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Neutron Cross Section Evaluation of Tungsten and Tantalum

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The evaluations of neutron cross sections and covariances are presented for tungsten and tantalum which are considered as a prime candidate of plasma facing materials in fusion reactors and/or a structural material of the Korea Helium Cooled Ceramic Reflector (Ko HCCR) Test Blanket Module (TBM). The Fusion Evaluated Nuclear Data Library (FENDL-2.1) has been employed as the nuclear data for the neutronics analysis to obtain the optimal design parameters for Ko HCCR TBM. However, the neutron cross sections and energy and/or angular dependent neutron spectra from FENDL-2.1 showed some discrepancies with the differential and integral measured data available for tungsten and tantalum. In response to these situations, the neutron cross section for ^{181}Ta and ^{180,182,183,184,186}W have been newly evaluated using the up-to-date nuclear reaction code and the measured data available.

I. INTRODUCTION

One of the main goals of ITER is to install and test the tritium breeding blankets which lead to a tritium self sufficiency and extraction of heat suitable for an electricity generation. Korea has developed a Helium Cooled Ceramic Reflector Test Blank Module (Ko HCCR TBM) considering the unique concept using the graphite reflector [1]. A Reduced Activation Ferrite/Martensite (RAFM) steel has been developed as a structural material such as first and side walls of TBM [2]. The neutronics analysis to obtain the optimal design parameters for materials of Ko HCCR TBM [3] has been performed using the Fusion Evaluated Nuclear Data Library (FENDL-2.1) [4] released in 2004.

However, the nuclear data from FENDL-2.1 failed to reproduce the differential and integral measured data from time to time. In particular, the data of tungsten showed a large discrepancies with the differential and integral measured data [5]. This is because FENDL-2.1 adopted the data from the old library which had not reproduced the measurements [6]. In response of those situations, we decided to evaluate newly nuclear data for several materials through reviewing the nuclear data of all constituents of Ko HCCR TBM and selected tungsten and tantalum as first materials evaluated. Table I shows the materials used in Ko HCCR TBM.

Nuclear data for tantalum in FENDL-2.1 was adopted from JENDL-3.3 [7] taken over from JENDL-3 [8], which was released in 1990. The data was later modified in 2002. The nuclear data for tungsten was from ENDF/B-VI.8 [9], which had come from ENDF/B-V [10] dating back to 1980. Even though several partial reactions were updated, some discrepancies with the integral measurements [5] persisted. To rectify these discrepancies, we produced the nuclear data file focused on neutron production data for incident-neutron energy up to 20 MeV [11]. The previous results showed a reasonable agreements with the measured data [6] below 20 MeV and reproduced the leakage neutron spectra from a sphere with 14 MeV neutrons [12]. Since the previous data were focused on neutron production data rather than all reaction channels, we had carefully evaluated all physical quantities such as cross sections, energy and/or angular distributions and particle spectra in this work. By extending the incident neutron energy to 150 MeV and including covariance data, our evaluated data are expected to be used for not only Ko HCCR TBM but also as a general purpose.

The complete ENDF-6 [13] formatted files were produced by adopting the resonance data from the existing library, producing the evaluated data using the EMPIRE

TABLE I. Materials used in the Ko HCCR TBM

Material	Element
RAFM Steel (Structural Material)	W, Ta, Zr, Fe, Mn, Mo, Nb, Cu, Ni, Co, Cr, V, Ti, S, P, Al, O, N, C, B, H
Li_4SiO_4 (Breeder)	Co, Fe, Ti, Ca, K, Si, Al Na, O, Li-7, Li-6
Beryllium (Multiplier)	Fe, Si, Al, Mg, O, C, Be
SiC Coated Graphite (Reflector)	Pb, Zn, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Ca, K, Si, Al, Mg, Na, C, Li, B

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code system [14] in fast neutron region. The covariance data were generated through the KALMAN filter implemented in EMPIRE.

II. EVALUATION METHODOLOGY

A. General

Nuclear data evaluation in the fast region has been performed with the EMPIRE code system, which has been used to provide a number of consistent and complete evaluations. The nuclear reaction physics of EMPIRE is described elsewhere [14]. The core point of evaluation in fast neutron region is to employ the best set of the reaction models and their parameters which are ingredients for the reactions such as direct reactions, pre-equilibrium emission and Hauser-Feshbach statistical decay [15]. In present work, we employed the microscopic combinatorial level densities (HFBM) and gamma-ray strength functions developed by Plujko [16]. In order to describe the pre-equilibrium reaction, we used the Multi-step Direct and Multi-step Compound (MSD/MSC) model for neutron and the exciton one with Iwamoto-Harada cluster emission for $\gamma-$ray and charged particles. The optical model parameters (OMP) were generated using the technique described in Ref. [17].

