Capture Cross Section and Gamma Spectra for Cd, In and Ag Isotopes

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1. Introduction

The method to control the nuclear reaction is the insertion or withdrawal of control rods made of materials having a large cross section for the absorption of neutrons. The widely used materials as neutron absorber are hafnium, silver, indium, cadmium, and boron. Especially in the PWR, a highly effective neutron absorber is produced by alloying cadmium, which has a thermal absorption cross section of 2450 barns, with silver and indium, which have high resonance absorption. Although there are evaluation data for these materials, they show some discrepancy with experimental data above unresolved resonance regions. In this work, we obtained the capture cross section and gamma emission spectra for Cd, In, and Ag isotopes.

2. Status and Models

The capture cross section of the thermal and resolved resonance regions for Cd, In, and Ag isotopes play a great role to control the nuclear power reactor, especially PWR. Therefore, the data for the regions have been evaluated well in nuclear data libraries. But the evaluation data above unsolved resonance regions show discrepancies with up-to-date experimental data, especially capture cross section. Thus, we produced the neutron cross section data for Cd-112, 113, 114, which have the experimental data for (n,tot), (n,n), (n,g), (n,2n) reactions. Recently the capture cross sections of them were measured anew by Wisshak at el [1]. For these isotopes, we could ascertain the characteristic which is observed in nucleus with large discrete interval at low excitation energy levels. We also produced the data for In-115 and Ag-107.

In order to calculate the neutron cross section, we used EMPIRE-II which is a modular system of nuclear reaction codes [2]. The code accounts for the major nuclear reaction mechanisms, such as optical model, Multi-step direct and compound model, and the full featured Hauser-Feshbach model.

2.1 Optical model and level densities

At high energies, the density of compound nucleus states becomes so large that the individual contributions can no longer be resolved. It then becomes impossible to distinguish the slow energy dependence of the direct contribution from the rapid variations of the compound nucleus one. Instead, only the average properties of the compound nucleus contribution to the cross section can be determined. The optical potential is used to achieve the two objectives. The principal one of the optical model is to describe just the prompt, direct reactions in a nuclear collision. In addition, it is also used to produce the transmission coefficients essential for the analysis of compound nucleus cross sections within the Hauser-Feshbach statistical theory. We tuned the optical model parameters which were searched from Reference Input Parameter Library (RIPL-2) [3], and calculated the transmission coefficient by using the SCAT-2 [4].

Nuclear excited levels display a discrete spectrum for low excitation energies. When the excitation energy increases, the mean spacing of these levels reduces, depending on the mass of the nucleus, and the level spacing becomes so weak that it is experimentally impossible to distinguish all of them. Therefore the individual description of each level is replaced by a global description employing a level density function. Such level densities are also very important ingredients for both the statistical and pre-equilibrium models of nuclear reactions. For the statistical model, total level densities are required whereas the pre-equilibrium model needs particle-hole level densities which only involve restricted numbers of fermions. Up to now, although several level densities have been developed by many authors, we adopted the Gilbert-Cameron approach [5] of which parameters could be taken from RIPL-2.

2.2 Hauser-Feshbach statistical model

The statistical model describes the emission of the flux that is absorbed into the long-lived compound-nucleus states during a collision. Mathematically, the compound nucleus cross sections can be written as the product of a factor describing the creation of the compound nucleus and a factor describing its decay. Assuming that creation factor is Y_a and absorption/emission factor Y_c, the cross section is obtained as follows:

$$\sigma_{ac} = C_p W_a \frac{Y_a Y_c}{\sum_b Y_b}, \quad (1)$$

where C_p is the value related with spin and wave number, and b means all possible channels. In the Hauser-Feshbach model [6], angular momentum and parity conservation are taken into account as well as energy, charge and mass conservation. In order to obtain more improved results, one take into account a correction factor, known as a width fluctuation correction, W_a. In Eq. (1), the factors ($Y_{a,b,c}$) are described as the product of the level densities and transmission coefficients. Meanwhile, the transmission coefficient for gamma is expressed by Kopecky-Uhl method [7] added by E1 pygmy resonance [8, 9].

