Chapter 1

Introduction

Nuclear reactions are fundamental to various fields, including nuclear power generation, medicine, space exploration, and nuclear astrophysics. This chapter focuses on neutron and charged particle-induced nuclear reactions, emphasizing their role in understanding stellar energy production and nucleosynthesis—the processes that create elements in stars. The study also addresses practical applications, such as nuclear reactors, where structural materials and control rods are critical for safety and efficiency. The chapter emphasizes the critical role of accurate nuclear reaction cross-section data, especially in the development of cutting-edge technologies such as fusion reactors and Accelerator-Driven Systems (ADSs). It also delves into nuclear astrophysics, exploring how nuclear reactions drive stellar evolution and lead to the creation of elements, including the elusive p-nuclei.

1.1 Overview

Nuclear reactions are crucial for nuclear power generation, radiation therapy, medical applications, space exploration, and more. The nuclear reactions are essential not only from a nuclear physics perspective but also for understanding stellar energy production and the process of element formation, known as nucleosynthesis. Nuclear reactions are regarded as the engines powering stars, governing the structural formation, evolutionary pathways, and elemental composition of a wide range of cosmic bodies, including those within the solar system. The current study is focused on nuclear reactions which are induced by neutron and charged particle and the study of astrophysics from nuclear physics perspective called Nuclear Astrophysics.

In developing countries, there is a growing demand for clean and efficient electricity, leading to an increased interest in nuclear reactors as a viable option. While nuclear reactors can produce affordable clean energy, they also generate radioactive waste, which poses a significant drawback. This issue can potentially be addressed by employing a high neutron flux accelerator to convert the waste into stable nuclei. However, to expand the usage of reactors, a comprehensive understanding of safety aspects is essential. This includes rigorous safety protocols, thorough risk assessments, and continuous monitoring and maintenance.

Structural materials are essential for ensuring both the safety and performance of reactors. Structural materials are vital for the functioning of nuclear reactors, as they need to possess radiation resistance and long-term durability. Given their usage in the reactor structure, these materials are exposed to neutron irradiation resulting from fission or fusion processes. Unfortunately, data on structural materials used in reactor applications are sometimes insufficient and show significant discrepancies. Hence, a comprehensive and accurate cross-section data library is imperative. This data is of utmost importance for the development of ITER (International Thermonuclear Experimental Reactor) [1] and the advancement of Accelerator-Driven Systems (ADSs)[2].

In conjunction with the selection of appropriate structural materials, the control rods play a critical role in maintaining reactor stability and safety. Control rods are adjusted within the reactor core to regulate the rate of nuclear reactions and control the power output. Absorbing neutrons, control rods effectively manage the chain reaction and keep the reactor semi-critical. Consequently, accurate understanding of the control rod's material composition and its neutron interaction cross-sections is of critical importance [3].

Deuterium-tritium $(\mathrm{D-T})$ fusion reaction produces high-energy neutrons with an energy of 14 MeV. These energetic neutrons impart their energy to the breeding blanket and the first wall of the reactor system. Therefore, there is a significant demand for precise neutron data around 14 MeV, specifically for reactions such as (n, p), (n, α), and (n, 2n) [4]. To obtain high-precision data, significant experimental measurements, rigorous calculations, and thorough evaluations of the reaction cross-sections have been carried out. However, there is a substantial difference between the experimental data obtained for structural materials in fusion reactors and the evaluated data available from various databases at the same incident neutron energy. Consequently, acquiring precise activation cross-section data at neutron energies of 14-15 MeV is vital for the design, construction, and assessment of fusion reactors. However, in some cases, direct measurements of the data are not feasible or discrepancies arise among experimental results due to relative measurements and a lack of mono-energetic neutron sources. To overcome these challenges and achieve more accurate neutron-induced reaction cross-section data, a systematic approach or theoretical predictions are employed. These methods help to bridge the gaps in the data and provide reliable information for various scientific and practical applications.

Consequently, the present study aims to acquire accurate nuclear reaction cross-section data for the structural materials employed in reactors. This information will be crucial for advancing nuclear technology and promoting safer, more sustainable energy production.

