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Evaluation of Optical Model Potential using Neutron Induced Cross Section Reactions for Spherical Uranium-235 Isotope up to 20MeV

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Abstract
The evaluation is based mainly on the calculations of the nuclear optical model potential and the relevant parameters are collected and selected from References Input Parameter Library (RIPL) which is being developed under the international project coordinated by the International Atomic Energy Agency (IAEA). The analyzing of a complete energy range has been done starting from threshold energy for each reaction. The cross sections are reproduced in fine steps of incident neutron energy with 0.01MeV intervals with their corresponding errors. The recommended cross sections for available experimental data taken from EXFOR library have been calculated for all the considered neutron induced reactions for U-235 isotope. The calculated results are analyzed and compared with the experimental data. The optimized optical potential model parameters give a very good agreement with the experimental data over the energy range 0.001-20MeV for neutron induced cross section reactions *(n,f), (n,tot), (n,el), (n,inl), (n,2n), (n,3n), and (n,γ)* for spherical U-235 target element.
Keywords: EXFOR nuclear data, induced neutron reactions, 20MeV, recommended cross section, optical model potential.

1. Introduction

The excitation functions in induced neutron nuclear reactions *(n,f), (n,tot), (n,el), (n,inl), (n,2n), (n,3n), and (n,γ)* measured for U-235 with the aid of EXFOR library. The cross sections for these reactions have been evaluated in the present work for the exact estimation of the cross sections among different authors. This paper describes the standard optical model potential analyses of the spherical U-235 target element up to 20MeV. The present paper also describes the background of the References Input Parameter Library (RIPL) used for input parameters. These data are used in the real and imaginary part of optical model potential-special emphasis is placed in this study on the isotope dependence of the optical model potential.

2. Recommended Cross Section

The available measured data from EXFOR library for the cross section (n,f), (n,tot), (n,el), (n,inl), (n,2n), (n,3n) and (n,γ) reactions for U-235 have been plotted interpolated and recalculated in different fine steps and for different energy ranges of incident neutron by using Matlab-8.0 in order to calculate the recommended cross section for each mentioned reaction with a minimum χ^2=0.001046 for U-235 neutron induced reactions. This can be described in the following steps:

1- The interpolation for the nearest data for each energy interval as a function of cross sections and their corresponding errors have been done using Matlab-8.0.
2- The sets of experimental cross sections data are collected for different authors and with different energy ranges. The cross sections with their corresponding errors for each value are re-arranged according to the energy interval 0.01 MeV for available different energy ranges for each author.
3- The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each author has been done.
4- The interpolated values are calculated to obtain the adopted cross section which is based on the weighted average calculation according to the following expressions (Varalakshmi 2005):

$$\sigma_{w.a.} = \frac{\sum_{i=1}^{n} \frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n} \frac{1}{(\Delta\sigma_i)^2}} \qquad (1)$$

Where the standard deviation error is:

$$S.D. = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{(\Delta\sigma_i)^2}}} \tag{2}$$

Where σ_i : is the cross section value.

$\Delta\,\sigma_i$: is the corresponding error for each cross section value.

Figures (1 to 4) illustrate the recommended cross sections for the above mentioned reactions as calculated in the present work compared with EXFOR library. It is clear in the caption of each figure, the refry of authors name are arranged according to the year of measured data are listed with the present calculated recommended cross section. The results are in good agreement with the measured data.

3. Optical Model Potential

In the frame of the optical model, all the interactions between the nucleons of the projectile and the nucleons of the target are replaced by an average and central interaction V(r) between the projectile and the target in their ground states. The nuclear optical model used to describe the interaction between two nuclei is inspired by the optical phenomenon. The nuclear medium diffracts one part of the incident wave which models the incident particle and another part of the wave is refracted (Hussain 2009).

As the nucleon-nucleon interaction is a short range interaction, the potential $V_r \times f_r(r, r_r, a_r)$, which is approximately the sum of nucleon-nucleon interactions, has the same behavior. The nucleons in the core of the nucleus undergo only the interaction with their closest neighbors. Due to this saturation of the nuclear forces, $V_r \times f_r(r, r_r, a_r)$ is uniform inside the nucleus and then decreases exponentially in the surface region (Kim et al.1999).

