Neutron Capture Cross Section for Er-166 and Er-167

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1. Introduction

Erbium (Er) is a material considered as a neutron absorber in a nuclear fuel or in a reactor control rod. In the early stage of nuclear power plant (PWR type), Erbium was used as a burnable poisoning material. However, the relative low neutron capture property to other poisoning materials (i.e., boron (~3,800 b in (n, α) reaction), gadolinium (Gd-155 (~60,000 b) and Gd-157 (~250,000 b)), europium (Eu-152 (~13,000 b)), and dysprosium (Dy-160 (~60b) and Dy-164 (2500b)), a large amount of erbium was necessary to absorb the enough neutrons. However, especially, in the recent development of nuclear power plant, to produce the hydrogen as a future energy source (for example, very high temperature gas cooled reactor, VHTR), Erbium is considered as a burnable poison as well. Erbium is also considered as a control rod material in a nuclear power operated submarine. Therefore, an evaluation on the neutron induced cross sections based on the recent experimental data is necessary and important for a better application, system design.

Er-166 and Er-167 were selected to evaluate the neutron induced cross sections from several keV up to 20 MeV, among the erbium isotopes. Er-166 and Er-167 have 33.5% and 22.869% abundance respectively in a natural element composition and they are stable isotopes.

Scat2-Empire code[1] combination was adopted in the current cross section calculation for the total, elastic scattering and threshold reaction cross sections. The evaluation consists of an optical model calculation followed by a complete nuclear reaction model calculation. The energy dependent optical model potential was applied for a calculation of the transmission coefficients. The calculated cross sections are graphically compared with the experimental data and the evaluated files. The results will be merged with the resonance results to make the full data file.

2. Reaction Model

The main modules in Empire are: the Optical model, Multi-step Direct (MSD) and Compound (MSC), Pre-equilibrium exiton model (DEGAS) and Monte Carlo hybrid simulation (HMS) and a full featured Hauser-Feshbach including the width fluctuation correction. The individual nuclear reaction cross sections are calculated by using the Hauser-Feshbach model for the equilibrium energy region. In the statistical model, the Compound Nucleus (CN) state *a* with spin J, parity π and excitation energy E to a channel *b* is given by the ratio of the channel width Γ_b to the total width $\Gamma_{tot} = \sum_c \Gamma_c$ multiplied by the population of this state $\sigma_a(E,J,\pi)$. This also holds for secondary compound nuclei that are formed due to subsequent emissions of the particles. Each such state contributes to the cross section.

$$\sigma_b(E,J,\pi) = \sigma_a(E,J,\pi)\frac{\Gamma_b(E,J,\pi)}{\sum_c \Gamma_c(E,J,\pi)} \quad (1)$$

These have to be summed over spin J and parity π and integrated over an excitation energy E (in case of daughter CN) to obtain observable cross sections.

The approach to a statistical multistep direct reaction is based on the MSD theory of a preequilibrium scattering for the continuum[1]. The direct capture model[1] was inserted to enhance the fast neutron capture cross section in the pre-equilibrium energy range. The modeling of the MSC processes follows the approach of Nishioka et al. (NVWY)[1]. Like most of the precompound models, the NVWY theory describes the equilibration of the composite nucleus as a series of transitions along a chain of classes of the closed channels of increasing complexity

3. Results and Discussions

Fig. 1 shows the comparison of the calculated total cross section with the experimental data for the natural element and the evaluated files for Er-166. The calculation from the determined potential parameters for the natural element is in good agreement with the experimental data[2,3] in the whole energy range. The current evaluation is very consistent with the JENDL until 1 MeV. Above 1 MeV, there is a little difference, but, both evaluations are in good agreement with the experimental data. Above 5 MeV, ENDF/B-VI shows the difference from the measured data. Fig. 2 shows the capture cross section for Er-166. The evaluation is based on the recent measurement of Igashira experimental data[4]. The current evaluation and the ENDF/B-VI are in good agreement in the measured energy region. But, the difference from the measured data is shown at 600 keV.

