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Excitation Function of (n,α) Reactions of Hafnium and Tungsten Isotopes for Fusion Reactor Technology

Amit Badola[1,*], *S. K. Singha*[2] *and Manoj Bhatnagar*[1]

[1]Department of Physics, DIT University, Dehradun, Uttarakhand-248009, India.
[2]Faculty of Science & Technology, ICFAI University, Dehradun, Uttarakhand-247167, India.

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Abstract: The cross section of ^{176}Hf(n, α)^{173}Yb, ^{177}Hf(n, α)^{174}Yb, ^{178}Hf(n, α)^{175}Yb, ^{179}Hf(n, α)^{176}Yb, ^{180}Hf(n, α)^{177}Yb, ^{182}W(n, α)^{179}Hf, ^{183}W(n, α)^{180}Hf, ^{184}W(n, α)^{181}Hf and ^{186}W(n, α)^{183}Hf reactions have been analyzed by using TALYS 1.4 in the energy range between 13 MeV and 15 MeV. The result has been compared with several experimental values taken from EXFOR data library and evaluated data file of ENDF/B-VII.0 & ENDF/B-VII.I. It is concluded that the present results contribute significantly to enhance the knowledge of cross-sections and in optimizing the input parameters required in model based evaluation.

Keywords: Cross-Sections; TALYS 1.4; Pre-equilibrium; Systematic.

1 Introduction

The analysis of (n,α) reactions cross-section data is essential in fission and fusion reactor technology especially for the calculations on nuclear transmutation rates and radiation damage to the materials used in the construction of the core and inner walls of the reactor. Most of the core and inner walls of the reactor are available at around 14 MeV. (n,α) reaction cross section has also been used to check and improve the model calculations as well as to explain the observed systematic, especially the isospin and isotopic dependence. Cheng et al.[1] and Markovskij et al.[2] estimates induced radio activity, nuclear transmutation, radiation damage and so on from reaction cross-section data. In the case of isomeric cross-sections, Kao and Alford [3], Eapen and Salaita [4] and Vanska and Rieppo [5] concludes that they are useful for various studies such as transfer of angular momentum, spin-dependence of nuclear level density, refinements in gamma transition theories and testing of theoretical nuclear models. Although, in few reactions measured data of activation cross sections at few energies are available but complete excitation function of the reactions is necessary for the development of fusion reactors. Therefore, theoretical investigation is needed to support and extend the experimental cross-sections data for entire incident neutron Energies. The selection of reliable data is still difficult even after the published experimental values of cross-sections as in many cases they show unexpected deviations in the values of cross-section with energy. Keeping this in view we have taken experimental data along with various data libraries which are then compared with the nuclear model code TALYS-1.4.

A.J. Koning et al. [6] developed a versatile nuclear reaction code which has opened up options forcalculating cross-sections for various reaction channels. In the present, work (n,α) reactions cross-sections have been calculated for stable isotopes of heavy transition elements like Hafnium, Tungsten and its isotopes from 13-15 MeV of incident neutron energy by using nuclear reaction model code TALYS-1.4 and compared these with the existing experimental data values taken from EXFOR data library file as well as evaluated data files by Chadwick [7,8] in ENDF/B-VII.0 and ENDF/B-VII.I. The pre-equilibrium emission plays an important role in determining the (n,α) reactions cross-section and therefore we have studied the compound nucleus and pre-equilibrium components on these reactions. The main aim of this work is to check the predictive power of TALYS-1.4 to calculate the unknown cross-sections for some important nuclei reactions. This aim was accomplished by the consistency of the calculation method, cross checking of used parameters by the available

*Corresponding author e-mail: amitbadola555@gmail.com

experimental data, systematic studies and the trend of calculated results for that particular range of incident energies.