4. Background of (RIPL)

The Reference Input Parameter Library (RIPL) is being developed under the international project coordinated by the International Atomic Energy Agency (IAEA). The practical use of nuclear reactions requires a considerable numerical input that describes properties of the nuclei and interactions involved. The (RIPL) represents a fairly comprehensive set of such parameters, collected and selected from sources all over the world. The (RIPL) contains input parameters for theoretical calculations of nuclear reaction cross sections. The library is targeted at users of nuclear reaction interested in nuclear applications. The main recommended optical model parameters files in the (RIPL) are Los Alamos (U.S.A.), Beijing (China), and JAERI (Japan) files (Koning & Delaroche 2003).

5. Theoretical Basis of Optical Model Potential

The present evaluations are based mainly on the calculations the optical model potential. A standard form of the optical model potential and relevant parameters used in the present work contains volume, surface, and spin-orbit parts, each having real and imaginary components. This potential can be written as follows (Koning & Delaroche 2003, Herman 2001, Yong 1998):

$$\begin{aligned} V(r,E) &= -V_r \times f_r(r, r_r, a_r) \\ &+ i\left\{4 \times a_d \times W_d \times \left[\frac{df_d(r, r_d, a_d)}{dr}\right] - W_g \times \exp(-X_g^2) - W_v \times f_v(r, r_v, a_v)\right\} \\ &+ \frac{\lambda_\pi^2}{r} \times \left\{V_{so} \times \left[\frac{df_{so}(r, r_{so}, a_{so})}{dr}\right] + iW_{so} \times \left[\frac{df_{so}(r, r_{so}, a_{so})}{dr}\right]\right\} \times \left(\vec{\ell} \cdot \vec{s}\right) \end{aligned} \tag{3}$$

In equation (3) V_r and W_v are the real and imaginary volume potential well depths, W_d is the well depth for the surface derivative term, W_g is the well depth for the global nucleon-nucleon optical potential, V_{so} and W_{so} are the real and imaginary well depths for the spin-orbit potential, and λ_π^2 is the pion Compton wavelength squared ($\cong 2$). The quantity $\vec{\ell} \cdot \vec{s}$ is the scalar product of the orbital and intrinsic angular momentum operators and is given by Koning & Delaroche (2003):

$$\vec{\ell} \cdot \vec{s} = \ell \qquad for \quad j = \ell + \frac{1}{2} \tag{4}$$

$$\vec{\ell}\,.\,\vec{s} = -(\ell+1) \qquad for \quad j = \ell - \frac{1}{2} \tag{5}$$

The $f_i\,(r, r_i, a_i)$ are radial-dependent form factors. The real potential, imaginary potential and form factors are defined below (Koning & Delaroche 2003):

5.1 Real Potential

V_r, V_{so} are the depths of real potential in (MeV).

Since $V_i = V_{i0} + V_{i1}\times E + V_{i2}\times E^2 + (V_{i3} + V_{i4}\times E)\times(N-Z)/A$ with $i = r, so$ (6)

Where V_{r0} V_{r1} V_{r2} V_{r3} V_{r4} and V_{so0} V_{so1} V_{so2} V_{so3} V_{so4} are the depth parameters of real potential in (MeV) taken from (RIPL). Z, N, and A are the numbers of protons, neutrons and nucleons in the target nuclide respectively. E is the energy of incident particle. (Hint: We select the energy at maximum cross section for different authors for selected reactions).

5.2 Imaginary Potential

W_d, W_v, W_g, W_{so} are the depths of imaginary potential in (MeV).

Since $W_i = W_{i0} + W_{i1}\times E + W_{i2}\times E^2 + (W_{i3} + W_{i4}\times E)\times(N-Z)/A$ with $i = d, v, g, so$ (7)

Where W_d (W_{d0} W_{d1} W_{d2} W_{d3} W_{d4}); W_v (W_{v0} W_{v1} W_{v2} W_{v3} W_{v4}); W_g (W_{g0} W_{g1} W_{g2} W_{g3} W_{g4}); and W_{so} (W_{so0} W_{so1} W_{so2} W_{so3} W_{so4}) are the depth parameters of imaginary potential in (MeV) taken from (RIPL).

