Chapter 1

Introduction

1.1 Overview

A nuclear reaction is defined as two body interaction in which a nuclear particle such as a neutron, proton, deuteron, α particle, or a nucleus interacts with another, and an exchange of momentum and energy occurs. The momentum and total kinetic energy of the reactant and products are equal before and after the collision in an elastic collision. On the contrary, the fractional or total initial kinetic energy (KE) of the incident particle is altered to the target nucleus, but it is left in the same nuclear state as before the collision for inelastic collision [1]. The final resultant of the reaction is some nuclear particles or particles that leave a contact in different directions. This process results in the transmutation of the target nuclei [2]. The first transmutation was established by Rutherford in 1919 by bombarding high energy particles emitted from Polonium (^{214}Po) on Nitrogen (^{14}N), some of them were absorbed by the compound nucleus system that disintegrates by emitting proton, leaving new residual nucleus Oxygen (^{16}O). This reaction is referenced as an alpha-proton reaction.

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{18}_{9}\mathrm{F}^{*} \longrightarrow {}^{16}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$$

In 1933, F. Joliot and I. Curie generated the first artificial radioactivity utilizing α particles from natural radioactive isotopes to transmute Boron and Aluminium into radioactive Nitrogen and Oxygen. Further extension of this type of transmutation is not possible for heavier elements if only the α particles are available from natural radioactivity. As for the heavy elements, the coulomb barrier is too high to enter the particles into atomic nuclei. This barrier was removed by E. O. Lawrence when he invented the cyclotron.

Nuclear reactions have eminent importance in the field of nuclear reactors, nuclear medicine, nuclear astrophysics etc. They produce energy in stars, in reactors, and are the reason behind the existence of elements of the universe. In the present study, the reactions induced with the neutron, and deuteron have been studied for the nuclear reactor and other applications. The proton induced reaction has been studied for reactor and astrophysical applications. The overview of nuclear reactors and astrophysical processes is presented in the following sections.

1.1.1 Nuclear reactor & technology

Energy is an important part of powering human technologies and for sustainable economic growth. Nowadays, there are some challenges related to the increasing demand for energy, the threat of global warming, the exhaustion of natural sources etc. Therefore, the world demands sustainable, carbon free energy sources for the future. Nuclear power is generated via energy released by nuclear reactions such as nuclear fusion, nuclear fission, and nuclear decay reactions. The nuclear energy has a very high capacity and low greenhouse gas emission compared to other sources of energy [3]. At present, most of the electric energy is generated via nuclear fission of Plutonium and Uranium in nuclear reactors. The generation of electric energy via nuclear fusion is the focus of international research and nuclear decay processes are used in space probes for radioisotope thermoelectric generators. After the discovery of the fission process in 1938, the first nuclear reactor was built in the 1950s, and still, technical development is the subject of research and development [4].

The design of the nuclear reactors is categorized by the generations: i.e. GEN I, II, III, III+, and IV. The evolution of the generation of reactors is presented in Fig. 1.1. Generation I reactors are the early prototype reactors from the 1950 and 1960s.

Initially, they were used for military based applications and then without any safety they were launched for commercial use. GEN II are light water reactors (LWRs) as well as heavy water designs and have active safety designs compared to GEN I reactors. They have automatic or manual safety features involving electrical or mechanical operations. Their typical average lifetime is around 40 years. After learning from Chernobyl and Three Mile Island accidents, GEN III reactors are incorporated with passive safety features, which rely on natural convection or gravity to migrate abnormal activities with longer operating life of around 60 years. GEN III+ are initiated in the late 1990s and slightly updated in terms of safety, build-ability, and cost than the GEN III reactors. GEN IV systems are highly economical, increased efficiency, enhanced safety and protection features, a minimal amount of radioactive waste, and advanced actinide management. This generation of reactors can operate at high temperatures to support the production of economic hydrogen, and water desalination [5]. Three generations of nuclear reactors are in operational condition worldwide today. The concept of these reactors was started in the early 2000s, so still they are considered to be decades away from commercial use.