2 Hafnium and Tungsten in Reactor Technology

The excitation function of Tungsten and its isotopes by Kaugai et al. [9] and for Hafnium and its isotopes by Semkova et al. [10] demonstrates that these materials are widely used in fusion reactor technology. On assessing radioactive waste production in fusion reactors, neutron induced reactions on tungsten in reactor materials could leads to long lived isomeric states of Hafnium isotopes. Hafnium is used in reactor control rods as it has good absorption cross section for thermal neutrons and also has excellent mechanical properties. The estimation of the radioactive waste produced from tungsten and from many othermaterialsareconsideraslowactivationmaterialsforthefusi onreactorsconfirmthepresenceofHafniumas a product of neutron induced reactions. Various numbers of the neutron-induced reactions on Hafnium isotopes provides data sensitive to the strength functions, effective moment of inertia and the total cross-sections. However, the experimental data for neutron-induced reaction cross sections on hafnium isotopes are very scarce and comprise mainly the energy range around 14 MeV. On the other hand when 14 MeV neutrons are incident on pure tungsten produces various long lived and stable radio nuclides. The reliable cross sections of tungsten are required because it is the potential structure almaterial used in fusion reactors; however, the correctness of reported values is not enough therefore a number of computer codes have been developed to combine the statistical and pre-equilibrium theory for the purpose of data evaluation. The correct description of nuclear level density and other input parameters are pre-requisite for any code used to predict the cross section with the required accuracy.

3 Methodology

TALYS code can be executed manually using script. If we have created our own working directory with an input file named e.g. input, then a TALYS calculation can be easily started with talys¡input¿output.

The structure of mandatory input file:

Projectile	XX
Element	XX
Mass	XX
Energy	XX

Here for the calculations neutron is the projectile used, element is Hafnium,Tungsten and the iri sotopes, Energy is The incident energy of neutron in MeV which is taken from 13 MeV to 15 MeV. Out of the various given modes in TALYS, we used Excite on model in Preeq mode 2.We have also used ldmodel 2 which is Fermi back shifted model. Before running the code we have optimized the input file. InTALYS-1.4,we have used Idmodel5whichaccountsfor the microscopic nuclearlev eldensities from Hilaire' stable (Goriely et al.[11]) and preeq mode 2 which is an excit on model (Kalbach et al.[12]). The computed cross-sections together with the experimental data taken from EXFOR data library and data files namely ENDF/B-VII.0andlatest ENDF/B-VII.I file as shown in figures from Fig.1to Fig. 9

4 Results and Discussion

The results of the present investigation validate the input parameters for different neutron induced reactions on different stable isotopes of heavy transition elements of Hf and W. In the present work, the model based calculations are done by using nuclear reaction code TALYS-1.4 in the energy range from 13 MeV to 15 MeV and the results are compared with different experimental values taken from EXFOR data library and data files namely ENDF/B-VII.0 for Tungsten and ENDF/B-VII.I for Hafnium.

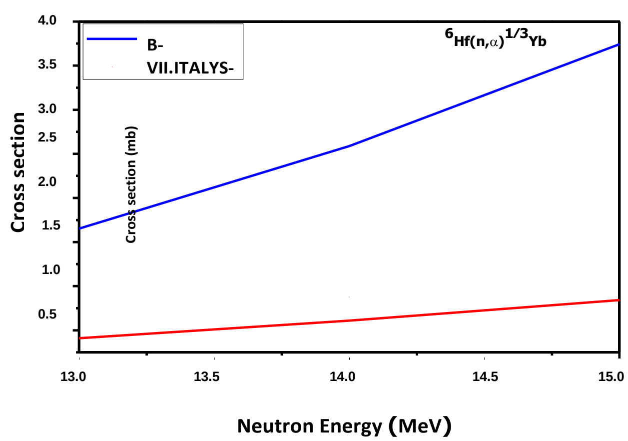

Fig. 1: Excitation function of the 176Hf(n,α)173Ybreaction.

