STUDY OF NEUTRON INDUCED REACTIONS OF DIFFERENT MATERIALS FOR REACTOR APPLICATIONS

A Synopsis Submitted

To

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

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IN

PHYSICS

By

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Introduction:

Efficient, cost-effective and environmentally suitable energy resources (renewable energy, nuclear power, and biofuels) are required to improve the standard of living worldwide. Towards the end of the 21st century, fission and fusion energy could be crucial components of an overall energy portfolio. Currently, about 15% of the world's electricity has been supplied by more than 430 nuclear fission reactors in around 30 countries [1]. Similarly, in the case of fusion facilities, recently National Ignition Facility (NIF) work has been completed and International Thermonuclear Experimental Reactor (ITER) is in under construction stage [2, 3].

A diverse range of structural materials is used in fission devices which include materials of nuclear fuel, moderators, control rods, neutron reflectors and shielding components. Nuclear fuel includes ^{235}U, ^{239}Pu and ^{233}U isotopes. Moderator includes D_2O, H_2O, lithium (Li) and beryllium (Be). Control rods are made of graphite, beryllium (Be), cadmium (cd) and boron carbide. The shielding materials are water, paraffin, polyethylene, lead (Pb), Iron (Fe), tungsten (W), lead (Pb) and concrete [4]. Similarly, in a fusion reactor, a variety of materials are present in the Plasma Facing Components (PFCs), test blanket module (TBM), super-conducting magnets, vacuum vessel, and bio-shield as well as in many other components. PFCs include Be, W and Cu/Cu alloy (Cu Cr Zr, CuAl25). TBM materials is made of Be, Li_4SiO_4, Li_2TiO_3, Pb-Li (breeder), the Eurofer reduced activation steel (Fe, Cr, W, Ta, V, Mn, C, and minor elements) and the He coolant. The shield modules and the vacuum vessel, e.g., are made of SS-316L (N) with Fe, Cr, Ni, Mo, Mn, C, N as major constituents, SS 30467 (2w% B) with Fe, Cr, Ni, Mo, Mn, B, C, N, P, S, and H_2O. The super-conducting magnet encompasses the super-conducting strand with Cu, Nb, Sn, Ta, Ti and Cr, the normal conducting Cu wire, the helium coolant and the Epoxy resin insulator with Si, O, B, Al, H and C as the main elements [5-7].

The reactor materials experience extremely harsh temperatures and neutron-loading environments during reactor operational time. Therefore accurate knowledge of nuclear data is necessary for the development of reactor technologies. They are important for (i) the design and operation of fission-fusion reactors and accelerators, (ii) shielding design for safety operations, and (iii) to check the performance of current fission power plants, Accelerator Driven Subcritical Reactor Systems (ADS) and for future Generation-IV concept based reactors [8-12]. They are also important for production and transmutation studies of radioactive waste in reactors and radiation damage studies due to the interaction of energetic ions and neutrons with the reactor materials. In fission-fusion reactors, neutrons are produced in a wide

energy range. These neutrons penetrate through various materials which leads to changes in the physical, chemical and mechanical properties of the reactor materials. Therefore the neutron induced reaction cross section data plays a vital role in selection and design of the reactor component materials [13, 14].

Literature survey and nuclear data:

The energetic neutrons produced in fission-fusion reactions interact with the surrounding materials creating defects during the operation of the reactors decreases the lifetime of the components. These energetic neutrons interact with the materials which open (n, γ), (n, n'), (n, p), (n, 2n), (n, α) reaction channels. A literature survey shows that various experimental work regarding neutron induced reactions has been carried out to study the behaviour of the reactor materials in the low to high neutron energy range. According to the importance of materials for the study of reactor devices, the need of neutron induced cross section data of materials like Be, Pb, Li, W, Cr, Ta, V, Fe, Sr, Zr, Nb, Y, Rb, etc. assigned to have highest priority reported in the literature [7, 13, 14].