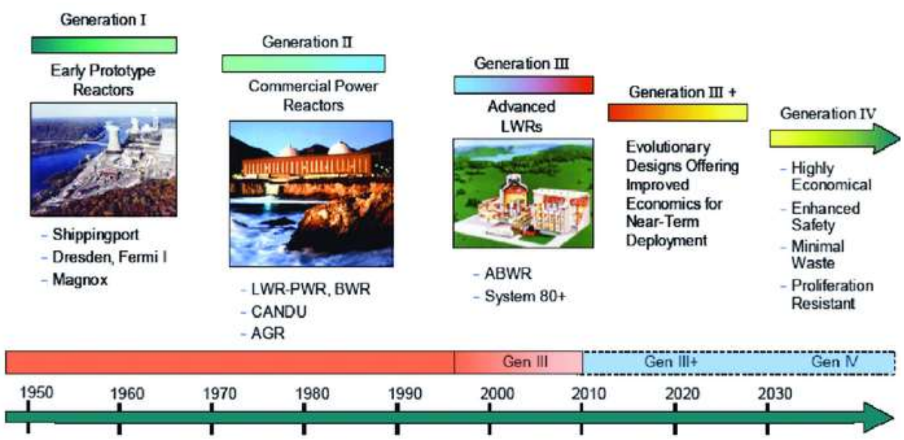

Figure 1.1: Evolution of the generations of nuclear reactors throughout history and predictions for future [6].

The fast reactors (Uranium based) [7–9], advanced heavy water reactor (AHWR) (Thorium based) [10,11], compact and high-temperature reactors (CHTR) (Uranium based), accelerator driven sub-critical systems (ADSs) (Th-U cycle based) [12–14], GEN-IV [15], and fusion reactors [16, 17] are the most important candidates of the current time to increase the nuclear power generation to fulfill the rising energy demand. ADSs can handle the issue of nuclear waste disposal and work as a nuclear incinerators. It has the capability of incinerating long-lived minor actinides (Am, Cm, Np etc.) and fission product (^{135}Cs, ^{129}I, ^{99}Tc, ^{93}Zr etc.) originated in conventional reactors and also produce the nuclear energy [18,19]. Further, efforts are going on the development of nuclear fusion reactors that uses fusion reactions which occur within the Sun under extreme conditions. The fusion reactors produce high, safe and long-term energy with no acidic emission or no greenhouse effects contribution [16]. The ITER (International Thermonuclear Experimental Reactor) is the first magnetic fusion-based project, launched in 1988 to provide a practical source of electric power without producing hazardous waste.

The present work is focused on providing nuclear data on neutron and charged particle reactions crucial for advanced nuclear design and development.

1.1.2 Nuclear astrophysics

Some open questions regarding the shining of stars, explosive cosmic phenomena, stellar evolution, stellar nucleosynthesis, the existence of the first stars in the universe, and the existence of heavier elements than iron (Fe) within the cosmos can be explained via nuclear processes.

The connection between astrophysics and nuclear physics was initiated when Arthur Eddington postulated that the creation of energy in the stars and sun can be explained via the conservation of hydrogen to helium [20]. A decade later, G Gamow, as well as Condon and Gourney have independently computed the quantum mechanical probability [21, 22] that explains the occurrence of nuclear reactions for energies less than the Coulomb barrier. Further, this concept of Gamow was used by Atkinson and Houtermans [23], who have suggested that the energy generation in stars via fusion reactions may be explained by quantum tunnelling. Further, the nuclear reaction sequence powering the sun was identified by von Weizscker in 1938 [24], Critchfield and Bethe in 1938 [25], and Bethe in 1939 [26]. E. M. Burbidge, G. R.

Burbidge, F. Hoyle, and W. A. Fowler in 1956 [27,28], as well as A. G. W. Cameron in 1957 [29], have presented the available knowledge of eight different synthesizing processes to explain the feature of abundance curve. All features of the abundance curve can be explained via different nucleosynthesis processes. The outline of the processes related to astrophysics is given below.

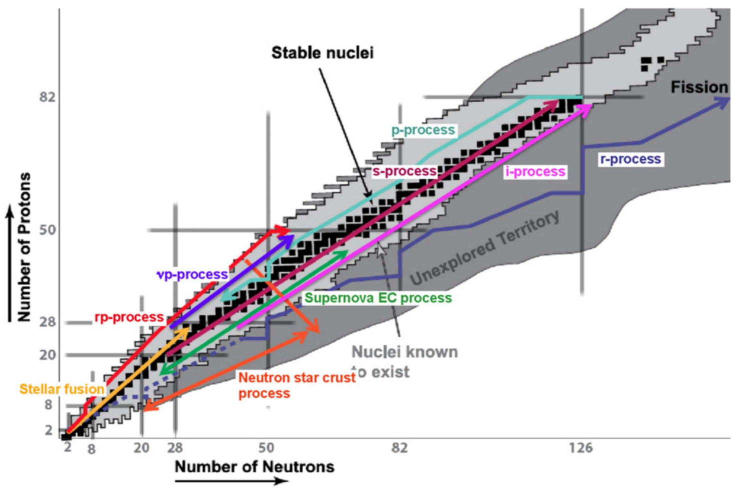

Figure 1.2: Schematic presentation of the nuclear processes in the Universe on the chart of nuclides [30].