Nuclear reactions are fundamental to the study of nuclear astrophysics. As these reactions act as a driving force for stars, affect how star develope, cause dramatic starbursts, and are the reason behind the creation of various elements. By simulating these reactions, we gain insights into how stars produce energy and form elements. The mystery surrounding the origin of chemical elements persisted until 1957, when E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle [5], along with A. G. W. Cameron [6], separately proposed the concept of nucleosynthesis as the explanation. Their research led to the creation of a new field called nuclear astrophysics, where techniques from nuclear physics are applied to solve problems in astrophysics [7]. All stable isotopes and those that are long-lived yet unstable are produced through various astrophysical processes, like stages of burning starting from hydrogen and helium and progressing through various stages such as triple-alpha process, neutron capture processes like s-process, r-process etc.

The elements beyond iron cannot be formed through nuclear fusion reactions and require different methods for their production. The elements with atomic numbers greater than iron are believed to be created through astrophysical processes known as s-process, r-process, and p-process. There are about 35 proton-rich stable isotopes located between ^{74}Se and ^{196}Hg that are not produced by the s- and r-processes [8]. These isotopes, termed p-nuclei, have origins that are still not fully understood. The origin of these nuclei can be explained by several processes summarized as p-process [9].

1.2 Advancing Nuclear Reactor Technologies

Energy is fundamental to technological advancement and sustainable economic development. However, escalating energy demand, climate change, and the depletion of natural resources present critical challenges, highlighting the need for the development of sustainable, carbon-free energy sources. Nuclear power is generated from the energy released during a range of nuclear processes, including fission, fusion, and the decay of radioactive isotopes. Nuclear energy demonstrates a high capacity for power generation while emitting significantly lower levels of greenhouse gases compared to alternative energy sources. As the world seeks cleaner energy alternatives to combat climate change, innovative nuclear technologies are emerging as vital solutions to meet global energy demands [10].

Nuclear reactors are categorized into generations (GEN: I, II, III, III+, IV) to indicate advancements in technology and safety. GEN I reactors, developed in the 1950s and 1960s, were early prototypes with limited safety measures originally designed for military applications. Later, some of these designs were adapted for commercial use, but they initially lacked comprehensive safety features. GEN II reactors, which include both light water reactors (LWRs) and heavy water designs, incorporate advanced active safety systems that enhance safety compared to GEN I reactors. They are equipped with automatic or manual safety features, employing electrical or mechanical operations. Their typical operational lifetime is about 40 years. After Chernobyl accident, GEN III reactors were designed with passive safety features that rely on natural convection and gravity to manage abnormal conditions. These advancements extend the reactors' operational lifespan to around 60 years. Generation III+ reactors, which were conceptualized in the late 1990s and further developed in the 2000s, offer improvements in safety and economic efficiency compared to earlier reactor designs. GEN II, III, and III+ reactors are currently operational worldwide. GEN IV reactors are still under development, are expected to offer improved efficiency, advanced safety features, reduced waste generation, and enhanced management of actinides. These reactors are designed for high-temperature operation, supporting applications like hydrogen production and water desalination [11]. Fig. 1.1 presents the evolution of nuclear reactor generations, highlighting projections for future technological developments [12].

To meet the growing energy demand, several advanced nuclear reactor technologies are under investigation, including fast reactors [13–15], advanced heavy water reactors (AHWRs) [16, 17], accelerator-driven sub-critical systems (ADSs) [18], Generation IV reactors [19], and nuclear fusion reactors [1, 20]. These innovations present substantial opportunities for enhancing nuclear power generation. Research is actively advancing the development of nuclear fusion reactors, which replicate the fusion processes occurring in the Sun. Fusion reactors promise a high-energy yield, long-term sustainability, and minimal environmental impact, as they do not produce greenhouse gases or acidic emissions. The

