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Revision of the Dy Isotopes Library for ENDF/B-VII

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Abstract

Neutron data for total and capture cross sections were re-evaluated for Dy-160, Dy-161, Dy-162, Dy-163 and Dy-164 up to 20 MeV, using a newly released Empire code package. The optical model, Hauser-Feshbach model and quantum mechanical models were used to produce the total and capture cross sections. The results showed a good agreement with the experimental data. The results were merged with the resonance part in the unresolved energy to make a full data set. The NJOY code was run to check the continuity of the merging energy and the consistency of the total cross section. A general description (MF=1) was completed for each nucleus. If necessary, the background was inserted into the capture and total cross sections. The final evaluated file is ready to be submitted for the release of the ENDF/B-VII.

1. Introduction

Dysprosium (Dy) is a material considered as a neutron absorber in a nuclear fuel or in a reactor control rod. They have features such that the isotopes after neutron capture have a large capture cross section as well. Therefore, Dy can absorb neutrons continuously and effectively for a long-term period. This slow burnout is a necessary property as a reactor control rod material. Meanwhile, the capture cross section of Dy, as one of the rare-earth elements, in a few to hundred keV energy region is important for the study of nucleo-synthesis in astrophysics[1]. Therefore, an evaluation of the neutron cross sections based on the recent experimental data is necessary and important for a better application.

Dy-160, Dy-161, Dy-162, Dy-163 and Dy-164 have a 2.34%, 18.9%, 25.5%, 24.9% and 28.2% in natural abundance, respectively. The thermal capture cross sections of the Dy isotopes range from ~60 b (Dy-160) to 2,500 b (Dy-164). The ENDF/B-VI.7, the version released in 2000[2], contains neutron cross sections of the Dy isotopes, Dy-160 ~ 164. It was the first revision of the Dy data since the data was evaluated for ENDF/B-V in 1974. The revision[3], however, was limited to the capture and total cross sections below several hundreds keV, while the present evaluation is aimed at a revision up to 20 MeV.

The merging process at the 1st excited energy point was done between the resonance and the fast energy part evaluations. From the different model calculations at the resonance part and fast energy part, generally a discontinuity happened at the merging energy. Therefore, If necessary, background and adjustments were put into the MF=3 based on the experimental data. In the re-evaluation, a (n, g) cross section was enhanced in a preequilibrium energy region. A checking by the NJOY code was run to check the continuity and smoothness of the whole evaluation energy range. In this paper, the total and capture cross sections will be compared with those in the ENDF/B-VI.7. The general description (MF=1) was completed. Therefore, a full data set for the ENDF/B-VII is ready

2. Nuclear Models

Empire[4] was selected as a basic tool for the re-evaluation of the nuclear reaction data. Empire involves the width fluctuation correction in the Hauser-Feshbach theory and offers the ENSDF nuclear level library. The searched potential as a function of the incident neutron energy was used in the optical model. This potential provides the basis of the theoretical cross section. The main modules for Empire are:

- Optical model: spherical and coupled channels deformed
- MSD/MSC: multistep direct (ORION & TRISTAN) and NVWY multistep compound
- Preequilibrium: exiton (DEGAS) and Monte Carlo hybrid simulation (HMS)
- HF: full featured Hauser-Feshbach, including HRTW width fluctuation correction.

The preequilibrium exiton model is important for a fast neutron capture reaction. Furthermore, the Empire package offers a powerful plotting code, Zvview, to compare both the experimental data and the evaluated neutron data files (ENDF/B-VI.7, JENDL, JEF, CENDL, BROND).

3. General Rule for Merge

The evaluation is basically dependent on reliable experimental data. From the different models used in the two different energy regions, thermal to unresolved resonance and unresolved resonance to 20 MeV, to get continuity at the merging energy, background is added into the MT=1 and 102. The general rules for merging are summarized here: For a total cross section, with experimental data, continuity is considered from agreement with the reference experimental data. Without experimental data, natural experimental data is considered instead. For a capture cross section, without experimental data, continuity is considered at the merging energy. NJOY[5] is used to check the continuity and background for the total and capture cross sections of the whole energy range

4. Evaluation Results

The calculated total and capture cross sections were compared with the experimental data and ENDF/B-VI.7. The calculated capture cross section is shown in Fig. 1 for Dy-160. The model calculation, the ENDF/B-VI.7 and the experimental data are in good agreement within a statistical fluctuation. Fig. 2 shows good agreement between the calculated capture cross section and the experimental data[1,6] for Dy-161. ENDF/B-VI.7 agrees with the experimental data as well. Fig. 3 and 4 show the comparison of the capture cross section for Dy-162 and Dy-163. In the measurement of the energy range, the calculation and ENDF/B-VI.7 agree well with the experimental data[1,6]. Fig. 5 shows the capture for Dy-164. The calculated capture cross sections are in good agreement with the experimental data[1,6,7,8] in the measured energy range.