5.3 Form Factor

Wood – Saxon form factors is permitted for $f_i\,(r, r_i, a_i)$ terms in equation (3), is as follows:

$f_i(r, r_i, a_i) = \dfrac{1}{[1+\exp(X_i)]}$ with $i = r, d, v, so$ (Wood–Saxon form factor) (8)

Where $X_i = (r - R_i)/a_i$ with $i = r, d, g, v, so$ (9)

r is the radial distance in (fm). The nuclear radius R_i is given by:

$$R_i = (r_{i0} + r_{i1}\times E)\times A^{\frac{1}{3}} + C_i \tag{10}$$

And the form used for the diffuseness, a_i is given by:

$$a_i = a_{i0} + a_{i1}\times E \tag{11}$$

Where:

r_r (r_{r0} r_{r1} C_r a_{r0} a_{r1}); r_d (r_{d0} r_{d1} C_d a_{d0} a_{d1}); r_g (r_{g0} r_{g1} C_g a_{g0} a_{g1});

r_v (r_{v0} r_{v1} C_v a_{v0} a_{v1}); r_{so} (r_{so0} r_{so1} C_{so} a_{so0} a_{so1})

are the geometry parameters of real potential in (fm) taken from (RIPL).

The optical potential poten.m program has been built in the present work using Matlab-8.0. The aim of this program is to calculate the real and imaginary optical potential as a function of radial distance and the energy of induced neutron for spherical U-235 target element.

6. Calculated Results and Discussion

A limited number of parameters for spherical potential are included for incident neutron particles. The energy dependence of the neutron potential based on the Uranium isotope (Z=92, A=235) is E=0.001-20MeV for spherical U-235 nucleus. Which are included in the present calculations to cover the same energy range for the same target charge and mass. The optical model potential (OMP) parameters are including in the (RIPL) optical file coordinated research project with Beijing Library. The parameters for optical model potential used in this work are tabulated in table (1) for spherical U-235 target element. The global potentials are calculated for systematic utilization of nuclear radial distance r=1 to 20fm as well as real and imaginary potential.

This model represents the scattering in terms of a complex potential V*(r,E)*, see equation (3), where the functions *V* and *W* are selected to give the potential its proper radial dependence. The real part, *V*, is responsible for the elastic scattering it describes the ordinary nuclear interaction between target and projectile and may therefore be very similar to a shell model potential. The imaginary part, *W*, is responsible for the absorption.

The usual optical potential for Uranium-235(spherical nucleus) has a real optical depth V_{ro} of the order of 48.8679MeV with radius of the real depth r_{r0} = 1.2647fm with spin orbit potential V_{so} =6.2000MeV with radius r_{so0} =1.2647fm ,and imaginary optical depth W_{do} = 6.3882MeV and W_{vo} = 0.2911MeV with radius r_{d0} = 1.3501fm and r_{v0} =1.3501fm with energy range(0.001-20MeV). The radial distance is to be at most of the order of the r=1:20fm and the energy of incident neutrons have been taken at maximum cross section. All parameters used in this work for optical model potential have been taken from (Beijing) library (Zhang et al. 1980). Table (1) shows these parameters for Uranium-235.

Figure (5) shows the optical model potential for Uranium target element (U; A = 235) induced by neutron, in which absorption *W* is relatively weaker than elastic scattering *V*. The absorptive part, *W*, at low energies must have a very different form.

Because of the exclusion principle, the tightly bound nucleons in the nuclear interior cannot participate in absorb the relatively low energy carried by the incident particle. The optical potential is thus often has the proper shape of being large only near the surface, as shown in figure (5). At higher energy, where the inner nucleons can also participate in absorption, *W*, may look more like *V*. A spin – orbit term is also included in this optical potential. It is also peaked near the surface, because the spin density of the inner nucleons vanishes. A Wood – Saxon form factor is also included. The calculation using the optical model potential, as described in this work, does not deal with where the absorbed particles actually go; they simply disappear from the elastic channel.

7. Conclusions

We have evaluated the neutron induced nuclear cross section data of spherical Uranium-235 isotope for considerable energy ranges. The calculated recommended cross sections are in good agreement with experimental data. The reliability in this work is to estimate the global optical parameters chosen for the energy range 0.001-20MeV from Beijing library for spherical U-235 target elements of neutron induced reactions. The results confirm that the global optical potential parameters are appropriate for these calculations. Hence, the optical model potential is successful in accounting for neutron induced reactions and leads to an understanding of the nucleon-nucleon interactions.