2.3 Pre-equilibrium particles

As the incident energy increases, particles are emitted in nuclear reactions long before the attainment of statistical equilibrium: these are the so-called pre-equilibrium particles. We described the pre-equilibrium particles by using Quantum mechanical model, that is, Multi-step direct (MSD) and Multi-step compound (MSC).

3. Results

We obtained the capture cross section and gamma emission spectra for Cd, In and Ag isotopes. Figure 1 show the capture cross section for Cd-114. We used up-to-date experimental data measured by Wisshak to compare the calculated results. The existing files show some discrepancies with experimental data. The present results reproduced the experimental data better than other libraries.

From the figure, we could observe drastic drop, which is due to large discrete levels in low excitation energies, around 1 MeV incident neutron energy. We can observe it at Cd isotopes with even mass number: Cd-112, 114. But we could not find the same characteristic at Cd-113 because the level intervals in low excitation energies are dense.

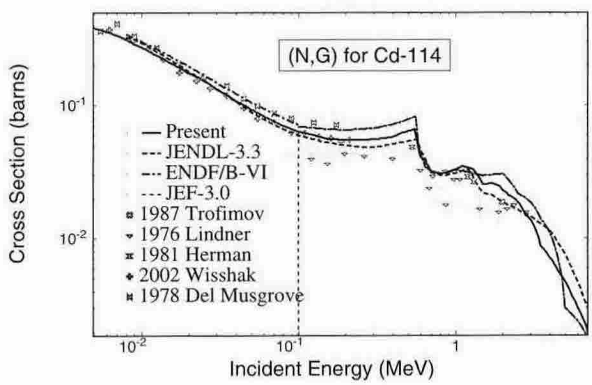

Fig. 1 Capture cross section for Cd-114.

4. Conclusion

We obtained the neutron capture cross section and gamma emission spectra of Cd, In, and Ag which are important materials to control nuclear power reactor. The present data show good agreements with up-to-date experimental data. We also could ascertain the characteristic which are observed in nucleus with large discrete interval in low energy level. In addition, we produced the gamma emission spectra by using Kopecky-Uhl strength function added by E1 pygmy resonance.

Acknowledgments

This work was performed under the auspices of Korea Ministry of Science and Technology as a long-term R& D project.

REFERENCES

[1] K. Wisshak, F. Voss, F. Kaeppeler and L. Kazakov, Neutron capture cross section for stellar cadmium production, Phys. Rev. **C66**, 2002.

[2] M. Herman, EMPIRE-II statistical model code for nuclear reaction calculation, IAEA, 2002.

[3] IAEA-CRP, Reference Input Parameter Library (RIPL-2), http://www-nds.iaea.org/ripl2/, 2003.

[4] O. Bersillon, SCAT2: un programme de modele optique spherique, Report CEA-N-2227 NEANDC(FR), INDC(E) 49, 1981.

[5] A. Gilbert and A. G. W. Cameron, A composite nuclear-level density formula with shell corrections, Can. J. Phys. 43, 1446, 1965.

[6] W. Hauser and H. Feshbach, The inelastic Scattering of Neutrons, Phys. Rev. 8, 366, 1952.

[7] J. Kopechy and M. Uhl, Test of gamma-ray strength functions in nuclear reaction model calculations, Phys. Rev. **C41**, 1941, 1990.

[8] M. Igashira, H. Kitazawa, M. Shimizu, H. Komano and N. Yamamuro, Systematics of the pygmy resonance In keV neutron capture γ-ray spectra of nuclei with N≈83-126, Nucl. Phys. **A457**, 301, 1986.

[9] H. I. Kim, Y. D. Lee, Y. O. Lee and J. H. Chang, Gamma Emission Spectra for Gd, Au, and Eu Isotopes, Proc. KNS Spring Meeting , Gyeongju, Korea, 2004.