Fig. 6 shows the total cross section of the calculation, the experimental data[1,9] and the ENDF/B-VI.7 for Dy-160. The model calculation is in good agreement with the experimental data. However, above 70 keV, the calculation and Voss data are lower than the ENDF/B-VI.7. The calculated total for Dy-161 follows the experimental data[1,9] well in Fig. 7. However, the shape difference between the calculation and the ENDF/B-VI.7 is shown. The total cross section of Dy-162 is compared in Fig. 8. The calculated total cross section is in very good agreement with the measured data. Fig. 9 is for Dy-163. Above 40 keV, the calculation and Voss data start to deviate from the ENDF/B-VI.7. Fig. 10 shows the difference between the calculated and the ENDF/B-VI.7 for Dy-164. ENDF/B-IV has a higher cross section value from 20 keV to 20 MeV.

5. Conclusion

The extracted optical model potential calculated the cross sections properly in the measured energy range and the parameters were applied satisfactorily up to 20 MeV. The calculated total and capture cross sections were in good agreement with the experimental data. However, the evaluated total cross sections were different from the ENDF/B-VI.7 in Dy-160, Dy-161, Dy-163 and Dy-164, above a few keV energy. The total cross sections were enhanced more than the ENDF/B-VI.7, based on the recent experimental data. The capture cross sections were agreed well with the experimental data and the ENDF/B-VI.7 in the measured energy region. In addition to the total and capture cross section evaluation, a possible reaction of the cross sections in the energy region was completed in the final file and compiled in the ENF-6 format. The neutron cross section data sets are ready for the ENDF/B-VII. In most cases, considerable improvement over the current ENDF/B-VI files was achieved. It will contribute to the release of the ENDF/B-VII.

Acknowledgements

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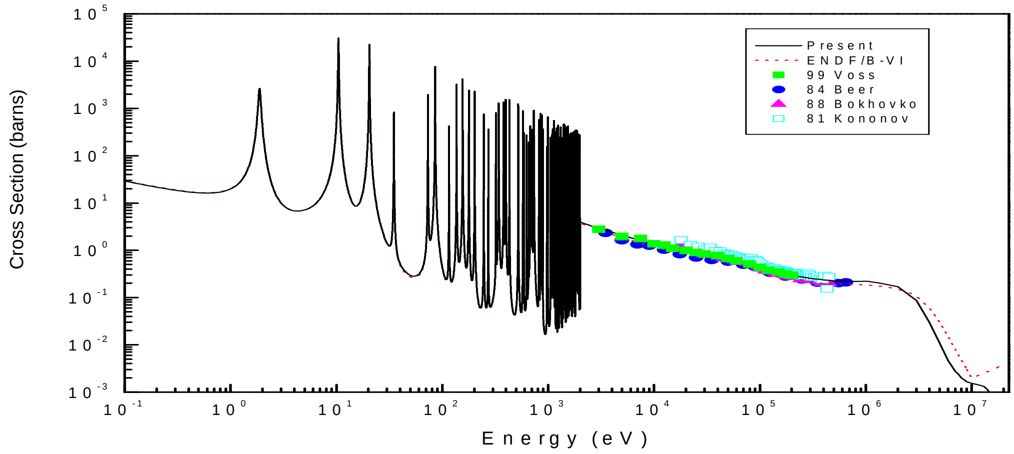

Fig. 1. Capture cross section of Dy-160.

