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Evaluation of tungsten isotopes in the fast neutron range including cross section covariance estimation

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Abstract. New evaluations for the tungsten isotopes ^{180,182,183,184,186}W in the neutron energy range up to 60 MeV were produced. In the resonance range only minor adjustments to the resonance parameters were made due to a lack of adequate experimental data. Evaluations in the fast energy region were based on nuclear model calculations using the EMPIRE-2.19 code. Recently derived dispersive coupled-channel optical model potentials for W and Ta isotopes were instrumental to achieve a very good description of the available microscopic cross section database. Model covariance data were generated with the Monte Carlo technique to produce a *prior* estimate for the covariance matrix. Experimental data were introduced through the GANDR system. The evaluated files were tested on selected fusion neutronics benchmarks and showed marked improvement compared to other existing evaluations.

1 Introduction

New design concepts of nuclear energy production and transmutation of radioactive waste are being investigated worldwide. Accurate nuclear data for tungsten isotopes are required because tungsten is a candidate material for first-wall components in fusion devices, target material for systems based on high-current accelerators, as well as neutron dosimetry with the ^{186}W(n,γ) reaction.

In spite of some recent attempts to improve the evaluated cross section data for tungsten [1], the status of the data is unsatisfactory. Systematic discrepancies are observed in criticality safety benchmarks containing tungsten [2], fusion neutronics benchmarks [3], and measured constants for neutron activation [4]. These discrepancies motivated the work presented herein. Preliminary results of experimental data analysis and evaluations for neutron interactions on tungsten isotopes ^{180,182,183,184,186}W in the neutron energy range up to 60 MeV are described.

2 Resonance range

The review of the resonance parameters of tungsten isotopes showed that no significant improvement in quality is possible without new measurements. Minor adjustments to existing resonance parameters of ^{182}W were made. The sources of other resonance parameters were: Mughabghab [5] for ^{180}W, IRDF2002 [6] for ^{186}W and ENDF/B-VII [7] for ^{183}W and ^{184}W isotopes. The unresolved resonance parameters were flagged for the calculation of self-shielding only; the cross sections from the model calculations in the URR were adopted as described below.

3 Fast energy range

Evaluations in the fast energy range were fully based on nuclear model calculations using the EMPIRE-2.19 code [8]. Starting values for nuclear model parameters were taken from RIPL-2 [9]. A crucial point was the selection of the coupled-channel optical model potential (OMP). Direct interaction cross sections to low-lying levels and transmission coefficients for the incident channel on $^{180-186}$W nuclei were obtained from the isospin-dependent dispersive coupled-channel OMP [10,11]. The same potential was used to calculate direct excitation of the collective levels in the continuum by DWBA method. Pre-equilibrium emission was considered using one-component exciton model PCROSS, which includes nucleon, gamma and cluster emission. Hauser-Feshbach and Hofmann-Richert-Tepel-Weidenmuller versions of the statistical model were used for the compound nucleus cross section calculations. Both approaches account for the multiple-particle emission, and the full gamma-cascade. Level densities were described by the "EMPIRE specific" formalism, which uses the super-fluid model below critical excitation energy and the Fermi gas model above. Deformation-dependent collective effects on the level densities due to nuclear vibration and rotation and their temperature-dependent damping were also taken into account Modified Lorenzian (MLO) radiative-strength function was taken as recommended by Plujko [9] and resulted in excellent agreement with the experimental neutron capture database. Total, capture, emission cross sections of neutrons and charged particles, average resonance parameters and angular distributions of neutron and proton scattering

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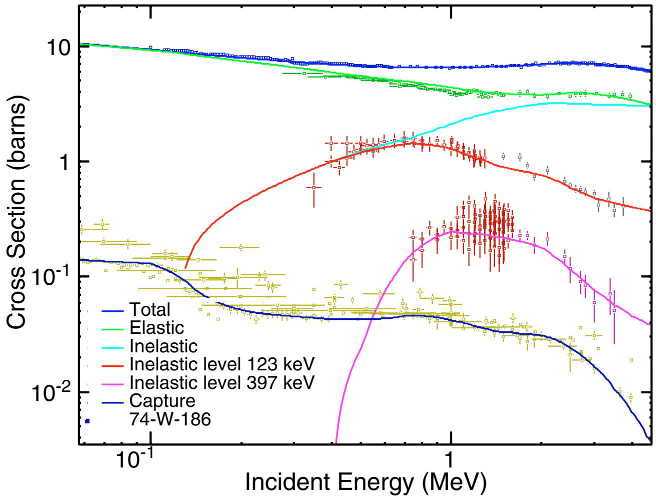