We have studied nine (n,α) reactions on different isotopes of Hf and W. There are no experimental data found for^{176}Hf(n,α)^{173}Yb,^{177}Hf(n,α)^{174}Yband ^{179}Hf(n, α)^{176}Yb reaction (as shown in Fig.1Fig.2and 4).
Limitation of activation technique due to unsuitable half-lives of product nuclei, uncertain decay scheme and unavailability of intense mono energetic neutron source account for this lack of data. Fig.3shows excitation function of ^{178}Hf(n, α)^{175}Yb reaction, from 13 MeV to15 MeV. For a large experimental data with recent one available that of Kong et al.[13] and Coleman [14] shows a close agreement with the present work whereas results obtained by Konno et al.[16,15] are in little disagreement with our results and therefore open for theorists for further understanding. Fig.5show excitation function of ^{180}Hf (n, α)^{177}Yb reaction. A very good agreement exists between present results and the data of Konno et al.[15], Kong et al.[13] and the data

obtained by Konno et al.,(1990) around 15 MeV while the data point of Hillman et al.[17] is higher or in disagreement. From Fig.3& Fig.5it has been shown that ENDF/B-VII.I values are in good agreement with our calculated values with pre- equilibrium exist on model. Avery good agreement exists between present results and the data of A.A. Filatenkov et al.[18] for the ^{180}Hf(n, α)^{177}Yb reaction around 15 MeV and higher neutron energy. Fig.6and fig.7 show excitation function of ^{182}W (n, α) ^{179}Hfand^{183W} (n, α)^{180}Hf reactions. ENDF/B-VII.0 values in both cases are in good agreement with our calculated values with pre-equilibrium exciton model. There are no sufficient experimental data for the given reactions however the data has been obtained recently by Avrigeanu et al. [19] and Qaim et al.[20] in fig.6 & 7 did not match to our values in this appropriate energy range of 13 MeV to 15 MeV. Fig.8show excitation function of^{184}W (n,α)^{181}Hfreaction. A very good agreement exists between present results and the data of Kasugai et al.[9] and Kasugai et al. [19] as the data obtained by them exactly matches with our values. Some of the experimental values calculated by Avrigeanu et al. [19], Grallert et al. [22], Qaim et al. [20] and Lindner et al.[23] also in good agreement with our values between the energy range of 13 MeV to 15 MeV.Fig.9show excitation function of ^{186}W(n, α)^{183}Hf reaction. The various experimental values obtained by Avrigeanu et al.

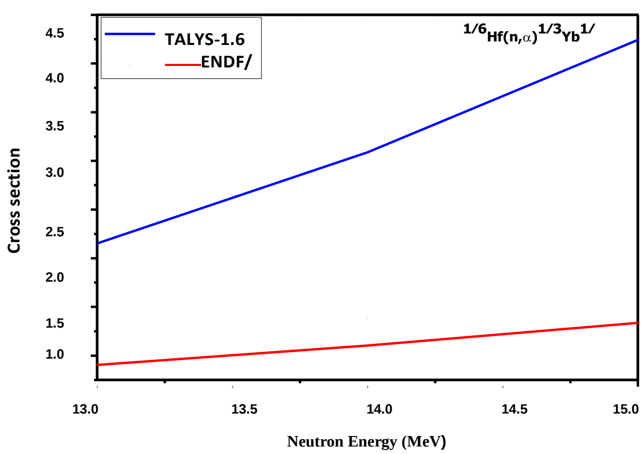

Fig. 2: Excitation function of the ^{177}Hf(n,α)^{174}Y b reaction.

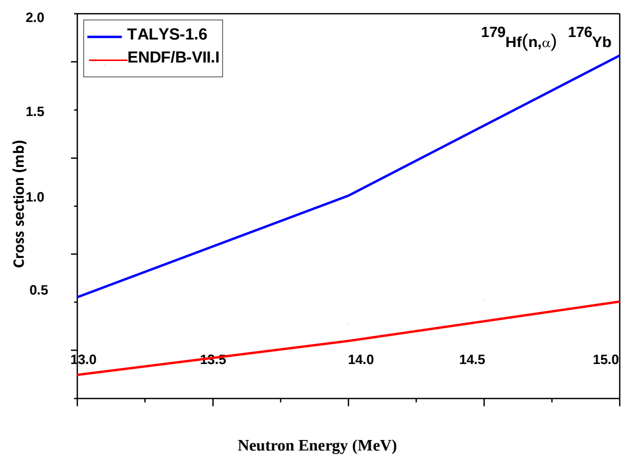

Fig. 4: Excitation function of the ^{179}Hf(n,α)^{176}Yb reaction.