- **Hydrogen Burning:** Most of the energy generation in the stars is due to H-burning. It converts Hydrogen (protons) to Helium.

- **Helium Burning:** This process involved with the reactions produced via α particles which is creating a forth most abundant isotope i.e. ^{12}C. A small fraction of produced ^{12}C is used via the ^{12}C(α, γ)^{16}O reaction. Further α-particle addition can produce ^{16}O, ^{20}Ne, and probably ^{24}Mg.

- α **process:** The source of α particles is different than the Helium burning process. The addition of α particles to ^{20}Ne for synthesizing the four structure nuclei ^{24}Mg, ^{28}Si, and ^{32}S to the very stable doubly magic nuclei ^{40}Ca. The time required for the whole α process is in the range of $\sim 10^2$-10^4 years.

- **e process:** This process is called as equilibrium process which is assumed to be responsible for synthesizing the iron group of nuclei (Mg, V, Cr, Fe, Ni, and Co).

Numerous collisions between high energy photons and nuclei take place under the extreme condition of temperature and density which is approximately $\geq 5 \times 10^9$ K and $\geq 3 \times 10^6$ g cm^{-3}, respectively. The collisions break the nuclide and instantly part of them combines with other particles. This process is presumed to occur in the supernova explosion. A few seconds or minutes of time scale is involved for this type of reaction.

- **s process:** This is a neutron capture process with emission of γ ray via (n, γ) that occurs for a longer time scale. This capture process occurs at a slow rate compared to the intervening beta decays. So, the s process nucleosynthesis occurs near the β stability valley. The neutron densities required for the s process are about $n_n = 10^8$ n-cm^{-3}. The isotopes in $23 \leq A \leq 46$ range (except those synthesized mainly via α process), and also for the significant proportion of the isotopes from $63 \leq A \leq 209$ are considered to be synthesized via s process.

- **r process:** This process involves a high neutron capture rate than the β decay rate of the resultant nuclei. A very short time scale is required for the process which is about $\sim$ 0.01 to 10 seconds. The intense neutron density of about $n_n = 10^{20}$-10^{25} n-cm^{-3}. The time scale of neutron capture varies inversely to the ambient neutron density. The r process exists far from the stability valley where the unstable and neutron-rich nuclei are present. This process is accountable for the synthesis of the isotopes in the range of $70 \leq A \leq 209$, and also for Thorium and Uranium nuclei. Also, some of the light nuclei such as ^{48}Ca, ^{46}Ca, ^{36}S, and certainly ^{50}Ti ^{49}Ti, and ^{47}Ti are synthesized via rapid process.

- ***p* process:** The synthesis of the neutron deficient (proton rich) nuclei within the isotopic range of $74 \leq A \leq 196$, having low abundances compared to other nuclei are synthesized using this process. The synthesis of the many light nuclei occurs via consecutive proton captures on stable seeds is known as the rp-process [31, 32]. Heavier neutron deficient (proton rich) elements are primarily produced via photo-dissociation of stable or neutron rich elements [33]. While the above mentioned mechanisms are responsible for producing the bulk of the p nuclides, some neutrino induced mechanisms such as the ν process [34]. The α-rich freeze out [35, 36] and the νp-process [37, 38] contribute to the p process by producing some of the least abundant p nuclides. This proton capture reaction emits γ ray via (p, γ), or emit neutron by following absorption of γ ray (γ, n).

- **x process:** This process builds light isotopes such as Deuterium (H-2), Lithium (Li), Beryllium (Be), and Boron (B). The elements produced via the x process if very unstable at stellar temperatures. So, they are produced in low density and temperatures. More than one process is required for the synthesis process, hence called the x process.

- **i process:** This process is called as intermediate neutron capture process. It occurs between the s- & r processes and is assumed to occur in metal-poor stars and red giant stars when helium and hydrogen burning zones mix up easily [39]. The required neutron density is around $n_n = 10^{15}$ n-cm^{-3}.

