen, H. van Dam, T.H.J.J. van der Hagen, Nucl. Instr. Meth. A **531**, 392 – 406 (2004). DOI: 10.1016/j.nima.2004.05.087

[19] F. Emiliani, K. Guber, S. Kopecky, C. Lampoudis, C. Massimi, P. Schillebeeckx, K. Volev EPJ Web of Conferences **42**, 02002 (2013). DOI: 10.1051/epjconf/20134202002

[20] H.S. Camarda, H.I. Liou, G. Hacken, F. Rahn, W. Makofske, M. Slagowitz, S. Wynchank, J. Rainwater, Phys. Rev. C **9**, 1813-1826 (1973). DOI: 10.1103/PhysRevC.8.1813

[21] R.L. Macklin, D.A. Drake, E.D. Arthur, Nucl.Sci. Eng. **84**, 98 – 119 (1983).

[22] K. Knopf, W. Waschkowski, Z Naturf. **42A**, 909 (1987).

[23] S.J. Friesenhahn, E. Haddad, F.H. Fröhner, W.M. Lopez, Nucl. Sci. Eng. **26**, 487 – 499 (1966).

[24] H. E. Jackson, J. E. Lynn, Phys. Rev. **127**, 461 – 468, (1962). DOI: 10.1103/PhysRev.127.461

[25] C. Kittel, Introduction to Solid State Physics, 6th Edition, John Wiley & Sons, Inc., ISBN 0-471-87474-4 (1986)

[26] H. Derrien, L.C. Leal, N.M. Larson, A. Courcelle, Neutron resonance parameters of ^{238}U and the calculated cross sections from Reich-Moore analysis of experimental data in the neutron energy range from 0 keV to 20 keV, ORNL/TM-2005/241, Oak Ridge National Laboratory, Oak Ridge, Tenn. (2005). DOI: 10.2172/885973

[27] F.G. Perey, Status of the parameters of the 1.15-keV resonance of ^{56}Fe, Proc. Intern. Conf. Nuclear Data for Basic and Applied Science, Santa Fe, New Mexico, pp. 1523 – 1528 (1985).

[28] F. Emiliani, Thesis, to be published.

[29] M.B. Chadwick *et al.*, Nuclear Data Sheets **112**, 2887 – 2996 (2011). DOI: 10.1016/j.nds.2011.11.002

Table 3: Resonance parameters (energy E_r, neutron width Γ_n, radiation width Γ_γ) for ^{182}W

$\mathbf{E}_r$ eV	l	$\mathbf{\Gamma}_\gamma$ eV		$\mathbf{\Gamma}_n$ eV	
4.144625	0	4.942E-02	(6.E-05)	1.437E-03	(9.E-07)
21.078962	0	4.182E-02	(1.5E-04)	4.17E-02	(1.2E-04)
114.479984	0	5.6731E-02		0.2675E+00	
157.490000	1	5.3E-02		3.26E-04	(1.5E-05)
213.036180	0	5.3E-02		2.58E-03	(1.3E-04)
248.655713	0	4.669E-02	(1.1E-04)	9.831E-01	(1.9E-03)
341.880533	0	5.3000E-02		6.17E-03	(3.0E-04)
376.580998	0	4.899E-02	(3.7E-04)	1.1907E-01	(6.8E-04)
409.116148	1	5.3E-02		9.6E-05	(2.6E-05)
428.962949	0	4.700E-02	(6.3E-04)	2.534E-01	(2.0E-03)
484.781503	0	4.530E-02	(2.5E-04)	4.280E-01	(2.6E-03)
493.364461	1	5.3E-02		3.73E-04	(3.6E-05)
578.664806	0	4.236E-02	(6.5E-04)	3.0162E-01	(6.0E-03)
607.539249	1	5.3E-02		1.36E-04	(3.6E-05)
614.184145	1	5.3E-02		6.04E-04	(4.1E-05)
655.588719	0	4.187E-02	(7.0E-04)	1.435E-01	(1.9E-03)
663.448908	1	5.3E-02		7.6E-05	(3.6E-05)
670.576516	1	5.3E-02		5.83E-04	(4.3E-05)
687.483689	1	5.3E-02		2.31E-04	(3.7E-05)
719.257000	1	5.3E-02		6.6E-05	(5.6E-05)
720.210000	1	5.3E-02		6.51E-05	(1.2E-04)
721.352499	1	5.3E-02		1.67E-04	(5.2E-05)
759.887502	0	4.63E-02	(1.6E-03)	6.89E-03	(2.3E-03)
782.116607	0	2.25E-02	(1.8E-03)	1.03E-03	(1.6E-03)
858.359313	1	5.3E-02		8.44E-04	(5.8E-05)
863.513902	0	5.3E-02		8.84E-03	(2.5E-04)
907.414890	1	5.3E-02		3.32E-04	(5.0E-05)
919.292823	0	6.24E-02	(1.0E-03)	3.594E-01	(8.8E-03)
948.130693	0	6.50E-02	(6.4E-03)	2.254E-00	(4.8E-02)
1008.672509	0	4.734E-02	(7.7E-04)	4.731E-01	(1.1E-02)
1072.445160	1	5.3E-02		6.09E-04	(7.5E-05)
1095.671895	0	4.884E-02	(7.5E-04)	1.332E-00	(1.0E-02)
1137.860000	1	5.3E-02		3.03E-04	(7.0E-05)
1162.675511	0	4.563E-02	(7.6E-04)	5.028E-01	(6.6E-03)
1191.360000	1	5.3E-02		4.45E-04	(7.6E-05)
1269.555910	1	5.3E-02		4.51E-04	(7.7E-05)
1276.011625	0	3.33E-02	(2.1E-03)	5.10E-02	(4.6E-03)
1287.773290	0	4.37E-02	(1.1E-03)	1.042E-01	(5.6E-03)

