

Evaluation of Tungsten Neutron Cross Sections in the Resolved Resonance Region

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We generated a preliminary set of resonance parameters for ^{182,183,184,186}W in the neutron energy range of thermal up to several keV. The evaluation methodology uses the Reich-Moore approximation to fit with the *R*-matrix code SAMMY, the high-resolution measurements performed in 2010 and 2012 at the Geel linear accelerator facility. For ¹⁸³W, the transmission data and capture cross sections calculated with the set of resonance parameters are compared with the experimental values, and some of the average properties of the resonance parameters are discussed. In the analyzed energy range, this work almost doubles the existing resolved resonance evaluations in the ENDF/B-VII.1 library. A preliminary analysis of the performance of the calculated cross sections based on Lead slowing-down benchmarks is presented and briefly discussed.

I. INTRODUCTION

Following the series of measurements on tungsten isotopes performed at the GEel LINear Accelerator (GELINA) by Lampoudis in 2010 [1] and by Guber in 2012 [2], this paper aims to present the status of the resonance evaluations for total and capture cross sections on ^{182,183,184,186}W in the neutron energy range of thermal energy up to several keV, with a particular emphasis on the ¹⁸³W evaluation. As a follow-up of the work presented at the PHYSOR 2012 conference [3], the resonance evaluation of ¹⁸³W was updated with the new evaluations of ^{182,184,186}W tungsten isotopes to account for the nuclide abundances of the sample used in the measurements. In the analyzed energy range (see Table I),

ENDF/B-VII.1 [4]. The Bayesian fitting method implemented in the *R*-matrix SAMMY code [5] was used to generate a comprehensive, albeit still preliminary, set of neutron resonance parameters with related correlations and cross-section covariance data.

Experimental conditions such as resolution function, finite size sample, nonuniform thickness, and nuclide abundances of sample, multiple scattering, self-shielding, normalization, background, and Doppler broadening were taken into account.

As noted in the previous paper [3], a meaningful fitting of the data in the energy region of 2.5–3.25 keV was not possible due to inconsistent data generated by one of the filters used in the measurements of transmission data. The fitting of the data in the mentioned energy region was improved by the use of a new set of experimental data recently provided by Guber [2], and the results are shown in Section II. Moreover, the updated set of resonance parameters allowed the contribution of the external levels to be redefined in a more comprehensive statistical manner and a preliminary analysis of their average properties to be generated.

In the thermal energy range, we utilized the recently published *Atlas of Neutron Resonances* [6], as well as the tabulated neutron scattering lengths [7], as a source of information on scattering and capture cross sections and resonance integral. In the context of this paper, we refer to Ref. [3] for the discussion of the preliminary values of the thermal cross sections.

In view of the interest in tungsten metal for several distinct types of nuclear applications, the performance of the calculated cross sections in Lead slowing-down (LSD) and

TABLE I. Neutron energy range for new and existing tungsten evaluations. The number of fitted levels is also shown.

No.	Nucleus (<i>I</i> ^π)	$E_{\min} - E_{\max}^{\text{ORNL}}(E_{\max}^{\text{existing}})$	No. Levels
1	¹⁸³ W (1/2 [−])	10 ^{−5} eV - 5 (2.2) keV	342
2	¹⁸² W (0 ⁺)	10 ^{−5} eV - 10 (5) keV	143
3	¹⁸⁴ W (0 ⁺)	10 ^{−5} eV - 10 (4) keV	125
4	¹⁸⁶ W (0 ⁺)	10 ^{−5} eV - 10 (8.3) keV	78

this work almost doubles the Resolved Resonance Region (RRR) present in the latest US nuclear data library,

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criticality benchmarks needs to be tested. In the current ENDF/B-VII.1 nuclear data library, the tungsten isotope evaluations were performed and tested by Trkov [8] by the use of benchmark models taken from the SINBAD [9] and the ICSBEP [10] compilation. The number of benchmarks used in that analysis involved neutron flux spectra in the intermediate and fast energy range. Since this energy range is only slightly sensitive to the extended resonance $^{182,183,184,186}\text{W}$ evaluations, we first tested the ^{183}W resonance evaluation on the basis of LSD benchmarks [11]. Preliminary results of the evaluation work on the neutron spectrum obtained by including the new set of ^{183}W resonance parameters in ENDF/B-VII.1 library are presented and briefly discussed in Section II.

II. RESULTS AND DATA ANALYSIS

Based on the set of resonance parameters described in Ref. [3], a new set of parameters for 342 resonances is obtained in the energy range up to 5 keV for ^{183}W . The values of resonance parameters are updated from the fit of a new set of transmission data [2]. Based on the R -matrix code SAMMY Reich-Moore approximation, the calculated cross sections for total, elastic, and capture reaction channels took into account the isotopic composition of the sample used in the measurements. Altogether, four isotopes of tungsten and related resonance parameters were simultaneously considered in the SAMMY regression calculations. For the transmission data, the isotopic compositions were ^{182}W (6.44%), ^{183}W (80.9%), ^{184}W (9.52%), and ^{186}W (3.14%). For the resolution function related to the experimental facility, we used the GELINA parameterization taken from Ref. [5].