Table: A list of 35 p nuclei with the solar abundances normalized to Si atoms (Si = 10^6) is indicated [40].

Nucleus	Z	Solar system abundance (Si = 10^6)	Isotopic abundance (%)	Nucleus	Z	Solar system abundance (Si = 10^6)	Isotopic abundance (%)
^{74}Se	34	$5.5 \cdot 10^{-1}$	0.88	^{132}Ba	56	$4.53 \cdot 10^{-3}$	0.1
^{78}Kr	36	$1.53 \cdot 10^{-1}$	0.34	^{138}La	57	$4.09 \cdot 10^{-4}$	0.09
^{84}Sr	38	$1.32 \cdot 10^{-1}$	0.56	^{136}Ce	58	$2.16 \cdot 10^{-3}$	0.19
^{92}Mo	42	$3.78 \cdot 10^{-1}$	14.84	^{138}Ce	58	$2.84 \cdot 10^{-3}$	0.25
^{94}Mo	42	$2.36 \cdot 10^{-1}$	9.25	^{144}Sm	62	$8.0 \cdot 10^{-3}$	3.1
^{96}Ru	44	$1.03 \cdot 10^{-1}$	5.52	^{152}Gd	64	$6.6 \cdot 10^{-4}$	0.2
^{98}Ru	44	$3.50 \cdot 10^{-2}$	1.88	^{156}Dy	66	$2.21 \cdot 10^{-4}$	0.06
^{102}Pd	46	$1.42 \cdot 10^{-2}$	1.02	^{158}Dy	66	$3.78 \cdot 10^{-4}$	0.10
^{106}Cd	48	$2.01 \cdot 10^{-2}$	1.25	^{162}Er	68	$3.51 \cdot 10^{-4}$	0.14
^{108}Cd	48	$1.43 \cdot 10^{-2}$	0.89	^{164}Er	68	$4.04 \cdot 10^{-3}$	1.61
^{113}In	49	$7.9 \cdot 10^{-3}$	4.3	^{168}Yb	70	$3.22 \cdot 10^{-4}$	0.13
^{112}Sn	50	$3.72 \cdot 10^{-2}$	0.97	^{174}Hf	72	$2.49 \cdot 10^{-4}$	0.16
^{114}Sn	50	$2.52 \cdot 10^{-2}$	0.66	^{180}Ta	73	$2.48 \cdot 10^{-6}$	0.01
^{115}Sn	50	$1.29 \cdot 10^{-2}$	0.34	^{180}W	74	$1.73 \cdot 10^{-4}$	0.13
^{120}Te	52	$4.3 \cdot 10^{-3}$	0.09	^{184}Os	76	$1.22 \cdot 10^{-4}$	0.02
^{124}Xe	54	$5.71 \cdot 10^{-3}$	0.12	^{190}Pt	78	$1.7 \cdot 10^{-4}$	0.01
^{126}Xe	54	$5.09 \cdot 10^{-3}$	0.11	^{196}Hg	80	$5.2 \cdot 10^{-4}$	0.15
^{130}Ba	56	$4.76 \cdot 10^{-3}$	0.11				

The present work is focused on the astrophysical p process that synthesizes the 35 neutron-deficient nuclides on the neutron-deficient side of the stability valley. These nuclei cannot be synthesized via explosive nucleosynthesis such as s process and r process. The 35 neutron-deficient nuclei are mentioned in the above Table.

1.2 Activation analysis

It is a most sensitive and rapidly growing technique for elemental analysis and a wide variety of ongoing research activities in laboratories. In 1934, this technique was discovered by Irene Joliot Curie and Frederic Joliot. They discovered that the bombardment of alpha particles on the aluminium, magnesium, and boron metal foil produces artificial radioactivity. In this technique, the neutrons, charged particles (proton, alpha, deuteron etc.) or photons are utilized for the irradiation purpose to produce instability in the target nuclei. With high sensitivity, the radiation emitted from the treated nuclei is measured [41]. The following criteria should be fulfilled for neutron and charged particle induced reaction to occur [42].

- The reaction should have considerably high cross sections.
- The resultant nuclei have sufficient half-lives and are compatible with counting equipment.
- The gamma disintegration line of the resultant nuclei should not overlap with the other lines contributing to the isotope.
- Interference of the reactions should be taken into account.
- Easy treatment of the sample after irradiation (limited matrix activity).