Table 4: Resonance parameters (energy E_r, neutron width Γ_n, radiation width Γ_γ) for ^{184}W

$\mathbf{E}_r$ eV	l	$\mathbf{\Gamma}_\gamma$ eV		$\mathbf{\Gamma}_n$ eV	
101.942300	0	3.96E-02	(3.3E-03)	3.795E-03	(3.2E-05)
165.954500	1	5.7E-02		5.32E-05	(5.0E-06)
184.165500	0	5.304E-02	(1.0E-04)	1.1634E-00	(1.6E-03)
235.044500	1	5.7E-02		1.17E-04	(1.7E-05)
242.946232	0	5.1E-02	(1.6E-02)	2.482E-03	(4.7E-05)
310.764500	0	4.026E-02	(3.4E-04)	8.216E-02	(5.5E-04)
423.337308	0	5.075E-02	(9.0E-04)	5.047E-02	(4.2E-04)
593.485000	1	5.7E-02		2.37E-04	(3.7E-05)
641.297929	1	5.7E-02		5.10E-04	(4.7E-05)
674.052046	1	5.7E-02		7.74E-04	(4.9E-05)
681.716900	0	5.900E-02	(6.1E-04)	7.17E-01	(5.9E-03)
703.828600	0	5.7E-02		7.22E-03	(7.3E-04)
722.822876	1	5.7E-02		5.27E-04	(5.1E-05)
784.642700	0	8.92E-02	(7.9E-03)	1.904E-02	(9.7E-04)
799.890700	0	5.38E-02	(2.1E-03)	2.011E-00	(2.8E-02)
852.354264	1	5.7E-02		2.61E-04	(6.0E-05)
900.551429	1	5.7E-02		1.89E-04	(5.8E-05)
926.318141	1	5.7E-02		4.58E-04	(5.9E-05)
957.706300	0	7.06E-02	(3.4E-03)	1.228E-00	(3.9E-02)
999.197500	0	5.27E-02	(1.1E-03)	9.75E-03	(2.0E-03)
1085.756506	0	5.05E-02	(1.0E-03)	3.552E-00	(1.2E-02)
1092.858040	1	5.7E-02		1.06E-03	(1.4E-04)

Table 5: Resonance parameters (energy E_r, neutron width Γ_n, radiation width Γ_γ) for ^{186}W

$\mathbf{E}_r$ eV	l	$\mathbf{\Gamma}_\gamma$ eV		$\mathbf{\Gamma}_n$ eV	
18.827814	0	4.516E-02	(2.0E-04)	3.2521E-01	(2.3E-04)
171.008863	0	5.026E-02	(9.0E-04)	3.128E-02	(2.8E-04)
197.070000	1	4.0E-02		3.28E-04	(2.7E-05)
218.036757	0	4.500E-02	(1.4E-04)	5.292E-02	(9.3E-04)
286.967333	0	4.354E-02	(5.3E-04)	3.193E-02	(2.5E-04)
316.957000	1	4.0E-02		1.00E-04	(1.7E-05)
406.087302	0	4.323E-02	(3.5E-04)	9.759E-02	(7.6E-04)
456.465105	1	4.0E-02		2.87E-04	(2.5E-05)
510.071229	0	4.751E-02	(7.3E-04)	9.16E-02	(2.6E-03)
541.573451	0	5.001E-02	(5.9E-04)	5.036E-01	(7.1E-03)
655.060000	1	4.0E-02		5.59E-04	(3.8E-05)
663.564545	0	6.461E-02	(7.5E-04)	6.728E-01	(2.5E-03)
721.180163	0	5.436E-02	(6.3E-04)	1.9994E-00	(4.6E-03)
729.543186	1	4.0E-02		5.83E-04	(5.4E-05)
771.448230	1	4.0E-02		4.64E-04	(4.3E-05)
831.760853	0	5.24E-02	(2.0E-03)	3.220E-02	(7.3E-04)
855.383648	1	4.0E-02		3.84E-04	(4.6E-05)
964.571615	0	4.87E-02	(8.8E-03)	1.123E-00	(8.7E-02)
1012.383648	1	4.0E-02		2.14E-04	(5.1E-05)
1068.813241	1	4.0E-02		4.83E-04	(5.7e-05)
1071.877039	0	4.571E-02	(7.6E-04)	5.287E-01	(5.2E-03)
1122.291586	0	5.588E-02	(8.8E-04)	3.227E-01	(4.5E-03)
1188.200370	0	4.078E-02	(6.9E-04)	8.473E-01	(6.6E-03)