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References

Armitage B.H. , G.Ferguson A.T. , Montague J.H. & Starfelt N. (1966)," Inelastic Scattering of Fast Neutron by U-235", *Conference on Nuclear Data ForReactors, Paris, France, June* ***1****, 383.*

Batchelor R. & Wyld K. (1969)," Neutron Scattering by U-235 and Pu-239 for Incident Neutrons of 2, 3 and 4 MeV", *Aldermaston Reports, UK, August, No.55/69.*

Brooks F.D. , Jolly J.E., Schomberg M.G. & Sowerby M.G. (1966)," Beta and neutron cross section of U-235 from 0.03 to 200 eV", *Proceeding of Reactor Physics Conference, San Diego, USA 193.*

Carlson A.D., Wasson O.A., Lisowski P.W., Ullmann J.L. & Hill N.W. (1991)," Measurements of the 235U(n,f) cross section in the 3 to 30 MeV neutron energy region", *Proceeding of Nuclear Data for Science and Technology Conference, Juelich , Germany, May 518.*

Drake D.M. (1969)," Inelastic neutron scattering and gamma production from fast-neutron bombardment of 235U", *Journal of Nuclear Physics, Section A* ***133****, 108.*

Frehaut J. , Bertin A. & Bois R. (1980)," Measurement of the U-235(n, 2n) Cross Section between Threshold and 13 MeV", *Journal of Nuclear Science and Engineering* ***74****, 29.*

Harvey J.A., Hill N.W., Perey F.G., Tweed G.L., Leal L. & Derrien H. (1988)," High-Resolution Neutron Transmission Measurements on 235U, 239Pu, 238U ", *Conference on Nuclear Data for Science and Technology, Mito, Japan, May 115.*

Herman M. (2001),"Overview of nuclear reaction models used in nuclear data evaluation", *Journal of Radiochim. Acta.* ***89****, 305-316.*

Hopkins J.C. & Diven B.C. (1962)," Neutron Capture to Fission Ratio in U233, U235, Pu23", *Journal of Nuclear Science and Engineering* ***12****, 169.*

Hughes R.O., Beausang C.W. , Ross T.J., Burke J.T. , Scielzo N.D., Basunia M.S., Campbell C.M. , Casperson R.J., Crawford H.L., Escher J.E. , Munson J., Phair L.W. & Ressler J.J. (2012)," Utilizing (p,d) and (p,t) reactions to obtain (n,f) cross sections in uranium nuclei via the surrogate-ratio method" , *Journal of Physical Review, Part C, Nuclear Physics* ***85****, 024613.*

Hussain M. (2009),"Evaluation of nuclear reaction cross sections relevant to the production of emerging therapeutic radionuclides", *Ph.D. thesis, Government College University Lahore, Pakistan.*

Iwasaki T., Karino Y., Matsuyama S., Manabe F. , Baba M., Kanda K. & Hirakawa N. (1988), "Measurement of U-235 fission cross section around 14 MeV", *Proceeding of Nuclear Data for Science and Technology Conference, Mito , Japan, March 87.*

Johnson R.G., Carlson A.D. , Wasson O.A., Duvall K.C., Behrens J.W., Meier M.M., Patrick B.D. & Dias M.S. (1988)," Measurements of the 235U(n,f) standard cross section at the national bureau of standards", *Proceeding of Nuclear Data for Science and Technology Conference, Mito , Japan, March* 1037.

Kim D., Lee Y.O., & Chang J. (1999)," Calculation of proton – induced reaction on Ti, Fe, Cu and Mo", *Journal of the Korean Nuclear Society **31**(6), 595.*

Knitter H.H., Islam M.M. & Coppola M. (1972)," Investigation of fast neutron interaction with U-235", *Journal of Zeitschrift fuer Physik **257**, 108.*

Koning A.J. & Delaroche J.P. (2003), " Local and global nucleon optical models from 1 keV to 200 MeV ", *Journal of Nuclear Physics A **713**, 231-310.*

Kononov V.N. , Poletaev E.D. , Prokopets Yu.S. , Metlev A.A. , Stavisskiy Y.Y. & Yurlov B.D. (1975)," Measurements of the capture-to-fission cross-section ratios from 10 keV to 1 MeV, neutron capture and fission cross-sections from 10 to 80 keV for uranium-235 and plutonium-239 ", *Journal of Atomnaya Energiya **38**(2), 82.*

Mather D.S., Bampton P.F., Coles R.E., James G. & Nind P.J. (1972),"Measurement of (n, 2n) Cross Section for Incident Energies Between 6 and 14 MeV ", *Aldermaston Reports, UK, May, No.72/72.*

Merla K., Hausch P., Herbach C.M., Musiol G., Pausch G., Todt U.,Drapchinskiy L.V., Kalinin V.A., Shpakov V.I., Alkhazov I.D., Kovalenko S.S. , Kostochkin O.I., Solin L.M., Arlt R., Grimm W. , Josch M., Ortlepp H.G., Teichner R., Wagner W., Dushin V.N. & Petrzhak K.A. (1991)," Absolute measurement of neutron induced fission cross-sections of U-235, U-238, Np-237 and Pu-239", *Proceeding of Nuclear Data for Science and Technology Conference, Juelich, Germany, May 510.*