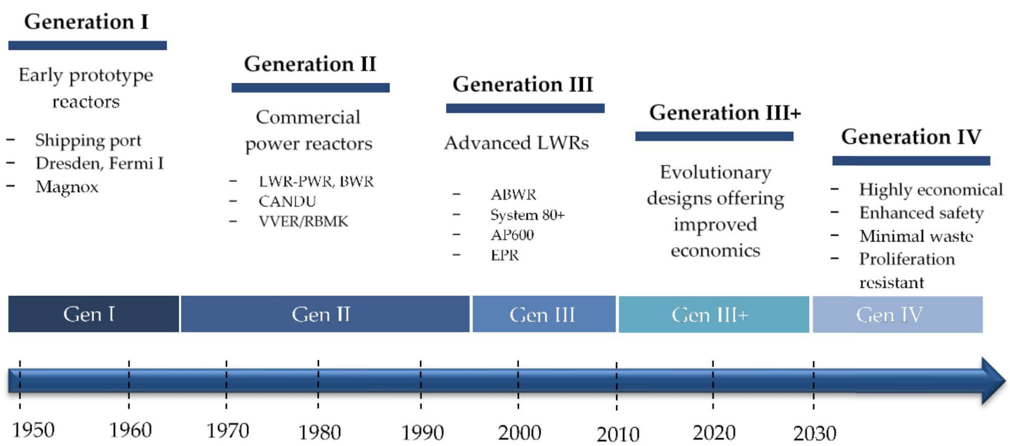

Fig. 1.1: Evolution of nuclear reactor generations, with future projections for technological advancements [12].

ITER (International Thermonuclear Experimental Reactor) [21], represents the first large-scale magnetic confinement fusion project. Its goal is to demonstrate the feasibility of producing clean, safe electrical power without generating long-lived radioactive waste, marking a major step toward practical fusion energy.

The present study is aimed at providing critical nuclear data required for the development and optimization of advanced nuclear technologies.

1.3 Nuclear Astrophysics

Nuclear astrophysics serves as an interdisciplinary domain that connects nuclear physics and astrophysics, focusing on the nuclear processes that influence the formation and evolution of celestial bodies and the universe as a whole. This field studies how nuclear reactions in stars and other astronomical environments lead to the synthesis of elements and isotopes, a process known as nucleosynthesis.

The various processes occurring in nuclear astrophysics can be broadly categorized based on the environments and conditions under which they occur. Each process contributes uniquely to the abundance and distribution of elements in the universe. Different nuclear processes on the chart of the nuclide is shown in Fig. (1.2). Key processes in nuclear astrophysics are highlighted here:

(a) Big Bang Nucleosynthesis (BBN)

BBN is a key process in nuclear astrophysics, facilitating the synthesis of light elements shortly after the Big Bang, as temperatures fell to levels conducive to nuclear reactions. In this phase, neutrons and protons fused to form $^{2}\mathrm{H}$, $^{3}\mathrm{He}$, $^{4}\mathrm{He}$, and trace amounts of $^{7}\mathrm{Li}$ and $^{7}\mathrm{Be}$. The resulting elemental abundances, especially the He/H ratio provide strong empirical support for the Big Bang model. BBN is highly sensitive to the baryon-to-photon ratio, neutron decay, and nuclear reaction rates, making it fundamental to understanding the observed chemical composition of the universe.

(b) Stellar Nucleosynthesis

Stellar nucleosynthesis is central to nuclear astrophysics, as it involves the nuclear fusion reactions within stars that synthesize elements heavier than hydrogen. These processes not only drive stellar evolution but also enrich the interstellar medium and influence the chemical evolution of galaxies. The pathways of nucleosynthesis depend on the star's mass and core temperature, leading to distinct reactions at different evolutionary stages.

- **Hydrogen Burning:** Hydrogen burning is a fundamental nuclear process in stars, occurring through the proton-proton (pp) chain in stars with core temperatures $\mathrm{T} \lesssim 15\ \mathrm{MK}$ and the CNO cycle in stars with core temperatures $\mathrm{T} \gtrsim 18\ \mathrm{MK}$. In the pp chain, protons fuse into $^{4}\mathrm{He}$ via intermediate steps involving $^{2}\mathrm{H}$ and $^{3}\mathrm{He}$, releasing energy in the form of γ-rays, positrons, and neutrinos. In the CNO cycle, carbon, nitrogen, and oxygen act as catalysts to enhance the H to He fusion rate at higher stellar temperatures.

- **Helium Burning:** Following the exhaustion of hydrogen in stellar cores, gravitational contraction raises temperatures to $\mathrm{T} \approx 100\ \mathrm{MK}$, initiating helium burning. This process predominantly involves the triple-alpha reaction, where three $^{4}\mathrm{He}$ nuclei fuse to form $^{12}\mathrm{C}$. Subsequent reactions, including $^{4}\mathrm{He}$ capture by $^{12}\mathrm{C}$, lead to the synthesis of $^{16}\mathrm{O}$.