In fusion reactor, tungsten is considered as a prime material used in plasma facing components. Literature shows that there is a discrepancies in the neutron induced capture cross section of ^{186}W-isotope in the energy range from 0.1 to 6 MeV. Similarly, for ^{186}W-isotpe, very few (n, γ) reaction cross section data reported in the energy range from 6 to 14 MeV and around 14.1 MeV neutron energies there is a scarcity in cross section data available in EXFOR data base [15].

Zirconium (Zr) and its alloys have been extensively used as cladding material of fuel elements in fission reactors and also structural materials in fusion reactors. These elements have also been used as nuclear fuel pellet in the design of accelerator-driven sub-critical system (ADSs). The ^{90}Zr (n, 2n)^{89}Zr reaction have cross section data available from threshold to 20 MeV neutron energy and published. For ^{90}Zr(n, p)^{89m}Y reaction, the cross section data are available except, few data available in neutron energy range from 6 to 14 MeV [15].

The detailed literature survey of (n, 2n) reaction cross section of Nb, Sr isotopes indicated that the data are available in the neutron energy range from threshold to 20 MeV. In case of ^{86}Sr(n, 2n)^{85}Sr reaction, the available experimental cross section data are scattered from threshold to 20 MeV neutron energy range. Similarly, literature survey of (n, 2n) and (n, p) reactions of ^{85}Rb shows that the experimentally measured cross section data are cluttered from threshold to 20 MeV neutron energies [15].

The extensive experimental work of neutron induced reaction cross section measurement of reactor materials has been carried out and published in various kinds of literature showing that the need for cross section data of these materials is important with precision in the reaction threshold to high neutron energy range for the design of reactors and accelerators. During the operation of reactors, different reaction channels open as the energetic neutrons interact with the surrounding materials. The present scenario indicated that the availability of cross section data for these materials is limited and has discrepancies for various materials. Therefore the experimental work of neutron-induced reaction cross section measurement for different materials and reaction cross section will fill the gap and provide the data with accuracy.

Objective:

The objective of the present thesis work is as follows;

- The measurement of neutron capture reaction cross section of different materials like tungsten (W) used in Plasma Facing Components (PFCs) and target material in accelerator driven subcritical system (ADS) was done in the neutron energy range 0.6 to 3.2 MeV at Folded Tandem Ion Accelerator- Bhabha Atomic Research Centre (FOTIA-BARC) facility.

- The (n,2n) and (n,p) reactions cross section of zirconium (Zr), rubidium (Rb) used in structural materials and niobium (Nb), strontium (Sr) materials used in superconducting magnets were determined in the range from 10 to 20 MeV at 14UD Tata Institute of Fundamental Research - Bhabha Atomic Research Centre (TIFR-BARC) Pelletron facility. The quasi mono-energetic neutrons were produced by ^{7}Li(n, p)^{7}Be reaction.

- A detailed uncertainties measurements, propagate from attributed considered for cross section measurement was done using covariance analysis for the selected reactions.

- Theoretically, the reactions cross section of selected materials were predicted by using TALYS and EMPIRE codes with optimized input parameters. The experimental results were compared with the previously reported data available in the EXFOR data library, the evaluated data and also with the predicted data by TALYS and EMPIRE codes.

Plan of Thesis:

An overview of the thesis compiled in six chapters as below:

Chapter-1: Introduction

This chapter started with preamble about need of cost-effective and sustainable energy source in today's century and importance of advancement in development of recently active fission reactors, in-built fusion devices and accelerators. This chapter gives the insight idea about the work carried out different authors regarding requirement of accurate nuclear data for development of fission-fusion reactors and accelerator technologies. It also gives the information regarding how the interaction of neutral and charged particles takes place during operation of reactors. The chapter concludes by giving information behind the work performed and the problems addressed in the thesis.