Muradyan G.V., Voskanyan M.A., Yastrebova L.P., Volkov V.L., Shatrov O.Ya., Furman V.I. & Konovalov V.Yu. (1999), " Measurements of Neutron Capture Cross Sections of 234-U and 236-U and Fission Cross Section of 236-U", *Journal of Atomnaya Energiya **110**(2), 100.*

Nolte R., Allie M.S., Brooks F.D., Buffler A. , Dangendorf V., Meulders J.P., Schuhmacher H., Smit F.D., Weierganz M. & Roettger S. (2007)," Cross Sections for Neutron-Induced Fission of U-235, U-238, Bi-209i, and Pb-nat in the Energy Range from 33 to 200 MeV Measured Relative to n-p Scattering" , *Journal of Nuclear Science and Engineering **156**, 197.*

Perez R.B., De Saussure G., Silver E.G., Ingle R.W. & Weaver H. (1973)," Simultaneous Measurement of the Neutron Fission and Capture Cross Section for Uranium-235 for Neutron Energies from 8 eV to 10 keV", *Journal of Nuclear Science and Engineering **52**, 46.*

Poenitz W.P. & Whalen J.F. (1983)," Neutron total cross section measurements in the energy region from47 keV to 20 MeV", *Report: Argonne National Laboratory Reports, No.80.*

Smith A.B. & Guenther P.T. (1982)," On Neutron Inelastic-Scattering Cross Sections of 232Th, 233U, 235U, 238U, 239Pu and 240Pu", *Conference on Nuclear Data for Science and Technology, September (Belgium). 39.*

Smith A.B. & Whalen J.F. (1964)," Search for Structure in the Fast Neutron Interaction with 235U", *Journal of Nuclear Science and Engineering **18**, 126.*

Varalakshmi T.V., Suseela T.n., Gnana Sundaram T.G., Ezhilarasi T.S. & Indrani T.B. (2005),"Statistics", *Tamilnadu Textbook Corporation, College Road, Chennai-600 006. 98-100.*

Veeser L.R. & Arthur E.D. (1978)," Measurement of (n, 3n) cross sections for 235U and 238U", *Conference on Neutron Physics and Nuclear Data, Harwell, USA, September 1054.*

Yong P.G. (1998)," 4 Optical Model Parameters: Handbook for calculations of nuclear reaction data Reference Input Parameter Library (RIPL) ", *IAEA-TECDOC-1034, August.*

Zhang B., Zhang Y. & Mo J. (1980)," Col. of Theo. Meth. On Nuclear Reaction and Their Application". *Optical Model Potential Collected in Beijing [hsj-78233(11js)], 115.*

Zhong C., Li J.Q. & Wu Y.S. (1978)," Review of experimental data of U-235(n,g) cross sections - E(n)=1 kev to 14 MeV" , *Institute of Atomic Energy, Beijing Reports, China No.77105.*

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Table 1. Parameters for optical model potential used for spherical Uranium-235 from Beijing Library, with energy range 0.001-20MeV (Zhang et al. 1980).

Well depth parameters of real optical potential in (MeV)						
V	V_r	V_{r0}	V_{r1}	V_{r2}	V_{r3}	V_{r4}
		48.8679	-4.4650	0.0235	-24.0000	0.0000
	V_{so}	V_{so0}	V_{so1}	V_{so2}	V_{so3}	V_{so4}
		6.2000	0.0000	0.0000	0.0000	0.0000
Well depth parameters of imaginary optical potential in (MeV)						
W	W_d	W_{d0}	W_{d1}	W_{d2}	W_{d3}	W_{d4}
		6.3882	0.1283	0.0000	-12.0000	0.0000
	W_v	W_{v0}	W_{v1}	W_{v2}	W_{v3}	W_{v4}
		0.2911	0.0059	0.0000	0.0000	0.0000
	W_g	W_{g0}	W_{g1}	W_{g2}	W_{g3}	W_{g4}
		0.0000	0.0000	0.0000	0.0000	0.0000
	W_{so}	W_{so0}	W_{so1}	W_{so2}	W_{so3}	W_{so4}
		0.0000	0.0000	0.0000	0.0000	0.0000
Geometry parameters of real optical potential in (fm)						
r	r_r	r_{r0}	r_{r1}	C_r	a_{r0}	a_{r1}
		1.2647	0.0000	0.0000	0.5666	0.0000
	r_d	r_{d0}	r_{d1}	C_d	a_{d0}	a_{d1}
		1.3501	0.0000	0.0000	0.6415	0.0000
	r_g	r_{g0}	r_{g1}	C_g	a_{g0}	a_{g1}
		0.0000	0.0000	0.0000	0.0000	0.0000
	r_v	r_{v0}	r_{v1}	C_v	a_{v0}	a_{v1}
		1.3501	0.0000	0.0000	0.6415	0.0000
	r_{so}	r_{so0}	r_{s01}	C_{so}	a_{so0}	a_{so1}
		1.2647	0.0000	0.0000	0.5666	0.0000