Table 6: Resonance parameters (energy E_r, neutron width Γ_γ, radiation width Γ_γ) for ^{183}W

$\mathbf{E}_r$	l	J	$\mathbf{\Gamma}_\gamma$		$\mathbf{\Gamma}_n$	
eV			eV		eV	
7.634043	0	1	7.131E-02	(1.8E-04)	1.7541E-03	(1.7E-06)
27.057038	0	1	7.02E-02	(1.0E-03)	4.326E-02	(3.2E-04)
40.712995	0	1	7.48E-02	(2.0E-03)	2.006E-03	(1.8E-05)
46.274170	0	1	6.2998E-02	(9.4E-05)	1.6380E-01	(7.9E-04)
47.901739	0	0	5.980E-02	(1.7E-04)	1.226E-01	(1.1E-03)
65.391983	0	1	8.03E-02	(5.8E-03)	1.761E-03	(1.6E-05)
101.135466	0	1	6.412E-02	(3.3E-04)	1.1055E-01	(4.8E-04)
103.961887	0	0	6.55E-02	(8.4E-03)	8.36E-03	(2.8E-04)
138.008244	0	1	6.2E-02		3.538E-03	(8.6E-05)
144.327062	0	0	5.45E-02	(1.0E-03)	1.361E-01	(4.7E-03)
154.601270	0	0	5.140E-02	(4.1E-04)	4.806E-01	(1.9E-03)
157.045867	0	1	6.50E-02	(1.1E-03)	5.441E-02	(5.5E-04)
173.989152	0	1	6.087E-02	(6.7E-04)	6.105E-02	(5.7E-04)
192.219861	0	1	6.87E-02	(1.5E-03)	3.781E-02	(4.9E-04)
203.467209	0	1	6.2E-02		1.54E-03	(1.4E-04)
220.350963	0	1	6.2E-02		2.32E-03	(1.6E-04)
228.060016	1	2	6.2E-02		3.30E-04	(3.2E-05)
235.272656	0	1	6.2E-02		5.56E-03	(1.8E-04)
240.334402	0	1	7.39E-02	(4.4E-03)	1.097E-02	(1.5E-05)
243.723721	0	1	6.2E-02		3.02E-03	(1.9E-04)
258.813934	0	1	6.445E-02	(6.5E-04)	7.320E-02	(5.4E-04)
279.810225	0	1	5.983E-02	(3.2E-04)	1.7540E-01	(4.9E-04)
288.669155	0	1	6.2E-02		3.12E-03	(3.1E-04)
296.503251	0	1	8.58E-02	(3.1E-03)	2.694E-02	(3.0E-04)
322.066161	0	1	6.776E-02	(6.9E-04)	9.110E-02	(8.8E-04)
337.275931	0	1	6.2E-02		6.97E-03	(3.4E-04)
347.768340	0	1	6.634E-02	(4.4E-04)	1.712E-01	(1.0E-03)
352.939857	1	2	6.2E-02		5.19E-04	(4.5E-05)
360.668246	0	1	7.34E-02	(1.7E-03)	4.276E-02	(4.6E-04)
377.825362	0	1	5.457E-02	(8.3E-04)	8.274E-02	(7.7E-04)
391.069999	0	1	6.25E-02	(2.3E-03)	3.210E-02	(5.0E-04)
418.037033	0	1	6.90E-02	(2.3E-03)	3.423E-02	(5.2E-04)
425.687658	0	0	6.46E-02	(2.1E-03)	9.84E-02	(1.8E-03)
429.498370	0	1	5.56E-02	(1.1E-03)	5.566E-02	(9.5E-04)
460.132410	0	1	9.95E-02	(9.1E-03)	1.394E-02	(4.0E-04)
468.823928	1	2	6.2E-02		1.387E-03	(6.6E-05)
480.537704	1	2	6.2E-02		8.57E-04	(5.6E-05)
491.142261	1	2	6.2E-02		1.85E-04	(2.9E-05)
495.728660	1	2	6.2E-02		1.082E-03	(6.1E-05)
510.269730	0	1	6.2E-02		6.06E-05	(7.6E-06)
512.979980	0	1	6.2E-02		3.901E-03	(3.2E-05)
516.560000	1	2	6.2E-02		1.03E-04	(5.5e-08)
534.612071	0	1	7.81E-02	(8.4E-03)	2.21E-02	(6.9E-04)
549.033844	1	2	6.2E-02		2.51E-04	(6.1E-05)
549.780000	1	2	6.2E-02		5.6E-04	(3.6E-04)

Continued on next page . . .