- **Carbon Burning:** In the later stages of massive star evolution, core temperatures rise to approximately $\mathrm{T} \gtrsim 600\ \mathrm{MK}$, initiating carbon burning. During this phase, $^{12}\mathrm{C}$ nuclei fuse through a series of nuclear reactions, producing elements such as $^{20}\mathrm{Ne}$, $^{23}\mathrm{Na}$, and $^{24}\mathrm{Mg}$. Key reactions include $^{12}\mathrm{C} +^{12}\mathrm{C} \rightarrow^{20}\mathrm{Ne} + \alpha$ and $^{12}\mathrm{C} + \alpha \rightarrow^{16}\mathrm{O} + \alpha$.

- **Oxygen Burning:** After the completion of carbon burning, the core temperature rises further to approximately $\mathrm{T} \gtrsim 800\ \mathrm{MK}$, initiating the fusion of oxygen nuclei. During oxygen burning, $^{16}\mathrm{O}$ nuclei undergo fusion reactions, producing elements such as $^{28}\mathrm{Si}$, $^{32}\mathrm{S}$, and $^{31}\mathrm{P}$. These reactions include processes like $^{16}\mathrm{O}$ + $^{16}\mathrm{O} \rightarrow$ $^{28}\mathrm{Si}$ + α and $^{16}\mathrm{O}$ + $\alpha \rightarrow$ $^{20}\mathrm{Ne}$ + $^{12}\mathrm{C}$.

- **Silicon Burning:** Silicon burning is the final phase of nuclear fusion in the most massive stars, occurring at core temperatures of $\mathrm{T} \gtrsim 3\ \mathrm{GK}$. During this phase, $^{28}\mathrm{Si}$ undergoes a series of complex nuclear reactions, including fusion with α particles and protons, to produce $^{56}\mathrm{Fe}$ and other elements in the iron peak. The reactions involved are $^{28}\mathrm{Si}$ + $\alpha \rightarrow$ $^{32}\mathrm{S}$ and $^{32}\mathrm{S}$ + $\alpha \rightarrow$ $^{36}\mathrm{Ar}$, progressing to $^{56}\mathrm{Fe}$. Due to the high binding energy per nucleon of Fe, further fusion does not provide energy, leading to core collapse and a supernova explosion.

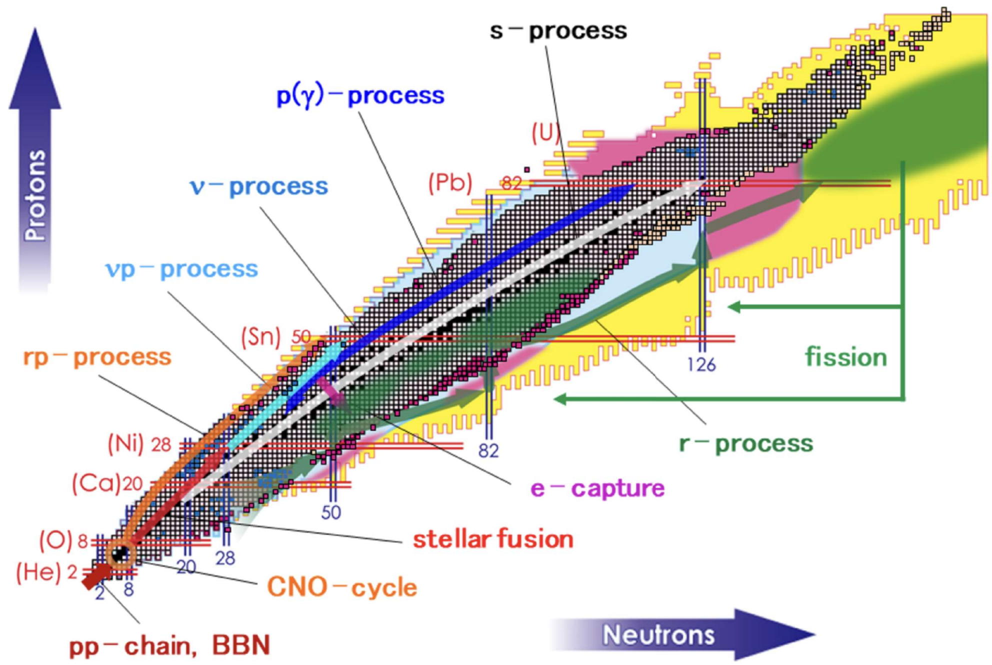

Fig. 1.2: Nuclear processes in the Universe, systematically presented on the nuclide chart [22].