Fig. 1. Evaluated cross sections of ^{186}W below 5 MeV.

on all tungsten isotopes were in good agreement with the available experimental data. An example of the evaluated cross sections for selected reactions of ^{186}W below 5 MeV in comparison with experimental data is shown in figure 1.

4 Covariance data

The covariance matrix prior was generated by the Monte Carlo (MC) technique with the EMPIRE code. The prior and selected experimental data from the EXFOR database were fed into the GANDR system [12] to produce the final covariance matrices. An example of the prior covariance matrix generated by the MC method using nuclear model calculations for the (n,γ) cross section is shown in figure 2.

5 Validation

To validate the data a series of benchmark test cases from the SINBAD compilation [13] were analysed:

- FNG Tungsten [14]: several reaction rates with sensitivities covering fast and intermediate energy ranges.
- FNS Clean Experiment on Tungsten [15]: neutron spectra above 5 keV and neutron reaction rate measurements.
- OKTAVIAN tungsten sphere [16]: neutron spectra above ~0.1 MeV and gamma spectra measurements.

The benchmarks were analysed in detail using MC and deterministic transport codes, as well as codes for the cross section sensitivity and uncertainty studies [17]. They test major tungsten cross sections, particularly the (n,2n), (n,γ), inelastic and elastic reactions. The cross section libraries ENDF/B-VII, JENDL-3.3 and fusion library FENDL-2.0 were of primary interest for comparison. The JEFF-3.1 library contains tungsten data from JENDL-3.3, therefore it is excluded; the FENDL-2.1 fusion library contains tungsten data from ENDF/B-VI Release 8, which differ from ENDF/BVII only in some minor details that do not affect the results, therefore either FENDL-2.1 or ENDF/B-VII results are shown. For the sake of completeness the comparison with a candidate evaluation for JEFF-3.2 library [18] is also given.

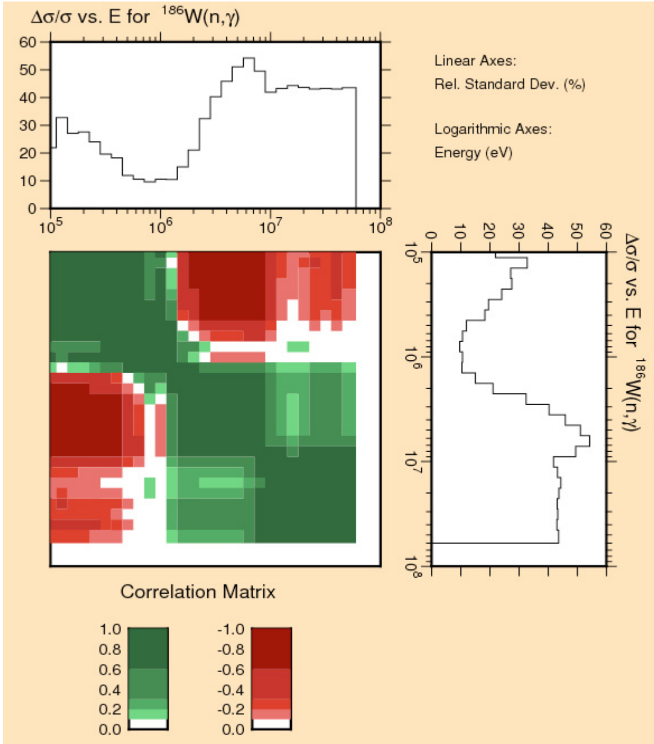

Fig. 2. Prior for the capture covariance matrix of ^{186}W.

