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Analysis of reaction cross-section production in neutron induced fission reactions on uranium isotope using computer code COMPLET

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HIGHLIGHTS

- Theoretical calculation of reaction cross-section using Computer code COMPLET.
- Experimental data base verifications using EXFOR, nuclear reaction cross-section data center.
- Comparison of the calculated reaction cross-section values with the experimental data.

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ABSTRACT

This study provides current evidence about cross-section production processes in the theoretical and experimental results of neutron induced reaction of uranium isotope on projectile energy range of 1–100 MeV in order to improve the reliability of nuclear stimulation. In such fission reactions of ^{235}U within nuclear reactors, much amount of energy would be released as a product that able to satisfy the needs of energy to the world wide without polluting processes as compared to other sources. The main objective of this work is to transform a related knowledge in the neutron-induced fission reactions on ^{235}U through describing, analyzing and interpreting the theoretical results of the cross sections obtained from computer code COMPLET by comparing with the experimental data obtained from EXFOR. The cross section value of $^{235}U(n,2n)^{234}U$, $^{235}U(n,3n)^{233}U$, $^{235}U(n,\gamma)^{236}U$, $^{235}U(n,f)$ are obtained using computer code COMPLET and the corresponding experimental values were browsed by EXFOR, IAEA. The theoretical results are compared with the experimental data taken from EXFOR Data Bank. Computer code COMPLET has been used for the analysis with the same set of input parameters and the graphs were plotted by the help of spreadsheet & Origin-8 software. The quantification of uncertainties stemming from both experimental data and computer code calculation plays a significant role in the final evaluated results. The calculated results for total cross sections were compared with the experimental data taken from EXFOR in the literature, and good agreement was found between the experimental and theoretical data. This comparison of the calculated data was analyzed and interpreted with tabulation and graphical descriptions, and the results were briefly discussed within the text of this research work.

1. Introduction

Neutron induced reaction cross-section (T´ark´anyi et al., 2014:Naik et al., 2017) database provides a fair chance to develop a theoretical tool to predict competing reaction cross-section. Fission reaction is a special kind of nuclear reaction (Kaplan, 1962; T´ark´anyi et al., 2014) in which a heavy nucleus such as uranium breaks in to two or more lighter nuclei. This was discovered by Hahn and Strassman in 1939 (Ermias and Gizachew, 2012; Kailas and Mahata, 2014). When a fission reaction is generated by a bombardment of an incident neutron on uranium isotopes (Timo, 2010; Ayhan, 2017), a large amount of energy would be released with fission fragments. Neutron induced fission cross-section data (Kaplan, 1962; T´ark´anyi et al., 2014; Naik et al., 2017) provide a sound basis to extract fission barrier parameters elaborated level density modeling approach and check it's validity up to 100 MeV (Maslov, 2000).

In the case of ^{235}U, 6.2 MeV has to be added to ^{236}U in order to have a fission process (Roy and Nigam, 1967). Nuclear theory, using quantum mechanics, is used to predict the probability that a specific nuclear process will occur under certain conditions. The quantitative measure of this prediction is the cross section of the process. This cross section may be measured in the laboratory using experimental

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techniques that have been strongly developed in the last decades, investigating nuclear reactions involving radioactive nuclei and playing a crucial role in many areas of basic and applied nuclear sciences (Escher, 2008).

As to the report of Opera et al. (2014), theoretical and experimental reaction cross section values obtained for nuclei has been used in many fields of sciences, and one of great interest nowadays is the nuclear meeting ground between theory and experiment. Similarly, Anne (2009) also ratified that some theoretical and experimental research work has been conducted on nuclear reactions induced by energetic neutrons. Nuclear reaction cross-sections (Sneh and Mohindra, 2006; Hodgson, 1972) are intrinsically very complicated and yet in some circumstances they can be treated quite successfully by appropriate models. Broeders et al. (2006) also uncertain calculations of cross-section, for reactions induced by neutrons with energy above 0.1 MeV using nuclear models and computer codes having direct relations to the generation of nuclear data files, and comparisons of the experimental data with evaluated cross-sections from nuclear data files. Even up to this day, prescription and comparison of the calculated cross-section (Özdoğan et al., 2016; Naik et al., 2017;) of the theory with the experimental data allows the validity of these models to be assessed, but lacks to give scientific based evidences how to compare the theoretical and experimental nuclear reaction cross-sections.

Taking this problem as research gap, comparison between theoretical prediction and measurement is used to evaluate the significance of the underlying theory as no earlier and clear theoretical reaction cross-sections comparison mechanisms with the experimental one were found in the literature. On the other hand, theoretical calculations are desirable to fill the gaps (Maslov, 2000) for nuclei where fission cross-section data (Kaplan, 1962; T´ark´anyi et al., 2014: Naik et al., 2017) are lacking. Studying neutron capture (Dorsett and Krane, 2015) by radioactive nuclei presents considerable challenges compared with captures by stable nuclei.