(c) Explosive Nucleosynthesis

Explosive nucleosynthesis encompasses the synthesis of heavy elements during high-energy astrophysical events such as supernovae and neutron star mergers. These processes occur under extreme conditions of temperature and pressure, leading to the rapid formation of elements through various nucleosynthetic pathways. Unlike the more gradual stellar nucleosynthesis, explosive nucleosynthesis produces a significant fraction of the universe's heavy elements in a relatively short timespan.

- **s-process:** It is commonly referred to as the slow neutron capture process, occurs in environments characterized by moderate neutron fluxes, particularly within the interiors of asymptotic giant branch (AGB) stars. In this process, atomic nuclei capture neutrons at a rate that is slower than the beta decay rate, leading to the formation of neutron-rich isotopes. These isotopes then undergo beta decay to reach stability. The s-process is responsible for the nucleosynthesis of various heavy elements located between iron and bismuth, including strontium, barium, and the lanthanide series. A neutron density of $10^{7-12}\ \mathrm{cm}^{-3}$ is essential within stellar plasma to enable the s-process nucleosynthesis.

- **r-process:** It is also known as the rapid neutron capture process, occurs in astrophysical environments exhibiting exceptionally high neutron densities, often associated with core-collapse supernovae and neutron star mergers. In this process, nuclei capture neutrons at a rate much faster than their beta decay, resulting in the formation of very neutron-rich nuclei. These nuclei subsequently undergo beta decay to produce heavy elements, including uranium, thorium, and other actinides. The r-process is essential for understanding the synthesis of the heaviest elements and is a key mechanism for producing a significant fraction of the universe's heavy elements beyond iron. A neutron density of $> 10^{18}$ cm^{-3} is essential within stellar plasma to enable the r-process nucleosynthesis.

- **p-process:** The p-process contributes to the synthesis of proton-rich isotopes within the mass range of 74 $\leq \text{A} \leq$ 196, which occur at significantly lower abundances compared to other nuclear species. In lighter nuclei, consecutive proton captures on stable seeds drive the synthesis in what is referred to as the rp-process. For heavier neutron-deficient elements, synthesis primarily occurs through the photodisintegration of stable or neutron-rich nuclei. While these mechanisms account for most p-nuclides, additional contributions come from neutrino-induced reactions like the ν-process [23], as well as processes like the α-rich freeze-out and the νp-process, which produce some of the rarest p-nuclides. Proton capture reactions in this context may emit gamma rays via (p, γ) reactions or produce neutrons following gamma-ray absorption in (γ, n) processes. The p-process plays a vital role in the synthesis of specific isotopes, including molybdenum, ruthenium, and other p-nuclei, which are not produced via neutron capture processes. These proton-rich isotopes are crucial for understanding the complete range of isotopic compositions in the universe. This process is discussed extensively in Chapter 5.

The present work focuses on the astrophysical p-process, which produces 35 neutron-deficient isotopes situated on the proton-rich side of the stability valley, which cannot be formed through s- or r-processes. It particularly investigates proton capture reactions involving heavy, proton-rich nuclei.

1.4 Motivation

Considerable research has been carried out to investigate the nuclear reactions within the range of low to moderate energy regime though the utilization of neutrons. Reliable nuclear data is crucial for evaluating the sustainability and performance of various metal alloys under the extreme radiation conditions present near the cores of fusion and fission reactors. Consequently, the cross-sections for neutron-induced reactions were analyzed for specific isotopes relevant to reactor cladding and shielding materials at energies above 1 MeV, with uncertainties and correlation coefficients obtained through covariance analysis. Measurements for nuclear reaction cross-sections for reactor cladding and shielding materials from low to medium energy (upto 20 MeV) is necessarily required with mono

Table 1.1: Nuclear spectroscopic data for $^{58}\mathrm{Ni(n,p)}^{58}\mathrm{Co}$ and $^{115}\mathrm{In(n,n')}^{115m}\mathrm{In}$ reaction cross-section measured experimentally with significance for reactor applications [25].