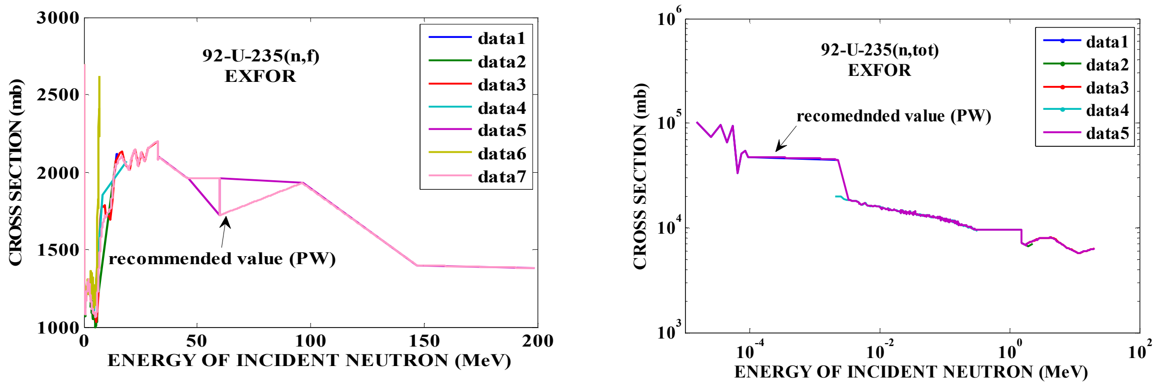


Figure 1. Left side: The recommended cross section of the $^{235}_{92}U(n,f)$reaction as calculated by the present work compared with EXFOR library. Right side: The recommended cross section of the $^{235}_{92}U(n,tot)$ reaction as calculated by the present work compared with EXFOR library. Data in left side: Data1: Iwasaki et al. (1988). Data2: Johnson et al. (1988). Data3: Carlson et al. (1991). Data4: Merla et al. (1991). Data5: Nolte et al. (2007). Data6: Hughes et al. (2012). Data6: Present work (PW). Data in Right side: Data1: Brooks et al. (1966). Data2: Knitter et al. (1972). Data3: Poenitz & Whalen (1983). Data4: Harvey et al. (1988). Data5: Present work (PW).