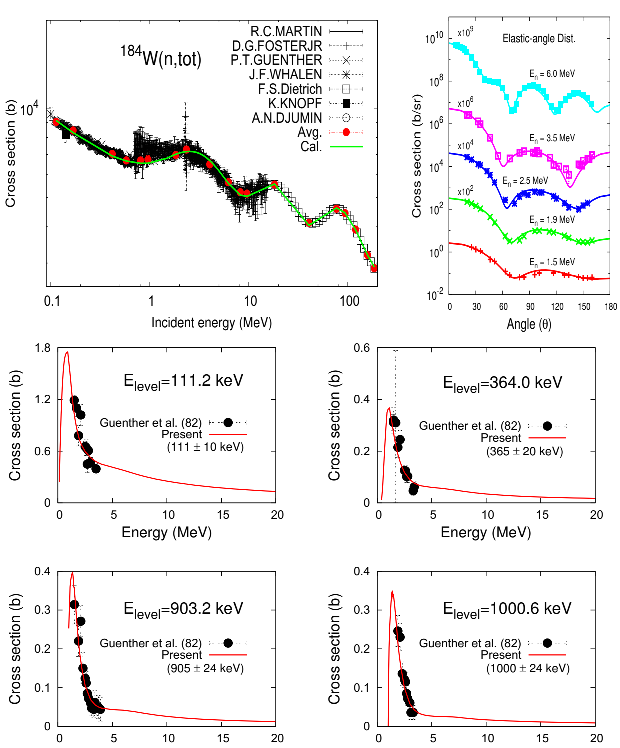

FIG. 1. Total and elastic cross sections, elastic angular distributions, and inelastic cross sections for ^{184}W compared to measurements. Data taken from EXFOR [20].

B. Optimization of OMP

Although many sets of OMP are available in RIPL [18], *i.e.* 336 sets for neutrons, we sometimes failed to find good OMP to produce a reasonable result for the considered nucleus and incident energy region. In order to settle the problem, we developed a code [17] to adjust OMP. This code calculates χ^2 between the measured data from EXFOR and OMP from RIPL using the ECIS06 code, and automatically iterates the calculation until χ^2 converges. Otherwise it can optimize the OMP parameters through graphic view. For instance, to obtain OMP for ^{184}W, we prepared the measured data of total and elastic cross sections and elastic-angular distributions from EXFOR. Because the calculated total cross section smoothly vary for the incident neutron energies, it is more efficient to consider the averaged values in energy bins rather than all measured data. The averaged cross sections with filled circles are shown in left-top plot of Fig. 1. A trial OMP which would be used at a first run was taken from RIPL. Although any potential in RIPL became a trial OMP, we adopted a global Koning-Delaroche potential [19] which is reasonable for not only a spherical nucleus but also a deformed one if the appropriate deformations and coupled levels are given. Through iterative calculations with changing OMP parameters, we obtained the result as shown in Fig. 1 which ensured that the adjusted OMP were reasonable for incident energies up to 150 MeV.

III. RESULTS

The same way producing OMP for ^{184}W was used to adjust the OMP parameters for the remaining tungsten isotopes and ^{181}Ta. Because no measurements of the total or elastic cross sections were available for ^{180}W and ^{183}W in the fast neutron region, those of natural tungsten were used as the measured data required in the adjusting procedure. Fig. 2 shows total cross sections of ^{182}W and ^{186}W compared with the experimental data. By merging all tungsten isotopes using their abundances, we produced the total cross sections of tungsten elements as shown in left-bottom plot of Fig. 2. The total cross sections of ^{181}Ta are compared to the measurements and the libraries in right-bottom plot of Fig. 2. Using the adjusted OMP and the reaction models described in Sec. II A, we calculated the physical quantities such as cross sections, energy and/or angular distributions and particle spectra. The calculated neutron spectra reproduced the measurements better than other libraries at 11.5 MeV as shown in Fig. 3. In case of 26 MeV incident neutron energy, all the libraries reproduced the experimental data well. Unlike the results in Fig. 3, neutron spectra showed strange shapes as the incident neutron energy increased. This is because two-step MSD in present version of EMPIRE is insufficient as the incident neutron energy increase. In order to rectify this problem, we switched it into the cluster model developed by Iwamoto-