Fig. 3 shows the comparison of the calculated total cross section with the experimental data and the evaluated files for Er-167. The calculation from the determined potential parameters is in good agreement with the experimental data[2,3,5,6]. Above 2 keV, the calculation

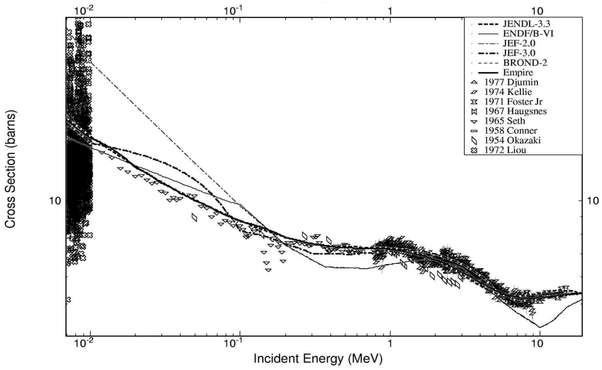

Figure 1. Total cross section of Er-166.

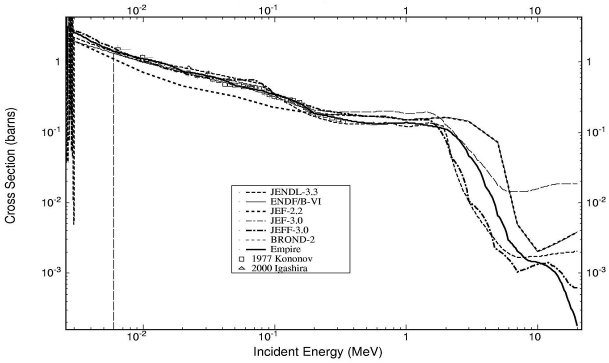

Figure 2. Capture cross section of Er-166.

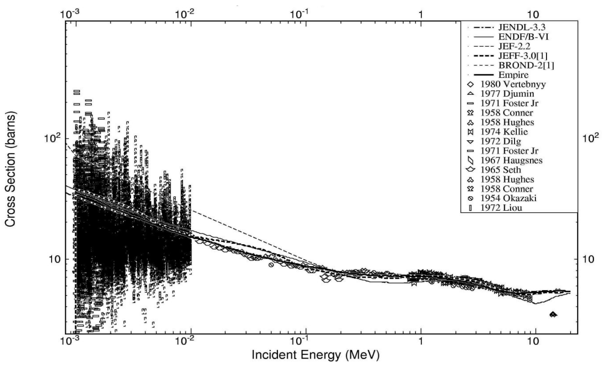

Figure 3. Total cross section of Er-167.

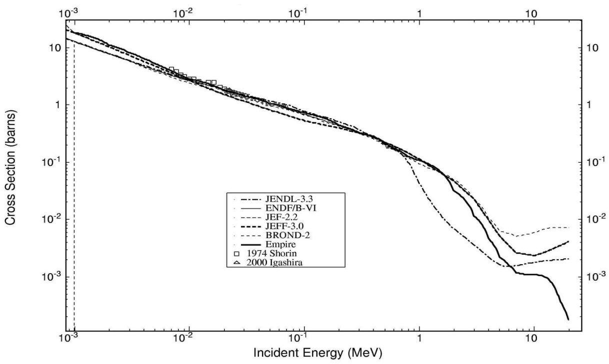

Figure 4. Capture cross section of Er-167.

shows the good agreement with the experimental data for the natural element as well. Fig. 4 shows the capture cross section for Er-167. The evaluation is based on the recent measurement of Igashira experimental data[4]. The current evaluation and ENDF/B-VI are in good agreement in the measured energy region.

4. Conclusion

The neutron induced cross sections were successfully evaluated in the fast energy region. The calculated total and capture cross sections were in good agreement with the experimental data. The direct capture model enhanced the fast neutron capture in the pre-equilibrium energy. The enhanced cross section data based on the recent experimental data will contribute to a better application of the materials.

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