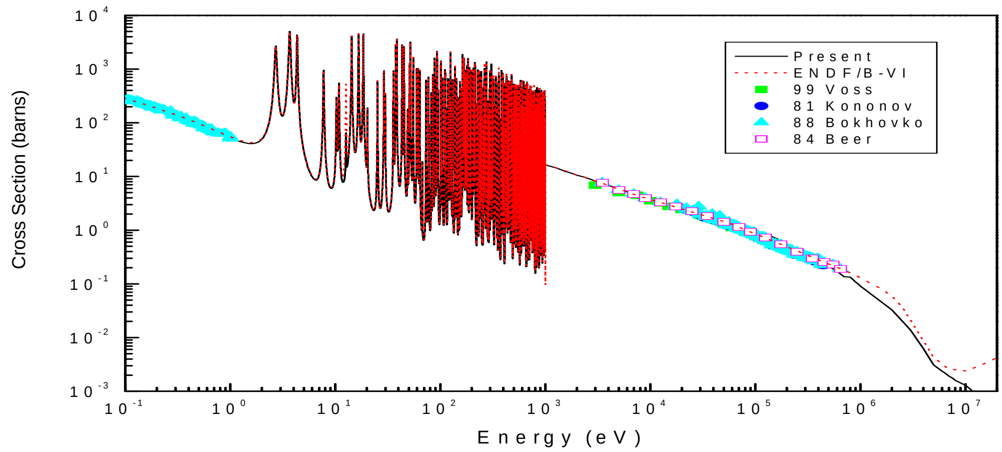

Fig. 2. Capture cross section of Dy-161.

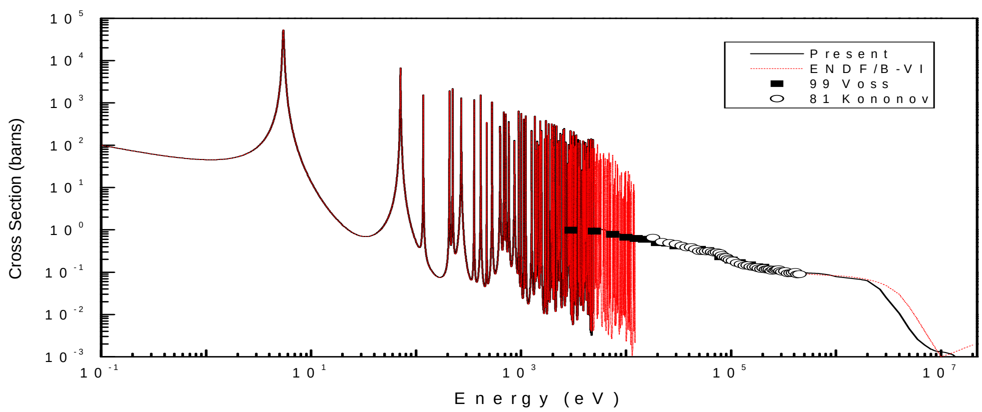

Fig. 3. Capture cross section of Dy-162.

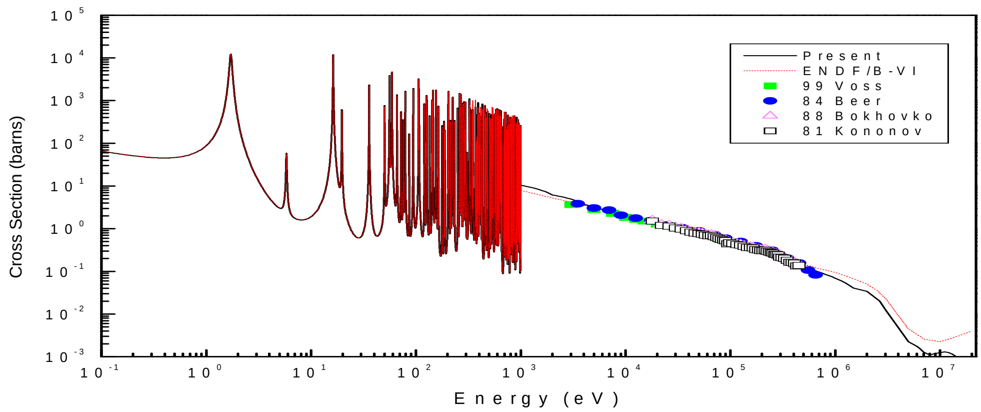

Fig. 4. Capture cross section of Dy-163.