Table 6 – continued from previous page

$\mathbf{E}_r$	l	J	$\mathbf{\Gamma}_\gamma$		$\mathbf{\Gamma}_n$	
eV			eV		eV	
551.203475	0	1	5.93E-02	(1.3e-03)	7.48E-02	(1.2E-03)
558.654562	0	0	5.350E-02	(8.2E-04)	2.1090E-01	(1.6E-05)
568.148490	0	1	8.69E-02	(6.9E-03)	2.815E-02	(8.6E-04)
571.493137	0	0	4.86E-02	(1.3E-03)	2.041E-01	(3.8E-03)
580.000000	1	2	6.2E-02		1.48E-03	(1.4E-04)
588.167670	0	1	6.93E-02	(4.6E-03)	3.794E-02	(9.9E-04)
603.306178	0	1	7.21E-02	(1.6E-03)	9.06E-02	(1.5E-03)
608.770000	0	1	6.5E-02	(1.5E-02)	1.595E-02	(6.9E-04)
647.193547	0	1	6.56E-02	(1.2E-03)	1.607E-01	(2.1E-03)
676.433391	0	1	5.87E-02	(2.2E-03)	4.99E-02	(1.4E-03)
690.658271	0	1	8.7E-02	(1.7E-02)	1.785E-02	(8.9E-04)
695.514364	0	0	5.97E-02	(1.6E-03)	8.374E-01	(9.0E-03)
701.022162	0	1	8.28E-02	(8.5E-03)	2.83E-02	(1.5E-03)
723.406295	0	1	7.18E-02	(5.8E-03)	4.24E-02	(1.5E-03)
725.499569	0	0	5.20E-02	(2.0E-03)	1.109E-01	(4.6E-03)
752.739581	0	1	8.87E-02	(1.6E-03)	1.873E-01	(2.5E-03)
761.868717	0	0	9.00E-02	(5.9E-03)	3.52E-03	(1.5E-03)
780.028348	1	2	6.2E-02		3.65E-03	(1.3E-04)
792.422195	0	1	6.06E-02	(4.3E-03)	3.38E-02	(1.5E-03)
797.178269	0	0	5.24E-02	(1.4E-03)	6.93E-01	(1.0E-02)
808.280771	0	1	6.82E-02	(3.4E-03)	5.75E-02	(1.9E-03)
852.754633	0	1	6.2E-02		9.96E-03	(3.3E-04)
861.805155	0	0	4.69E-02	(2.0E-03)	1.450E-01	(6.7E-03)
867.878017	0	1	6.62E-02	(3.6E-03)	5.94E-02	(2.2E-03)
870.071356	0	1	6.19E-02	(1.7E-03)	1.220E-01	(2.8E-03)
894.287685	0	1	6.50E-02	(2.5E-03)	6.95E-02	(2.3E-03)
907.485072	1	1	6.2E-02		1.68E-03	(1.7E-04)
927.851371	0	1	6.2E-02		1.446E-02	(4.6E-04)
941.238847	0	0	6.27E-02	(1.5E-03)	4.04E-01	(1.1E-02)
951.260744	0	1	6.89E-02	(4.8E-03)	4.71E-02	(2.5E-03)
961.168010	0	1	6.79E-02	(1.8E-03)	1.722E-01	(4.0E-03)
970.058919	1	2	5.5E-02		8.4E-04	(1.3E-04)
983.591305	1	2	6.2E-02		7.79E-03	(2.3E-04)
1000.147455	0	1	7.87E-02	(2.1E-03)	1.421E-01	(3.6E-03)
1007.392704	0	1	6.33E-02	(3.1E-03)	6.94E-02	(2.9E-03)
1010.879970	0	1	6.00E-02	(1.5E-03)	2.215E-01	(4.3E-03)
1024.285207	1	2	6.2E-02		1.78E-03	(1.3E-04)

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Abstract

Neutron resonance parameters of the ^{182,183,184,186}W isotopes were obtained by a resonance shape analysis of experimental data measured at the time-of-flight facility GELINA using the REFIT code. In this document the analysis procedures of capture and transmission data are described. The deduced resonance parameters have been adopted in the new release of the Joint Evaluated Fusion and Fission file, i.e. JEFF-3.2, maintained by the Nuclear Energy Agency of the OECD.

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