The neutron activation analysis (NAA) and Charged particle analysis (CPAA) techniques were used for our study and discussed in subsections §1.2.1 and §1.2.2, respectively.

1.2.1 Neutron Activation Analysis (NAA)

In 1936, Levi and Hevesy discovered that some of the rare earth elements get highly radioactive after neutron exposure [43] and they introduced the NAA technique. When the interaction of neutrons and the nucleus occurs via inelastic collision, the compound nucleus (CN) is produced in its excited state. The excitation energy of the CN is because of the binding energy of neutrons and the nucleus. The CN acquire a more stable state after emitting one or more prominent γ rays. In other cases, a radionuclide decays via emitting one or more γ rays however at a very slow rate as per the particular half-life of the radionuclide. By considering the time factor, NAA is categorized into two : (i) Prompt γ ray NAA (PGNAA), and (ii) Delayed γ ray NAA (DGNAA) [43, 44].

The PGNAA technique is used for the elements having high neutron capture; elements producing stable isotopes, elements having weak gamma decay intensity, and elements decaying too rapidly. The latter technique is a conventional NAA technique due to the flexibility of time and is vastly used for the majority of elements. The DGNAA technique is used for the present case.

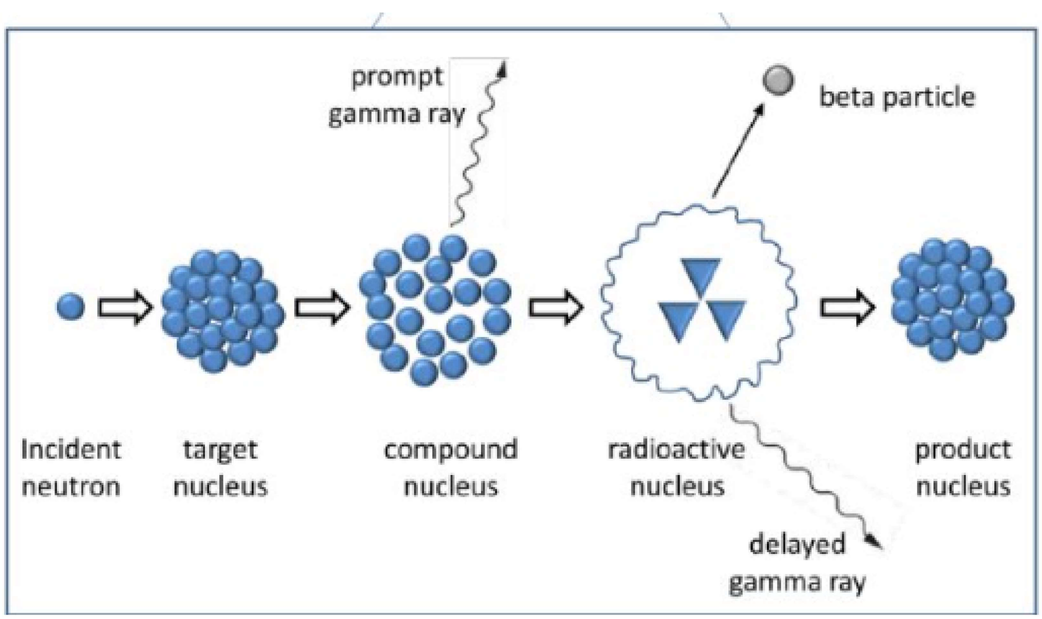

Figure 1.3: A diagram represents the basic principle of NAA.

1.2.1.1 Neutron Source

Neutron is a neutral charge particles and insensitive to electromagnetic interactions experienced by other charged particles. Hence, it will directly interact with the nucleus rather than the electron cloud and is ideal for nuclear structure research and sensitive to different isotopes of the same element. The neutron source required in the laboratory to study reactions is based on nuclear reactions or spontaneous fission.

- **The spontaneous fission neutron source:**

The majority of transuranic heavy nuclei have the considerable ability of spontaneous fission decay. The ^{252}Cf is commonly used as a source of neutrons as its having 2.65 years half-life. This isotope is enclosed in a thick vessel to collect the emission of only gamma rays and neutrons when it is used as a neutron source.