Chapter-2: Experimental Methodology

This chapter gives the details of the particle accelerators and neutron sources used for irradiation experiments in FOTIA-BARC and TIFR-BARC Pelletron facilities. The chapter describes the preliminary details of the neutron activation analysis and gamma ray spectroscopy method used to measure the reaction cross section of different materials. It also gives the details of the efficiency and energy calibration of HPGe detector used to record and analyse the γ-ray spectrum of various nuclides.

Chapter-3 Theoretical Calculations

In this chapter, a detailed description of TALYS and EMPIRE nuclear codes is given which predicts the reaction cross sections. These two codes use various input parameters like nuclear models, and level density models. A brief discussion has been given in this chapter regarding details of parameters used to predict the reactions cross section of selected target materials in the present work. The structure of input data files has been presented for both the codes.

Chapter-4 Neutron capture cross section measurement for tungsten isotope in the neutron energy range 0.6 to 3.2 MeV

This chapter describes the neutron induced capture reaction cross section measurement of ^{186}W isotope using activation and off line γ-ray spectroscopic method. The low energy neutrons are generated by ^{7}Li(p, n) reaction in FOTIA facility. A detailed calculations of the uncertainties propagate from the parameters involved in the measurements of the detector efficiency and the reaction cross sections were presented with covariance and correlation matrix.

Chapter-5 Neutron induced reaction cross section measurement for zirconium (Zr), niobium (Nb), strontium (Sr) and rubidium (Rb) isotopes up to the energy of 20 MeV

This chapter describes the experimental work carried out for the cross section measurement of (n, 2n) and (n, p) reactions of Zr, Nb, Sr and Rb isotopes. In this work, the experiments has been carried out at a 6-meter TIFR-BARC Pelletron facility in which neutrons are produced by ^{7}Li(p, n) reaction. The measured cross sections were presented with uncertainties, covariance and correlation matrix.

Chapter-6 Summary and Conclusion

This chapter describes a brief summary of research work carried out in the present work along with the future works.

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LIST OF PUBLICATIONS IN PEER-REVIEWED JOURNALS

[1]. **Neutron capture cross section of ^{186}W isotope in the energy range from 0.6-3.2 MeV with covariance analysis**

Mayur Mehta, N. L. Singh, A. Gandhi, P.V. Subhash, Rebecca Pachuau, Ratankumar Singh, R. Makwana, S.V. Suryanarayana, B. K .Nayak, H. Naik, K. Katovsky

Radiation Physics and Chemistry, RPC-D-23-01362 (In Review)   Impact Factor = 2.9

[2]. **Activation cross section for ^{85}Rb(n,p)^{85m}Kr and ^{85}Rb(n,2n)^{84m}Rb reaction with uncertainty propagation and covariance analysis**

Mayur Mehta, N. L. Singh, Ratankumar Singh, R. Makwana, P. V. Subhash, Rakesh Chauhan, B. K. Soni, S.V. Suryanarayana, H. Naik, R. Palit, K. Katovsky

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[3]. **Measurement of ^{85}Rb(n,2n)^{84m}Rb reaction cross section at 15.72±0.59 and 16.73±0.66 MeV**

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IEEE Xplore Conference Proceedings (EPE-2023), pp. 237-4 (2023)

Impact Factor = 3.557

DOI: 10.1109/EPE58302.2023.10149237

[4]. **Cross section of (n,2n) reaction for Niobium and Strontium isotopes between 13.97 to 20.02 MeV neutron energies**

Mayur Mehta, N. L. Singh, Ratankumar Singh, Rakesh Chauhan, Rajnikant Makwana, S. V. Suryanarayana, H. Naik, P. V. Subhash, S. Mukherjee, Jan Varmuza, Karel Katovsky

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[5]. **Measurement of ^{90}Zr(n,2n) ^{89}Zr and ^{90}Zr(n,p)^{90m}Y reaction cross sections in the neutron energy range of 10.95 to 20.02 MeV**