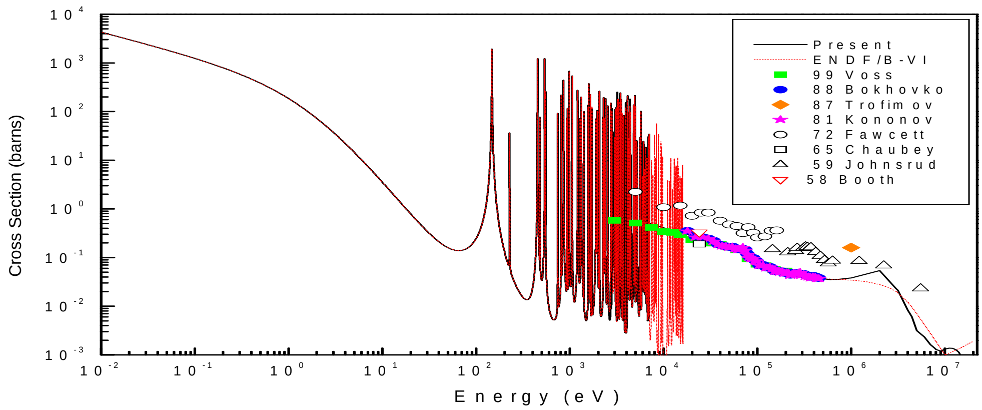

Fig. 5. Capture cross section of Dy-164.

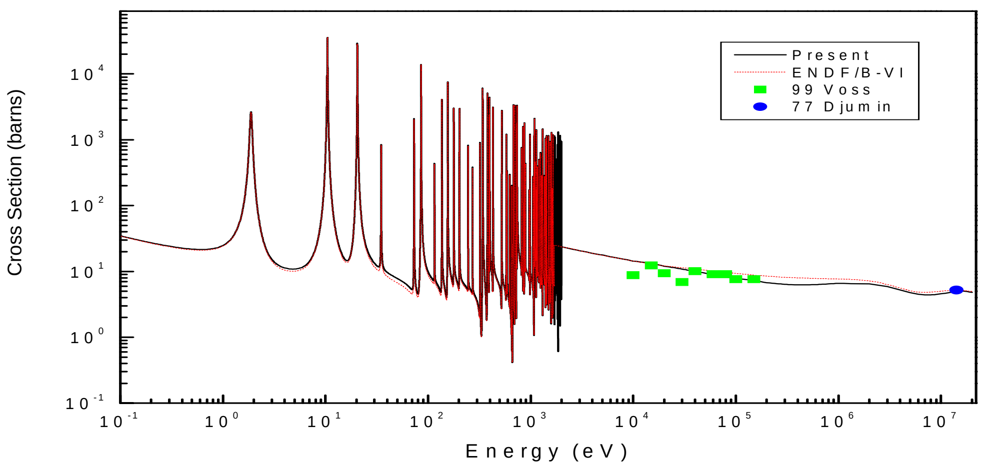

Fig. 6. Total cross section of Dy-160.

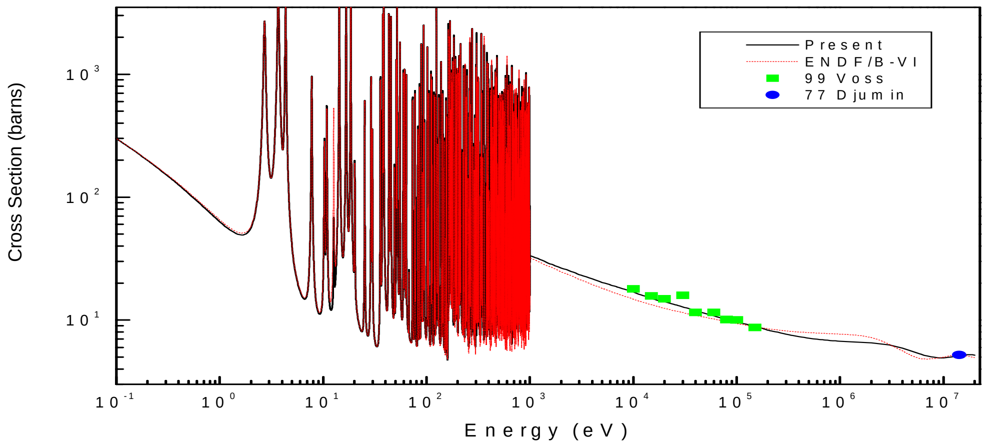

Fig. 7. Total cross section of Dy-161.