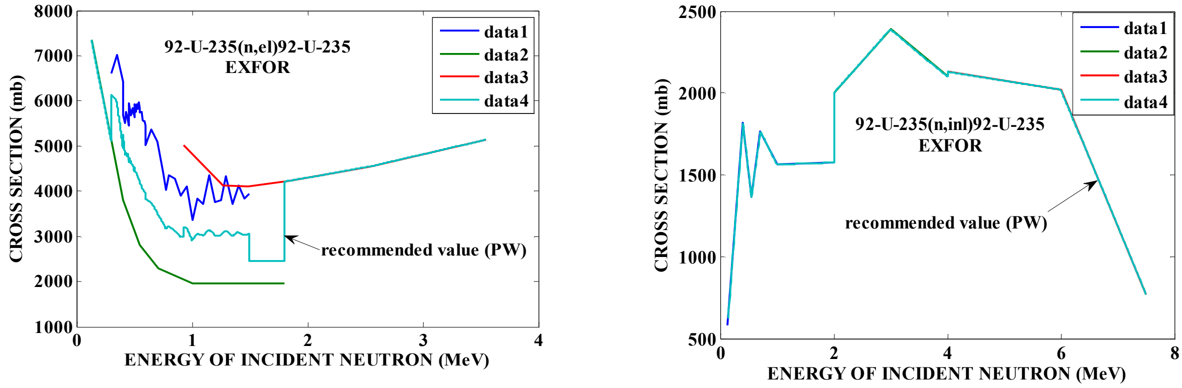


Figure 2. Left side: The recommended cross section of the ${}^{235}_{92}U(n,el){}^{235}_{92}U$reaction as calculated by the present work compared with EXFOR library. Right side: The recommended cross section of the ${}^{235}_{92}U(n,inl){}^{235}_{92}U$reaction as calculated by the present work compared with EXFOR library. Data in left side: Data1: Smith & Whalen (1964). Data2: Armitage et al. (1966). Data3: Smith & Guenther (1982). Data4: Present work (PW). Data in Right side: Data1: Armitage et al. (1966). Data2: Batchelor & Wyld (1969). Data3: Drake (1969). Data4: Present work (PW).

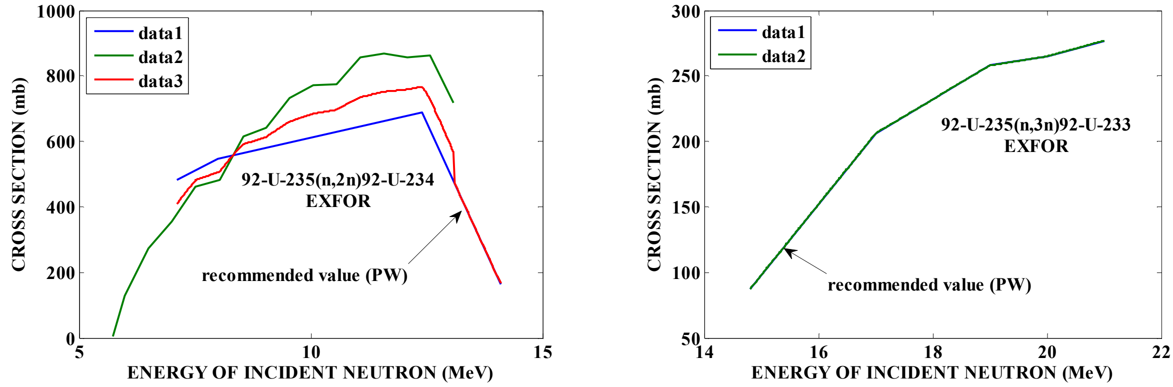


Figure **3. Left side: The** recommended cross section of the ${}^{235}_{92}U(n,2n){}^{234}_{92}U$ reaction as calculated by the present work compared with EXFOR library. Right side: The recommended cross section of the ${}^{235}_{92}U(n,3n){}^{233}_{92}U$reaction as calculated by the present work compared with EXFOR library.
Data in left side: Data1: Mather et al. (1972). Data2: Frehaut et al. (1980). Data3: Present work (PW).
Data in Right side: Data1: Veeser & Arthur (1978). Data2: Present Work (PW).

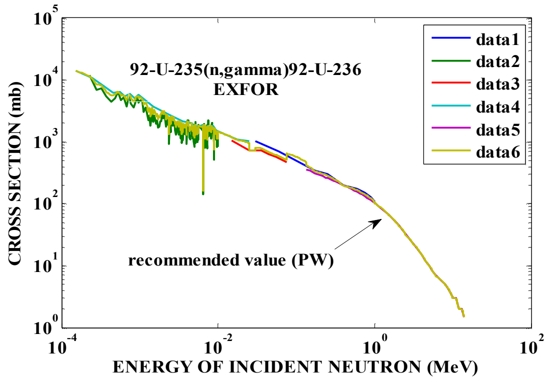
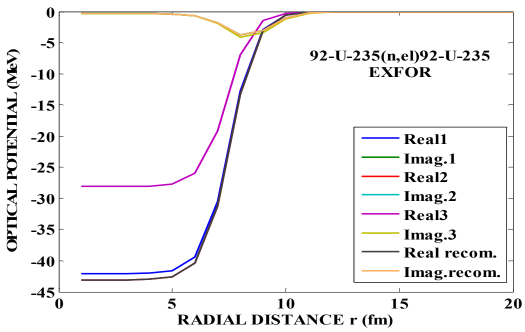
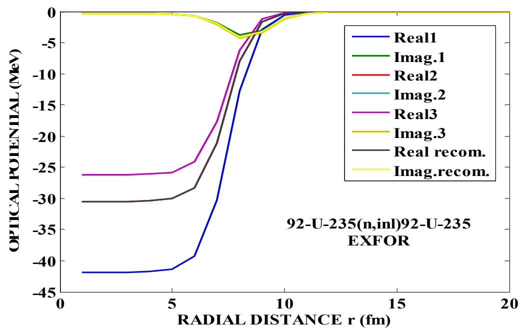