Reaction	$T_{1/2}$	Decay Mode (%)	E_γ (keV)	I_γ (%)	Spin state J^π
$^{58}\mathrm{Ni(n,p)}^{58}\mathrm{Co}$	70.86 ± 0.06 d	$\varepsilon(100\,\%)$	810.759 ± 0.002	99.45 ± 0.01	2^+
$^{115}\mathrm{In(n,n')}^{115m}\mathrm{In}$	4.486 ± 0.004 h	IT$(95.00\,\%)$ $\beta^-(5.00\,\%)$	336.241 ± 0.025	45.9 ± 0.1	$1/2^-$

d $\rightarrow$ day, h $\rightarrow$ hour

energetic neutrons for deeper insight into the excitation functions. Hence, measuring various reaction cross-section within the stated energy range is vital for gaining a detailed understanding of their energy-dependency. This endeavor will culminate in a comprehensive database, ultimately advancing our grasp of nuclear reaction mechanisms and contributing to future advancements in reactor technology. Table 1.1 provides a concise summary of the neutron-induced reactions explored in this study specifically in the context of their application in reactor systems.

Assessing the uncertainties associated with the activation cross-section is vital for identifying an appropriate margin that ensures economic efficiency and safety in the context of reactor operations [24]. In cases where multiple activation cross-section data points contribute to the assessment of a specific quantity, it is crucial to analyze the correlation (covariance) among these points to mitigate the potential for overestimating or underestimating the resultant uncertainty. Therefore, the aim of modern evaluation reports is not only to estimate the most accurate cross-section but also to identify the uncertainty and covariance describing the correlation among the cross-sections. However, in most previous data, details regarding error propagation and correlations among the different attributes are not reported. Considering the above facts, new experimental cross-sections with covariance analysis are needed to enhance the accuracy and reliability of these evaluated nuclear data and theoretical models.

When direct measurements are unfeasible or experimental data exhibit discrepancies due to relative measurements and the unavailability of monoenergetic neutron sources, systematic methods or theoretical models become essential. This encourages the formulation of advanced semi-empirical formulas to enhance the accuracy of estimates for neutron-induced reaction cross-sections. In the present work, new semi-empirical formulas have been developed for incident neutron energies around 14.5 MeV to calculate and to predict (n, p), (n, α), and (n, 2n) reaction cross-sections within the target mass regions $24 \leq \mathrm{A} \leq 238$ (including both $\mathrm{Z} \leq 45$; >45), $26 \leq \mathrm{A} \leq 181$, and $45 \leq \mathrm{A} \leq 238$ (including both even and odd nuclei), respectively.

The motivation behind studying the astrophysical p-process lies in its pivotal

Table 1.2: Nuclear spectroscopic data for reactions having astrophysical applications investigated theoretically [25].

Reaction	Product isotope	$T_{1/2}$	Decay Mode (%)	Spin state J^{π}
$^{92}Mo(p, \gamma)$	$^{93,g}Tc$	2.75 ± 0.05 h	$\varepsilon(100\ \%)$	$9/2^{+}$
$^{92}Mo(p, \gamma)$	$^{93,m}Tc$	0.725 ± 0.017 h	IT(77.40 %) $\varepsilon(22.60\ \%)$	$1/2^{-}$
$^{94}Mo(p, \gamma)$	$^{95,g}Tc$	20.0 ± 0.1 h	$\varepsilon(100\ \%)$	$9/2^{+}$
$^{74}Se(p, \gamma)$	^{75}Br	96.7 ± 0.13 min	$\varepsilon(100\ \%)$	$3/2^{-}$
$^{76}Se(p, \gamma)$	^{77}Br	57.036 ± 0.006 h	$\varepsilon(100\ \%)$	$3/2^{-}$
$^{82}Se(p, n)$	^{82}Br	35.282 ± 0.007 h	$\beta^{-}(100\ \%)$	5^{-}

h $\rightarrow$ hour, min $\rightarrow$ minute

role in shaping the universe's elemental composition, offering profound insights into the origins and evolution of celestial bodies. The "p-process," or proton capture process, gives rise to a range of naturally occurring neutron-deficient isotopes, known as p-nuclei, spanning elements from selenium to mercury. The origins of these isotopes remain unclear, as prevailing p-process models struggle to accurately represent the observed abundances of p-isotopes present in the solar system. This discrepancy may arise from uncertainties associated with the astrophysical environments in which the process takes place. Alternatively, it could be attributed to limitations in our understanding of nuclear physics models. The p-process occurs in extreme astrophysical conditions, including supernovae and X-ray bursts. During these events, protons are involved in nuclear reactions with heavy isotopes, leading to the creation of heavier elements. Precise cross-section data are essential for modeling these high-energy, high-temperature environments accurately. In light of these challenges, it is essential to obtain cross-section data for proton capture at low energies involving heavy isotopes to improve our comprehension of the astrophysical p-process. Cross-section data are a fundamental input for nuclear reaction network simulations used in astrophysics. These simulations are vital for modeling nucleosynthesis in various astrophysical environments and making predictions about the composition of stellar ejecta. Table 1.2 summarises theoretically studied nuclear reactions in this study specifically in the context of their astrophysical applications using the TALYS nuclear modular code [26].