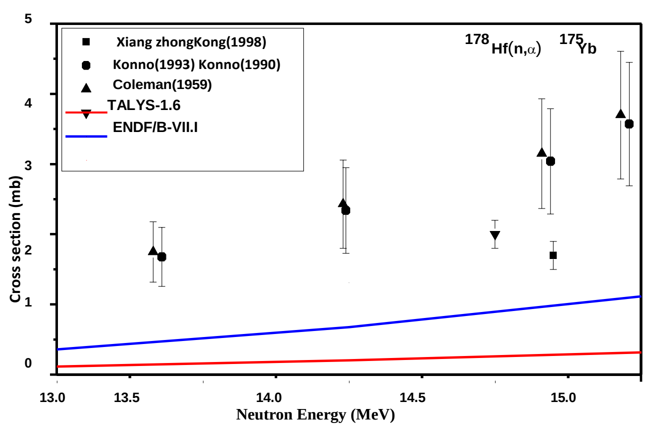

Fig.3: Excitation function of the^{178}Hf (n,α)^{175}Y b reaction.

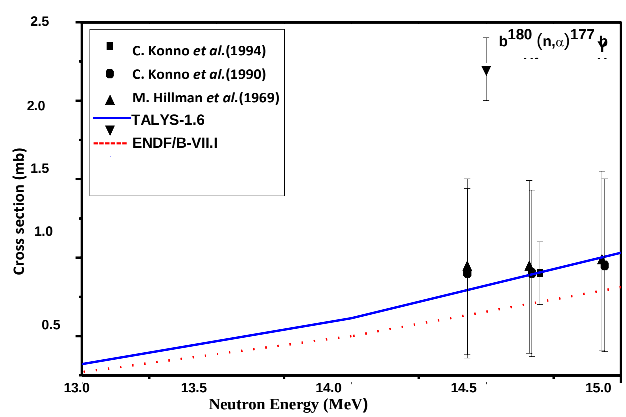

Fig. 5: Excitation functions of the ^{180}Hf (n, α) ^{177Yb} reaction.

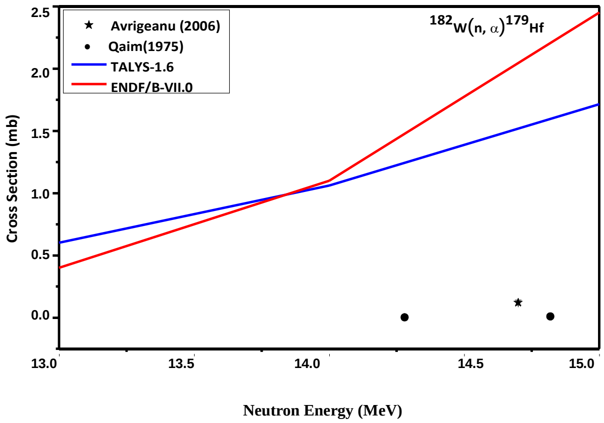

Fig. 6: Excitation functions of the ^{182}W (n, α) ^{179Hf} reaction.

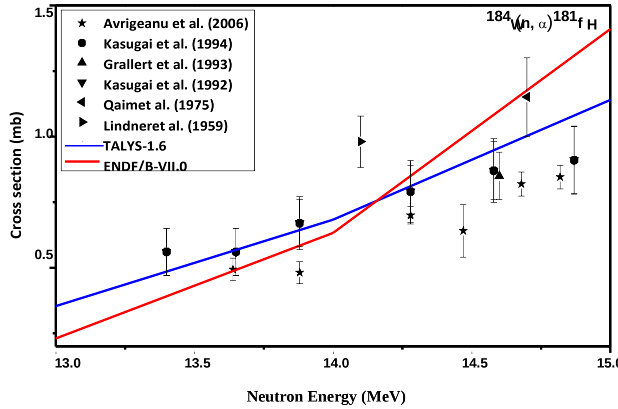

Fig.8: Excitation functions of the ^{184}W (n, α) ^{181Hf} reaction.