- **Reaction with Ions:**

Light particle fusion reactions as well as other reactions are commonly used and easiest reactions for the neutron generations. These reactions are given in Table 1.1. The DD and DT reactions have low atomic numbers and large positive Q values so that they can generate high yields of fast neutrons even at low energies of the incident deuteron. The other necessity to produce high yield is a high neutron generation cross section and a small amount of energy loss of incident particles. The neutrons produced from the first four reactions of Table 1.1 are considered monoenergetic neutrons.

^{7}Li(p, n) reaction has considerable interest in producing accelerator-based quasi monoenergetic fast neutrons [45,46]. The monoenergetic neutrons are available around 8 MeV of low proton energy [47–49] and above 20 MeV of high energy [50–53]. The generation of the neutrons via ^{7}Li(p, n) reaction are contributing to the quasi monoenergetic neutrons for less than 2.3 MeV of proton energy and for the higher energy the main drawback is that the higher excited states of ^{7}Be and three body break emission are also contributing to those neutrons [48, 54].

- **Reaction with photons:**

Photo fission is one of the sources for the production of neutrons. High energy photons are usually used to generate neutrons via (γ, xn) or (γ, f) reactions with some nuclei such as ^{2}H, ^{6}Li, ^{7}Li, ^{9}Be*, ^{210}Pb, ^{235}U, and ^{238}U. The most commonly used nuclei are deuterium and beryllium. The incident photons with sufficient energy could overcome the binding energy of the selected nuclei. The neutrons generated from these reactions is not monoenergetic.

In all of the above-mentioned neutron sources, ^{7}Li(p, n) reactions are utilized for the generation of quasi-monoenergetic neutrons for the present study.

Table 1.1: List of nuclear reactions used to produce neutrons [55].

Reactions	Q-value (MeV)	Threshold (MeV)	Min. Neutron Energy (MeV)	Monoenergetic Neutron Energy Range (MeV)
^{2}H(d,n)^{3}He (DD reaction)	3.269	0.0	2.45	1.64-7.75
^{3}H(d, n)^{4}He (DT reaction)	17.589	0.0	14.05	11.74-20.5
^{3}H(p, n)^{3}He	-0 .763	8.35	0.3	0.3-7.6
^{7}Li(p, n)^{7}Be	-1.644	1.880	0.03	0.12-0.6
^{1}H(^{7}Li, n)^{7}Be	-1.644	13.094	1.44	
^{7}Li(d, n)^{8}Be	15.031	0.0	13.35	
^{9}Be(p, n)^{9}B	-1.850	2.057	0.023	
^{9}Be(d, n)^{10}B	4.361	0.0	3.96	

1.2.2 Charged Particle Activation Analysis (CPAA)

The CPAA technique is the most analytic, precise and sensitive technique. In this technique, the bombardment of the charged particles (p, α, d) on the sample target produces nuclear reactions. The resultant radionuclide is detected after the irradiation process. The treated nuclei emit the characteristic γ lines accordingly the different isotopes of the same nuclide can be acknowledged by considering their half-lives and other properties [42, 44, 45]. Charged particles are slowed down in matter and stopped at the depth called the range as a result the intensity of the beam is hardly reduced compared to neutrons [43].

1.3 Nuclear Data Requirement

A great amount of work was performed for the low and moderate energy for the neutron, and light and heavy charged particle induced reactions. As these reactions have significant importance in basic nuclear physics research, nuclear reactors, and astrophysics, the latest and improved nuclear data are required with high accuracy. For nuclear reactors, the accurate estimation of nuclear data is needed to predict the suitability and sustainability of different materials to withstand with the high radiation condition around the fission/fusion reactor core. The nuclear data also help us to find out different ways to tackle radiation waste. In the field of nuclear astrophysics, nuclear data are important to gain knowledge about the reaction mechanism behind the existence of chemical elements.

First of all, the literature survey was performed for neutron and charged particle (proton, deuteron) induced reactions for nuclear reactor applications. It suggests that the cross section data is rather scarce or discrepancy is observed for some reactions [56, 57]. Also, it is observed that few of the reactions have very old data so for those reactions, it is important to measure new data with the latest facility and high precision. Therefore, we aim to measure accurate proton and neutron induced reaction cross-section data to fulfill the requirement of data for nuclear reactors advancement. Also, to validate the results and reproduce the nuclear data, the statistical model codes including TALYS, EMPIRE, and ALICE are used. The goal of our theoretical study with different model codes is to acquire optimum conditions for the calculations.