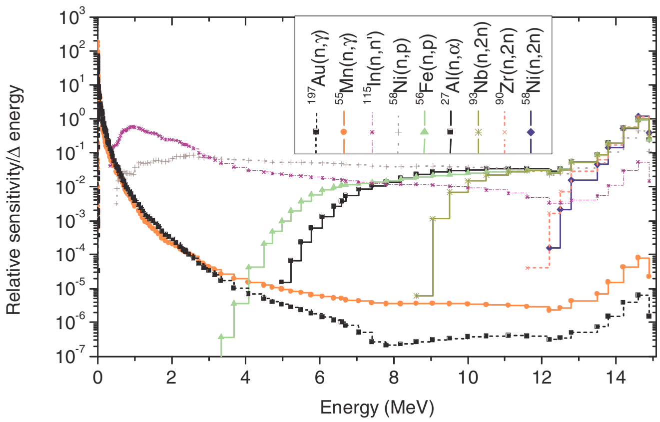

Fig. 3. Sensitivity with respect to the detector response functions at 35 cm in the tungsten block.

5.1 FNG Tungsten experiment

In the FNG Tungsten benchmark [14] the neutron reaction rates and gamma heating were measured at four positions along the central beam axis of the tungsten block, at approximately 5, 15, 25 and 35 cm depths. The following nine reaction rates, covering fast and thermal neutron energies, were used in this exercise: ^{27}Al(n,α), ^{55}Mn(n,γ), ^{56}Fe(n,p), ^{58}Ni(n,2n), ^{58}Ni(n,p), ^{90}Zr(n,2n), ^{93}Nb(n,2n), ^{115}In(n,n′), and ^{197}Au(n,γ). The uncertainties in the ^{55}Mn(n,γ), dosimetry cross sections are large, therefore this reaction was excluded from further consideration. The comparison of reaction rates for the other monitors from benchmark calculations with different libraries is shown in figure 4.