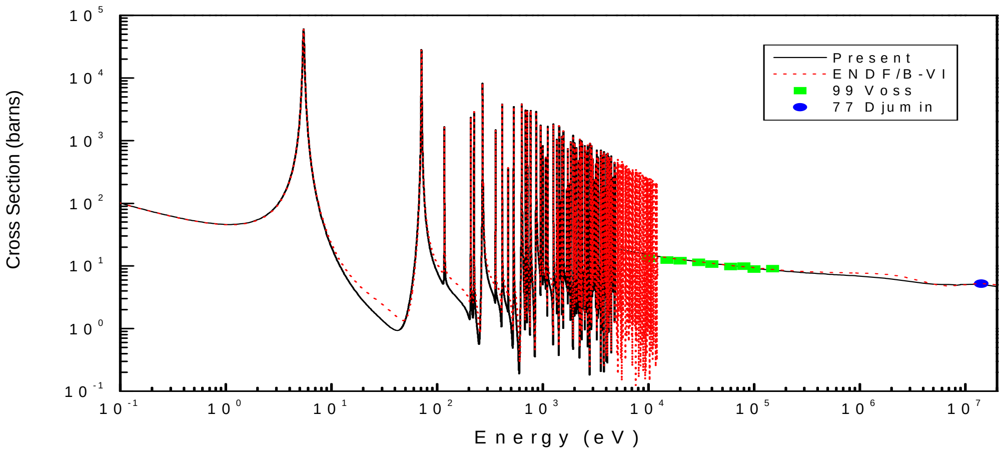

Fig. 8. Total cross section of Dy-162.

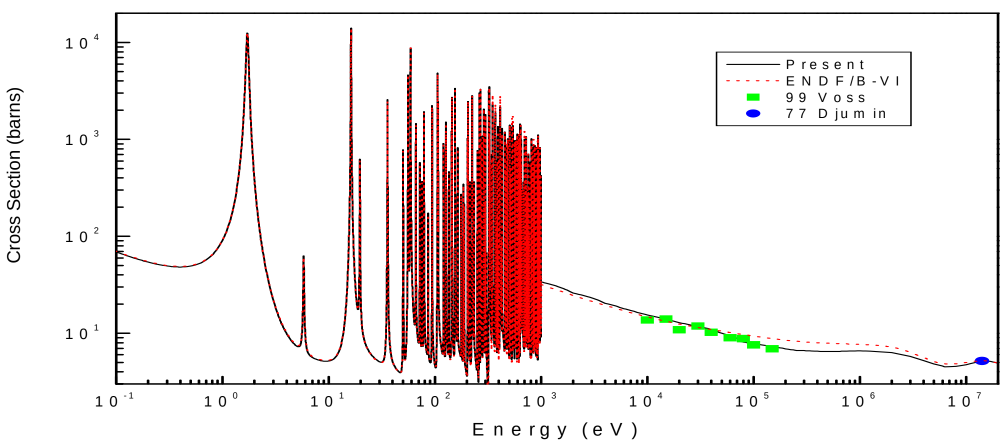

Fig. 9. Total cross section of Dy-163.

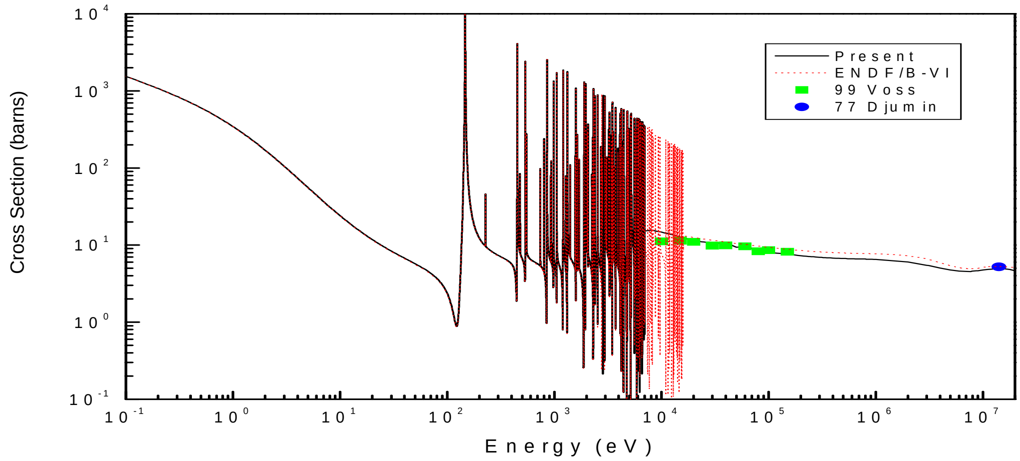

Fig. 10. Total cross section of Dy-164.