Further, the literature survey of the astrophysical p process suggests that the nuclear data are required to get the knowledge about the astrophysical p processes, and different astrophysical scenarios should justify the reliable abundance value of p nuclei [58]. It is crucial to update the detailed information about the driving reaction mechanism behind the creation of the chemical elements which is the fundamental quest but it is complex in nature and involves the interplay of different research fields. Also, numerous experimental efforts are carried out in recent years for charged particle (proton, α) induced reactions [59–61] but still data are insufficient. Therefore, we aim to provide data relevant to astrophysical p process to the existing dataset and also wanted to validate the statistical model code calculation for a large range of nuclides. In this manner, the uncertainties in the abundance of the p process coming from the input can also be restricted.

The multidisciplinary work has been carried out by measuring proton induced reaction cross sections, required for nuclear reactors and astrophysics. Also, proton-induced reactions are important for medical sectors and other applications.

1.4 Objectives

The objectives mentioned below have been fulfilled in the thesis work:

- The neutron-induced reactions were studied for (n, n'), (n, 2n), and (n, f) reaction channels up to 20 MeV of neutron energy. The quasi-monoenergetic neutrons were used to carry out the experiment. The neutrons were generated using ^{7}Li(p, n) reaction at the BARC-TIFR accelerator, Mumbai, India. The NAA technique was utilized for data analysis. The neutron flux was computed using flux monitor reactions. The reaction channels are studied for Au, In, U, and Th samples which are widely used for neutron flux calculations and other purposes in nuclear reactors.

- The reactions induced with protons were studied on natural Cadmium targets. The studied reactions are important for advanced nuclear reactors and astrophysical applications. The reaction study has been performed in the Cd-In-Sn nuclear reaction network for the astrophysical environment. The production of Cadmium isotopes are important as the network produces ^{113}In nuclei. The production of ^{113}In is not clearly understood. One of the production of ^{113}In is decay of proton capture by ^{112}Cd. Also, these reactions have significant importance in the medical sector. The stacked foil activation technique was adopted for the analysis. The 16 MeV of the proton beam was delivered from the BARC-TIFR accelerator.

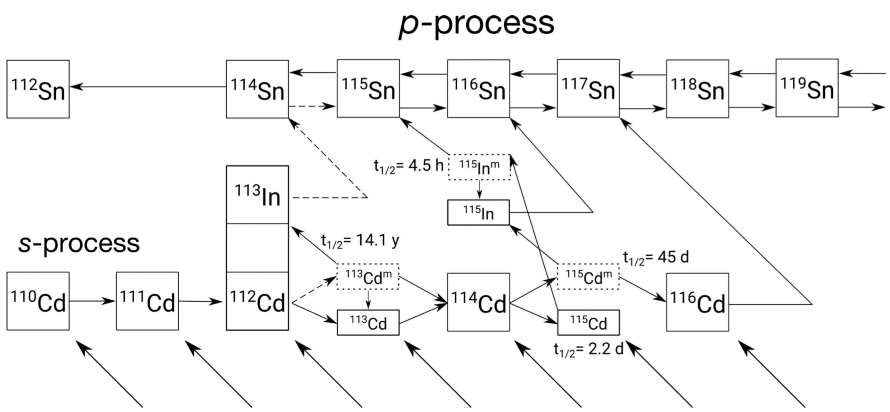

Figure 1.4: A sketch of the reaction flows in the vicinity of ^{113,115}In taken from Ref. [62]. Contributions from the corresponding s, r and p processes are shown. Our work is focused on proton induced reaction channels of ^{112,114}Cd.

- In this experiment, the targets mentioned in the table were irradiated with neutrons or proton beam and gamma ray spectroscopy was utilized. The γ ray counting was done at the HPGe detector for irradiated samples. The HPGe detector was connected to a 4k channel analyzer and pre-calibrated using ^{152}Eu source.

- The simulation of the measured data was performed with the Hauser-Feshbach nuclear model prediction, using TALYS [63], EMPIRE [64], and ALICE [65] codes.

- Further, the theoretical study has been also carried out using TALYS, EMPIRE, and ALICE codes, for the reaction produced by deuteron for some nuclear materials of the periodic table which are important in various fields of nuclear physics and technology and also in nuclear medicines.

1.5 Outline of the Thesis

The research work is bifurcated in the following chapters in the thesis.

Table 1.2: The spectroscopic data of selected neutron and proton induced reactions are considered in the present work.