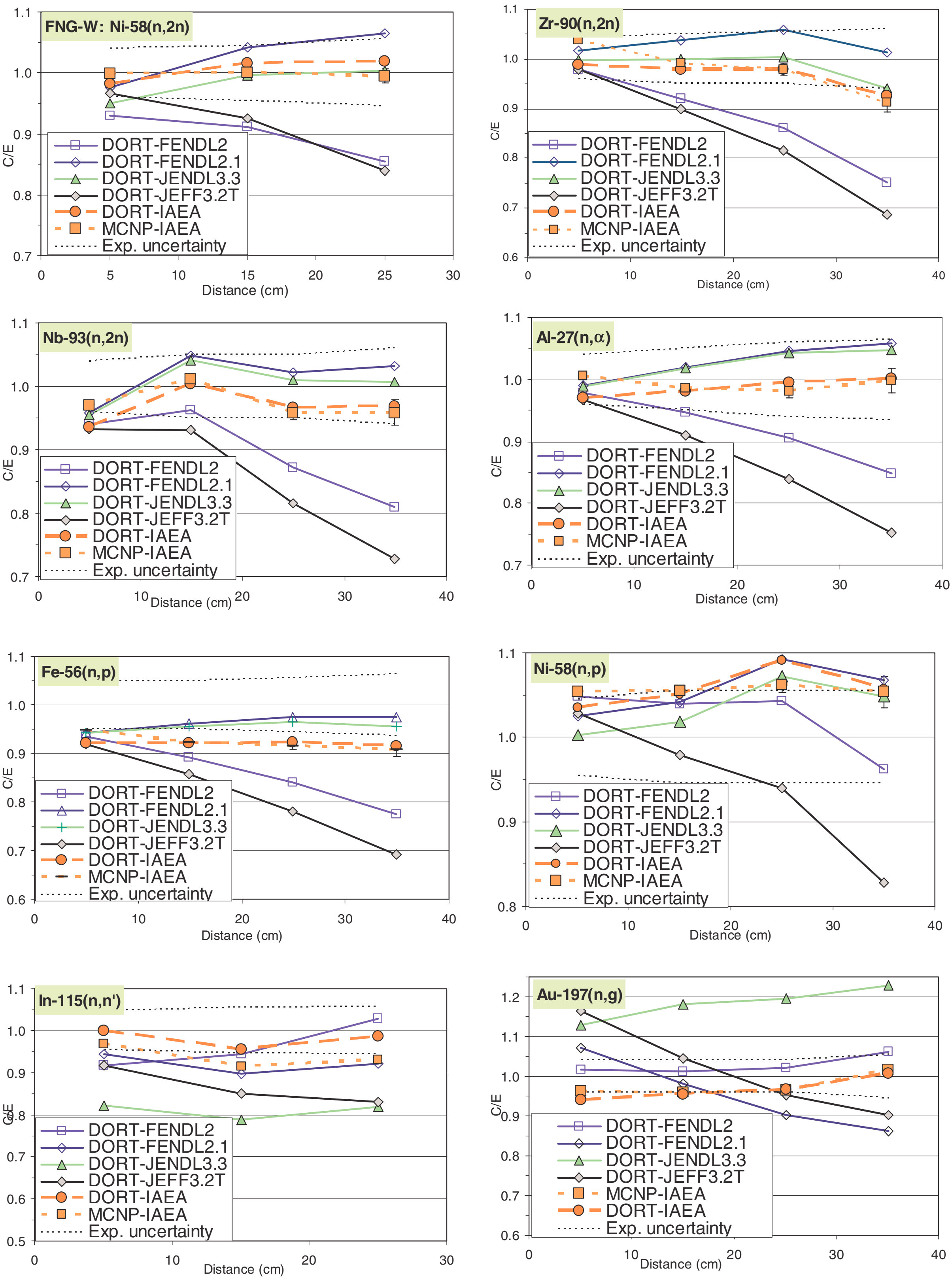

Fig. 4. Predicted reaction rates in the FNG benchmark.

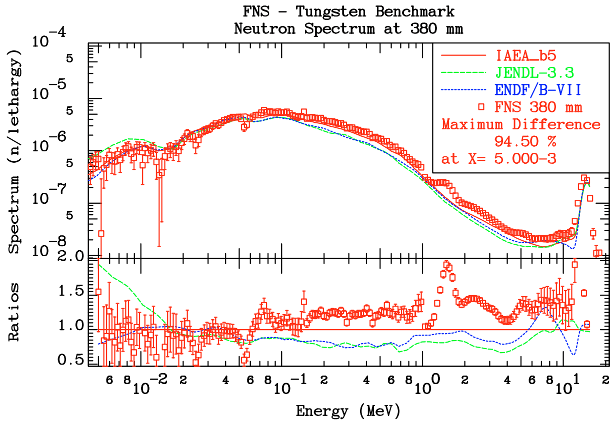

Fig. 5. Neutron spectra from the FNS benchmark.

5.2 FNS clean experiment on tungsten

The benchmark represents neutron flux attenuation from a deuterium-tritium source through a cylindrical assembly of about 40 cm thickness. The calculated neutron spectra at 38 cm penetration are compared to the measured ones in figure 5. Calculations with the new evaluation labelled IAEA_b6 indicate a marked improvement compared to other data libraries (JEF-3.2 corresponds to the evaluation of the ref. [18]). The spectra at smaller penetration depths show similarly good agreement.

5.3 Oktavian tungsten sphere

The benchmark represents neutron leakage spectrum from a tungsten sphere of 40 cm outer diameter and 10 cm shell thickness with a deuterium-tritium source at the centre. Qualitatively the results are very similar to those of the FNS benchmark, but due to the smaller thickness of the tungsten layer the benchmark is less sensitive to the differences in nuclear data libraries and hence less selective in discriminating between them.

6 Conclusions

Advanced nuclear model codes like EMPIRE with suitable model parameters prove to be capable of reproducing experimentally measured cross sections with good accuracy. They provide an excellent starting point for the evaluation of cross sections, double-differential data and their covariances. Using the results of model calculations as *prior*, experimental data and generalised least-squares codes can be used to improve the cross sections and constrain the uncertainties.

A trial evaluation of the tungsten isotopes was done. The results of a preliminary validation study on selected fusion neutronics benchmarks show significantly improved agreement with measurements. Activation measurements in the FNG benchmark, sensitive to a broad range of energies are particularly striking, since practically all results calculated with the new data lie within (or marginally outside) the uncertainty intervals.

The main shortcoming of the present file is the resonance energy range, where hardly any improvement is possible without new measurements.s

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