A uranium isotope (^{235}U) bombarded with a neutron breaks into two intermediate mass nuclear fragments such as:

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n \quad (1) $$

The gain in binding energy for a nucleon is about 0.9 MeV. Hence, the total gain in binding energy is 240 × 0.9 or 216 MeV (Krane, 1987). The original theory of the fission process was developed on the basis of the liquid-drop model (Roy and Nigam, 1967; Kailas and Mahata, 2014). This model (Kailas and Mahata, 2014) of a nuclear fission is the consideration of a nucleus to be analogous to a charged liquid drop. The drop is considered to deform from a spherical shape into dumbbell shaped on an axis of symmetry (Roy and Nigam, 1967; Gary, 2012).

Different nuclear model (Herman et al., 2007) parameters were adjusted, within their recommended limits, to obtain a good agreement between the theory and experiment (Aslam et al., 2015). Fission is modeled by a gradual transition of the molecules from an initial compact shape to such an elongated shape that the nucleus breaks into two fragments (Kailas and Mahata, 2014).

2. Materials and methods

2.1. Stimulation techniques using computer code COMPLET

The computer code COMPLET has been used for the calculation of ^{235}U(n,2 n)^{234}U, ^{235}U(n,3n)^{233}U, ^{235}U(n, γ)^{236}U, ^{235}U(n, f) nuclear reactions (Ayhan, 2017; Naik et al., 2017; Yaling e al, 2017) cross-section induced from projectile energy range of 1–100 MeV. Commercially available neutron sources (Arai and Crawford, 2009; James and Cynthia, 2002; Yaling et al., 2017; Ridikas and Mitt, 1998) are: (1). nuclear reactor sources, (2). large accelerator-based neutron sources, (3). fast neutron generators, (4). cyclotrons and (5). Isotopic neutron sources.

The stimulated results were compared with the experimental values taken from the EXFOR database (Ayhan, 2017; Author et al., 1979). COMPLET and EXFOR were preferable in order to gather the theoretical & the experimental data respectively. EXFOR **(**Author et al., 1979; Sneh and Mohindra, 2006; Brunetti et al., 2004**)** is the exchange format for the transition of experimental reaction data between national and international nuclear data centers for the benefit of nuclear users in all countries. It is the library and format for the collection, storage, exchange and retrieval of experimental nuclear reaction data (Ayhan, 2017).

2.2. Computer code COMPLET

Various computer codes were developed based on different models, which are enable to study nuclear structure and reaction mechanisms. The computer code COMPLET is an improved version of earlier computer codes and is very important for several technical applications if the experimental data are not available or unable to measure the reaction cross-sections due to the experimental difficulties. This code is capable of calculating equilibrium and pre-equilibrium emission cross-section, and valid for excitation energy of the compound nucleus (Escher, 2008) up to 300 MeV.

2.3. Data analysis procedure

The data of this work has been arranged in proper orders & organized by using tabulation **(**Tables 1–4**)** method. These organized data, described graphically with the help of Origin-8 and spreadsheet, analyzed and interpreted accordingly by comparing with the experimental data.

3. Results and discussions

The computed reaction cross-sections (Naik et al., 2017) based on the neutron energy using different approaches for uranium isotope are listed in Tables (1–4) along with the available experimental cross-sections. Such comparison of calculated and experimental reaction cross-sections is especially important because reaction model calculations have to be used to estimate important cross-section for applied purpose, which is difficult to measure.

Several isotopes (Aslam et al., 2015) having half-lives either too short or too long were not observed due to the constraints imposed by available experimental data taken from EXFOR databank, IAEA. The theoretical and experimental reaction channels (Sneh and Mohindra,

Table 1
The theoretical and experimental total cross-section depends on projectile energy of ^{235}U (n,2n)^{234}U fission reaction.

Projectile Energy *(Mev)*	Total cross-section (mb)	
	Theoretical value	Experimental data
5.73 ± 0.09	0	4 ± 24
5.98 ± 0.09	19.2 ± 0.228	128 ± 23
6.49 ± 0.085	64 ± 0.125	273 ± 30
7.01 ± 0.08	195.16 ± 0.072	355 ± 32
7.52 ± 0.075	332 ± 0.055	463 ± 34
8.03 ± 0.075	347 ± 0.054	482 ± 38
8.54 ± 0.07	598 ± 0.041	614 ± 52
9.04 ± 0.065	676 ± 0.039	642 ± 43
9.55 ± 0.065	712 ± 0.037	734 ± 48
10.0 ± 0.06	737 ± 0.037	772 ± 55
10.56 ± 0.06	817 ± 0.035	775 ± 55
11.07 ± 0.055	809 ± 0.036	857 ± 66
11.57 ± 0.055	793 ± 0.035	870 ± 71
12.08 ± 0.055	753 ± 0.036	857 ± 85
12.58 ± 0.05	733 ± 0.037	863 ± 109
13.09 ± 0.05	619 ± 0.04	717 ± 110