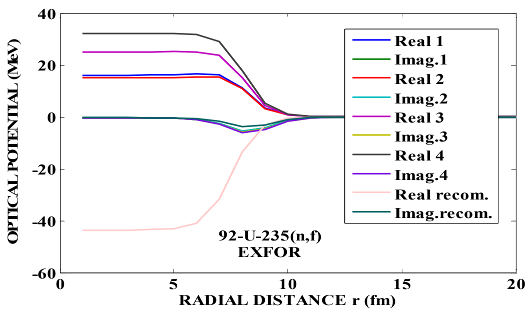
Figure 4. The recommended cross section of the $^{235}_{92}U(n,\gamma)^{236}_{92}U$ reaction as calculated in the present work compared with EXFOR library. Data1: Hopkins & Diven (1962). Data2: Perez et al. (1973). Data3: Kononov et al. (1975). Data4: Muradyan et al. (1999). Data5: Zhong Cet al. (1978). Data6: Present work (PW).



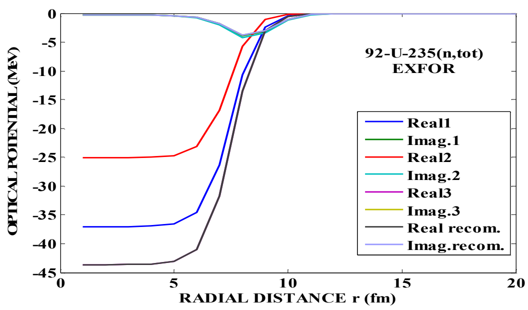
No.1, 2 & 3 related to Data1, Data 2, & Data 3 in the left side of figure 2.



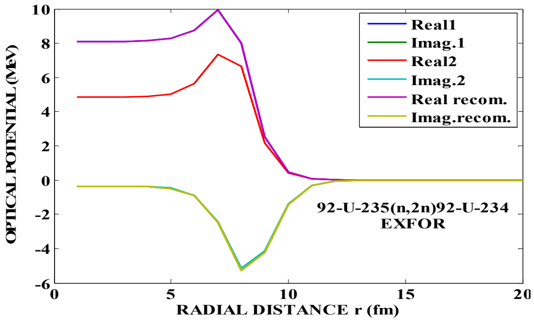
No. 1, 2 & 3 related to Data1, Data 2, & Data 3 in the right side of figure 2.



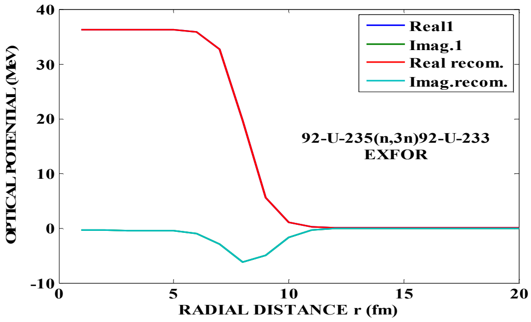
No.1, 2, 3 & 4 related to Data1, Data 2, Data 3, & Data 4 in the left side of figure 1.



No.1, 2 & 3 are equivalent to Data 2, Data 3 & Data 4 in the right side of figure 1 respectively.

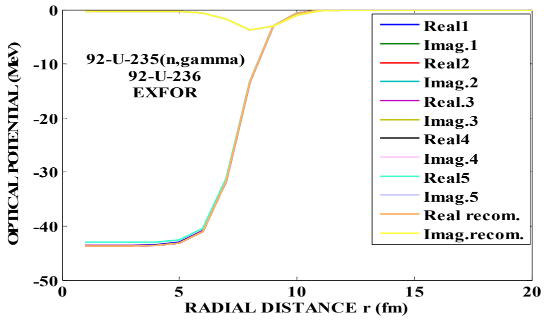


No.1 & 2 related to Data1 & Data2 in the left side of figure 3.



No.1 related to Data1 in the right side of figure 3.

Figure 5. The Optical Model Potential of neutron induced reaction on spherical U-235 calculated in the present work as a function of radial distance. Typical parameters chosen are taken for energy range 0.001-20MeV (Beijing Library).



No.1, 2, 3, 4 & 5 related to Data1, Data2, Data3, Data4 & Data5 in figure 4.