1.5 Objectives

The present work is carried out with the following objectives:

- To measure the $^{58}Ni(n, p)^{58}Co$ and $^{115}In(n, n')^{115m}In$ reaction cross-sections with respect to their utilization in reactor applications. The production of mono-energetic fast neutrons can be achieved through the $^{7}\mathrm{Li(p,n)}$ reaction at BARC-TIFR Pelletron and FOTIA facilities.

- The experimental work consists of the irradiation of Ni and In samples with quasi-monoenergetic neutron within 1.6 to 2.7 MeV and 7 to 20 MeV respectively. The measurements were performed via neutron activation analysis, followed by offline γ-ray spectrometry. The irradiated samples were counted by using HPGe detectors. The obtained results offer significant insights into nuclear reactions and their relevance in reactor studies.

- Covariance analysis was applied to evaluate the uncertainties and correlations present in the current experimental data related to neutron-induced reactions. This analysis incorporates the combined uncertainty from all factors involved in the measurement process.

- To develop new semi-empirical formulas for the reaction cross-sections of $\mathrm{(n,p)}$, (n, α) and $\mathrm{(n,2n)}$ at neutron energy of 14.5 MeV. This presents a novel approach for generating nuclear data at incident neutron energies of 14.5 MeV.

- To study proton capture reactions on Mo and Se isotopes at astrophysically relevant energies using TALYS code and calculating astrophysical S factors and reaction rates in a core-collapse supernova. Additionally the impact of different nuclear input parameter entering the reaction rate equation is also investigated. This research aims to enhance our understanding of low-energy proton capture cross-sections on heavy isotopes, particularly for the p-nuclei, and to unravel their origin and implications for astrophysical processes.

1.6 Outline of the Thesis

The thesis comprises six chapters, each with References listed at the end to ensure readers can easily access the information. The summarized details of each chapter are as follows:

Chapter 1 emphasizes the significance of investigating neutron and charged particle induced nuclear reactions in both reactor and astrophysical domains. The chapter outlines the specific research objectives and underscores the practical implications of understanding these reactions, such as advancing reactor technology and enriching our knowledge of astrophysical phenomena.

Chapter 2 provides a thorough understanding of the nuclear codes used in the thesis for analyzing reactions in both reactor and astrophysical scenarios. It offers brief discussions about each code, aiding readers in grasping their specific details and applications.

Chapter 3 involves the measurement of $^{58}\mathrm{Ni(n,p)}^{58}\mathrm{Co}$ reaction cross-section in the neutron energy range of 1.6-2.7 MeV and the production of $^{115\mathrm{m}}\mathrm{In}$ using quasi-monoenergetic neutrons within the energy range of 7-20 MeV. The chapter presents the experimental procedure, data analysis, and cross-section measurements. Additionally, the ratio technique of covariance analysis is introduced to estimate uncertainties and correlations between experimental data, encompassing the collective uncertainty from all measurement attributes.

Chapter 4 describes development of new systematic formulas for $\mathrm{(n,p)}$, (n, α) and $\mathrm{(n,2n)}$ reaction cross-section at neutron energy of 14.5 MeV based on the statistical model considering Q-value dependence using the literature data available on EXchange FORmat (EXFOR) [27] data library.

Chapter 5 focuses on studying low-energy proton capture cross-sections on heavy isotopes to understand the astrophysical p-process. It involves investigating proton capture reactions on molybdenum (Mo) and Selenium (Se) isotopes using the TALYS nuclear code and calculating astrophysical S-factors and reaction rates in a core-collapse supernova. The effect of different nuclear input parameters on the stellar reaction rate is also investigated.

Chapter 6 containing the summary, key findings and outcomes of the current study, alongside a concise depiction of its potential implications for the future.

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