Mayur Mehta, N. L. Singh, R. K. Singh, Siddharth Parashari, P. V. Subhash, H. Naik, R. D. Chauhan, R. Makwana, S. V. Suryanarayana, S. Mukherjee, A. Gandhi, J. Varmuza And K. Katovsky

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[1]. **Activation cross section for the (n,2n) and (n,p) reactions on ^{103}Rh, ^{48}Ti and ^{52}Cr from reaction threshold up to 25 MeV energy region**

R. K. Singh, N. L. Singh, **Mayur Mehta**, Rakesh Chauhan, S.V. Suryanarayana, Rajnikant Makwana, B. K. Nayak, H. Naik, Jan Varmuza, K. Katovsky

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[2]. **Measurement of neutron capture cross section on ^{71}Ga at 2.15 and 3.19 MeV and uncertainty propagation and covariance analysis***

Rebecca Pachuau, A. Gandhi, Namrata Singh, A. Kumar, **Mayur Mehta**, S. V. Suryanarayana, L. S. Danu, B. K. Nayak and B. Lalremruata

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[3]. **Cross sections for production of ^{115m}In by quasi-mono energetic neutrons within 7-20 MeV**

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Radiation Physics and Chemistry 199, 110270 (2022)   *Impact Factor = 2.776*

DOI: https://doi.org/10.1016/j.radphyschem.2022.110270

[4]. **Cross section measurement of the ^{114}Cd(p,γ)^{115m}In reaction for nuclear reactor and astrophysical applications**

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Bhargav K. Soni, Siddharth Parashari, Rajnikant Makwana, S. Mukherjee, **M. Mehta**, R. Chauhan, S.V. Suryanarayana, I. Pasha, B.K. Nayak, and K. Katovsky

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[14]. **Neutron capture cross sections for ^{159}Tb isotope in the energy range of 5 to 17 MeV**

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S. Parashari, S. Mukherjee, A. P. Singh, V. Vansola, H. Naik, B. K. Nayak, R. Makwana, S. V. Suryanarayana, N. L. Singh, **M. Mehta**, Y. S. Sheela, M. Karkera, R. D. Chauhan, S. C. Sharma,

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DOI: 10.1103/PhysRevC.96.024608

LIST OF CONFERENCE PROCEEDINGS

[1]. **Measurement of ^{85}Rb(n,2n)^{84m}Rb reaction cross section at different neutron energies**
N. L. Singh, **Mayur Mehta**, Ratankumar Singh, P. V. Subhash, Rajnikant Makwana, Rakesh Chauhan, Bhargav Soni, H. Naik, S. V. Suryanarayana, J. Varmuza, K. Katovsky

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[2]. **Measurement of ^{88}Sr(n,2n)^{87m}Sr reaction cross section using activation method**
Mayur Mehta, N.L. Singh, P.V. Subhash, Ratankumar Singh, Rakesh Chauhan, R. Makwana, S.V. Suryanarayana, H. Naik, S. Sharma

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[3]. **Experimental and theoretical study of the ^{65}Cu(n,p)^{65}Ni reaction cross section from threshold to 25 MeV energies**

R. K Singh, N. L. Singh, Rakesh Chauhan, **Mayur Mehta**, S. V. Suryanarayana, Rajnikant Makwana, S. Mukherjee, B. K. Nayak, H. Naik, J. Varmuza, K. Katovsky

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[4]. **Experimental and theoretical cross sections of ^{115}In(n,n′) reaction at 19 and 16 MeV using quasi-mono energetic neutrons**

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[5]. **Excitation function of the ^{71}Ga(n,γ)^{72}Ga reaction cross section in the incident neutron energy range 0.6-3.1 MeV**

Rebecca Pachuau, A. Gandhi, Namrata Singh, **Mayur Mehta**, L. S. Danu, S. V. Suryanarayana, B. K. Nayak, A. Kumar, B. Lalremruata

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[6]. **Measurement of isomeric cross section at energy of astrophysical interest**

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