In Fig. 1, the calculated capture cross sections (in continuous red lines) and transmission data (in continuous magenta lines) are compared with the experimental data in the energy range of 2.5-3.6 keV. As shown in the figure, the improved set of experimental data allowed us to obtain meaningful values of the neutron and capture widths in the mentioned energy range. In addition, it was possible to redefine the contribution of external levels on the basis of statistical properties of the new set of resonance parameters. Fig. 2 shows the total and scattering cross section of $n+^{183}\text{W}$ at incident energies between 10^{-4} eV and 5 keV. The cross sections (black continuous line) are the contribution of the potential scattering cross section which, for s -waves, is given by

$$\sigma_{\text{pot}} = 4\pi a_c^2 \sum_J g_J (1 - \mathcal{R}_c^{J,\infty})^2 = 4\pi R'^2, \quad (1)$$

where the effective scattering radius R' is defined by the product of the channel radius a_c and the contribution of the distant-level parameter $\mathcal{R}_c^{J,\infty}$ weighted by the spin statistical factor g_J . For this case, the distant-level parameter was kept equal to zero and the channel radius was set to 7.3 fm. As expected, σ_{pot} is constant almost over the entire energy range, and the effect of positive

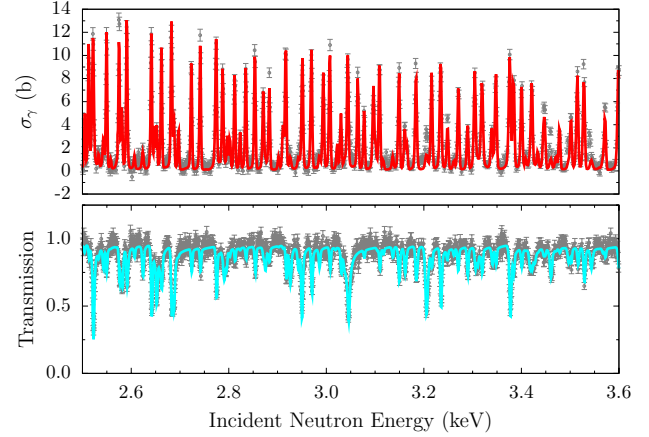


FIG. 1. Neutron capture cross sections (top) and transmission data (bottom) of ^{183}W in the energy range of 2.5-3.6 keV. The solid red lines calculated by the resonance parameters are compared with the experimental data.

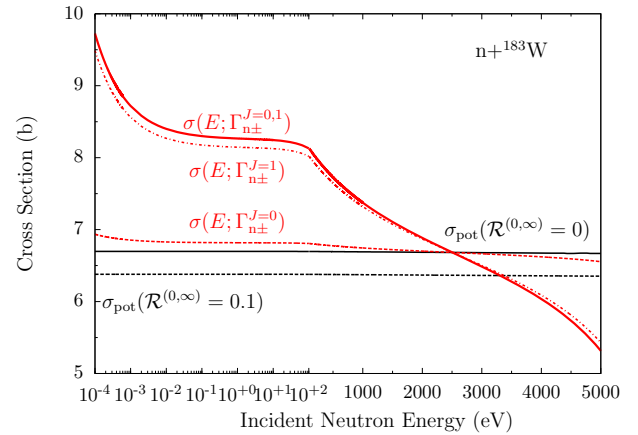


FIG. 2. The potential scattering cross section for $n+^{183}\text{W}$ calculated for a channel radius $a_c = 7.3$ fm and different values of the distant-level parameter $\mathcal{R}_c^{J,\infty}$. The full and partial contributions of the bound level(s) $E_- < 0$ and the level(s) E_+ above the RRR 5 keV upper limit are shown.

distant-level parameters is to decrease the scattering cross section (dashed black line). The effect of the two external levels, one for each spin below ($E < 0$) and above ($E = E_{\text{max}} > 5$ keV) the RRR, is shown in solid and dashed red lines along with the partial contribution of the external levels for different values of J . The two external levels are modeled on the assumption that the edges of the evaluated resonance region are represented by two very broad and symmetrically located resonances of equal strength [12]. Namely, for s -waves and $\bar{\Gamma}_\gamma \ll I$, this yields external levels $\Gamma_{n\pm}^J \simeq (3/2)IS_0^J \sqrt{|E_\pm|}/1$ eV calculated at energies $E_\pm \simeq \bar{E} \pm \sqrt{3}I/2$ with mid-energy $\bar{E} = (E_{\text{max}} + E_{\text{min}})/2$. The components of the s -wave strength function for different spin populations, namely,

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