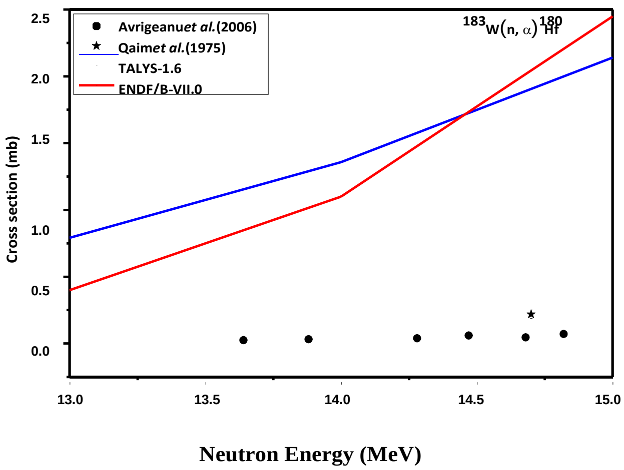

Fig. 7: Excitation functions of the ^{183}W (n, α) ^{180}H freaction.

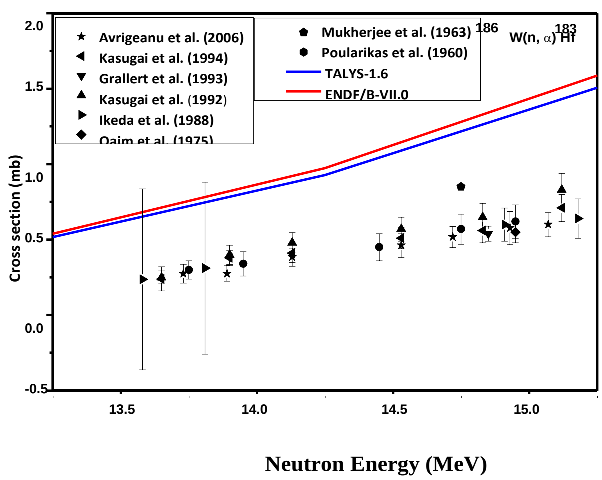

Fig. 9: Excitation functions of the ^{186}W (n, α) ^{183Hf} reaction.

[19],Kasugaietal.[9]Grallertetal.[22]Kasugaietal.[21]Ikedaet al.[24]Qaimetal.[20]Mukherjeeetal.[25] and Poularikas et al. [26] are also in good agreement and slightly matches with our values between the energy range of 13 MeV to 15 MeV. From Fig.8and fig.9 it has been shown that ENDF/B-VII.0 values are in good agreement and best matches with our calculated values with pre-equilibrium exciton model.

5 Conclusions

In the present work an important improvement in description of (n,α) cross section has been obtained. This improvement is due to the simultaneous introduction of pre-equilibrium process. The (n, α) reaction cross section is calculated for hafnium, tungsten and its stable isotopes theoretically by using TALYS 1.4. The model based calculations are done by using nuclear reaction code TALYS-1.4 The model based calculations are done by using nuclear reaction code TALYS-1.4 in the energy range from 13MeV to 15MeV and the results are compared with different experimental values taken from EXFOR data library and data files namely ENDF/B-VII.0 & ENDF/B-VII.I. From the results, it is concluded that Back-shifted Fermi gas model level density calculations is appropriate in this energy range i.e. from 13 MeV to 15 MeV for the studied nuclides. It is also concluded that the folding approach for alpha optical model potential are suitable for studied nuclides in this incident neutron energy range. It is further concluded that the pre-equilibrium exciton model is suitable to calculate pre-equilibrium contribution to total (n,α) reaction cross-section. It has also been concluded that Hafnium, Tungstenandtheiriso to pesare widely used as reactor materials and various other applications instead of that there is less experimental data for these materials. From this analysis it has also been confirmed that the consistency of calculated results with experimental data and systematic demonstrate the predictive power of TALYS-1.4 code to predict the cross-section for the remaining isotopes of Hafnium and Tungsten, where no experimental data is available for targetnuclei.

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