Reaction	E(level) (MeV)	Isotopic Abundance [66] (%)	Threshold Energy [67] (MeV)	Product Nucleus	J^π	Decay Mode	Half-life [68]	Eminent γ-ray Energy [68] keV	Branching Intensity (%)
^{197}Au(n,2n)	0.0	100	8.114	^{196}Au	2^-	ϵ : 93.00 % β^- : 7.00 %	6.183 d	355.73 (5)	87
^{115}In(n,n')	0.3362	95.71	0.0	^{115m}In	$\frac{1}{2}^-$	IT : 95.00 % β^- : 5.00 %	4.486 h	336.24 (25)	45.9 (1)
^{232}Th(n,f)	0.0	100	0.0	^{97}Zr	$\frac{1}{2}^+$	β^- : 100.00 %	16.91 h	743.36 (3)	93
^{238}U(n,f)	0.0	99.2745	0.0	^{97}Zr	$\frac{1}{2}^+$	β^- : 100.00 %	16.91 h	743.36 (3)	93
^{114}Cd(p, γ)	0.3362	28.73	0.0	^{115m}In	$\frac{1}{2}^-$	IT : 95.00 % β^- : 5.00 %	4.486 (4) h	336.24 (25)	45.9 (1)
^{114}Cd(p, n)	0.1903	28.73	2.247	^{114m}In	5^+	IT : 96.75 % ϵ : 3.25 %	49.51 (1) d	190.27 (3)	15.56 (15)
^{112}Cd(p, γ)	0.3917	24.13	0.0	^{113m}In	$\frac{1}{2}^-$	IT : 100.00 %	99.476 (23)m	391.698 (3)	64.94 (17)
^{110}Cd(p, n)	0.0	12.49	4.703	^{110g}In	7^+	ϵ = 100.00 %	4.92 (8) h	937.478 (13)	68.4 (19)
^{110}Cd(p, n)	0.0621	12.49	4.703	^{110m}In	2^+	ϵ = 100.00 %	4.92 (8) h	657.75 (5)	97.74
^{110}Cd(p, 2n)	0.0	12.49	12.829	^{109g}In	$\frac{9}{2}^+$	ϵ = 100.00 %	4.159 (10) h	203.3 (1)	74.2
^{110}Cd(p, 2n)	0.6501	12.49	12.829	^{109m_1}In	$\frac{1}{2}^-$	IT = 100.00 %	1.34 (7) m	649.8 (2)	93.51 (9)
^{110}Cd(p, 2n)	2.1018	12.49	12.829	^{109m_2}In	$\frac{19}{2}^+$	IT = 100.00 %	0.209 (6) s	673.52 (8)	97.6 (3)

A detailed depiction of the experimental arrangement and methodology of the BARC-TIFR accelerator utilized to carry out the neutron and proton induced nuclear reactions along with the activation analysis technique used for the cross section estimation is discussed in Chapter 2. A brief overview of the statistical nuclear codes utilized for the present simulation is included in Chapter 3. The statistical nuclear model codes including TALYS, EMPIRE, and ALICE used for theoretical cross-section predictions and a particle transport code MCNP used to calculate proton energy degradation have been discussed. Chapter 4 includes a complete description of the methodology that was followed to study reactions produced using neutrons for ^{197}Au(n, 2n)^{196}Au, ^{115}In(n, n')^{115m}In, ^{232}Th(n, f)^{97}Zr, and ^{238}U(n, f)^{97}Zr is discussed. The significance of the studied reactions in the nuclear reactor was portrayed. The chapter contains the detail of the experimental arrangement, cross section measurement technique, and theoretical calculations and then obtained results and discussion. Chapter 5 contains the proton induced reactions studied for the advanced nuclear reactors and astrophysics implementation. A detail of the standard approximation of the Gamow window for astrophysical interest followed by experimental methodology, and data analysis. The detail of the different nuclear models from the statistical model codes used for the present study has been discussed. The S-factor determination is also presented. Finally, the discussion of the obtained results. Further, a systematic study of deuteron induced reactions has been carried out for some of the elements used for the particle accelerator and nuclear reactors using the statistical nuclear model codes TALYS, EMPIRE, and ALICE has been included in Chapter 6. In the end, the summary and conclusion obtained through the results of the charged particle and neutron induced nuclear reactions are included in Chapter 7. Also, the future scope of such kind of work is discussed.

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