# Chapter 6

# Summary & Conclusions

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This chapter provides a comprehensive summary and outlines the key findings of the current research. It is structured into three sections: the first section presents the conclusions drawn from neutron-induced reactions, while the second section details the conclusions from charged particle-induced reactions relevant to the p-process. The third section outlines the future aspirations and potential directions for this research. In summary, the data presented in this thesis are fundamental for the progression of state-of-the-art reactor and accelerator technologies, accurate dose assessment of nuclear structural materials, developments in nuclear medicine, refinement of control rod performance, and comprehension of the astrophysical p-process.

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This chapter consolidates the key findings from the previous chapters, which explore neutron-induced and charged particle-induced reactions relevant to reactor applications and p-process nucleosynthesis. The investigation into neutron-induced reactions emphasizes the critical role of precise cross-section measurements in optimizing reactor performance and medical isotope production. Similarly, the analysis of proton capture reactions on p-nuclei highlights the importance of accurate theoretical models for understanding nucleosynthesis and refining global nuclear models. The conclusions drawn from these studies not only advance our understanding of nuclear reactions but also underscore the need for continued experimental and theoretical efforts to improve the accuracy and reliability of data used in nuclear technology and astrophysical research. This summary highlights the significant contributions of the research, providing a foundation for future investigations and emphasizing the ongoing challenges and opportunities in the field.

## 6.1 Neutron Induced Reactions for Reactor Applications

In the context of nuclear reactor applications, a comprehensive understanding of neutron-induced reactions is critical for optimizing reactor performance, enhancing safety measures, and improving waste management strategies. This study, conducted at the BARC-TIFR Pelletron and FOTIA accelerator facilities, involved the precise measurement of neutron-induced reactions in reactor structural materials, utilizing neutrons generated via the $^{\mathrm{nat}}\mathrm{Li}(\mathrm{p},\mathrm{n})$ reaction. Offline $\gamma$-ray spectroscopy, using a p-type single crystal HPGe detector, was employed to measure the $\gamma$-activity of irradiated samples. Covariance analysis was then applied to rigorously quantify the correlations and uncertainties in the reaction cross-sections. These findings significantly contribute to the refinement of theoretical models, thereby enhancing the reliability of data essential for advanced reactor applications. The outcomes of the neutron-induced reactions investigated in this study are summarized as follows.

- This study utilized neutron activation analysis combined with offline $\gamma$-ray spectrometry to measure the production cross-section of $^{58}$Co, using quasi-monoenergetic neutrons from the $^{7}$Li(p, n) reaction. The cross-sections were normalized against the reference reaction $^{115}$In(n, n′)$^{115\mathrm{m}}$In, with uncertainties and correlations meticulously calculated through covariance analysis. The results showed consistency with previous experimental data, evaluated data libraries (ENDF/B-VIII.0, JEFF-3.3, JENDL-4.0, CENDL-3.2), and theoretical calculations from the TALYS code. Notably, different level density models in TALYS were assessed to improve the accuracy of the results. The study emphasized the critical role of error propagation techniques in evaluating correlations between monitor reaction cross-sections, which is essential for minimizing uncertainties. These findings are significant for advancing medical accelerator and nuclear reactor technologies, and for enhancing the dose estimation of the medical isotope $^{58}$Co.

- Further analysis included the $^{115}$In(n, n′)$^{115m}$In reaction cross-sections at various neutron energies (7.89–18.99 MeV), compared with theoretical predictions using TALYS and EMPIRE codes. TALYS LD model 2 demonstrated the closest alignment with experimental data, while EMPIRE predictions tended to overestimate the cross-sections. Comparisons with evaluated data libraries revealed a discrepancy, with library data being significantly higher than experimental results, underscoring the recommendation to rely on experimental data for flux measurements.

- Additionally, three new semi-empirical formulas were developed to evaluate (n, p), (n, $\alpha$), and (n, 2n) reaction cross-sections at 14.5 MeV. These formulas showed consistency with existing literature data and offered enhanced predictive accuracy across specified mass ranges for various nuclear reactions.

In conclusion, the work provides essential insights and methodologies for accurate measurement and prediction of neutron-induced reaction cross-sections, enhancing the reliability of data used in nuclear technology applications. The findings of this study are especially significant for nuclear reactor safety, medical isotope production, and advancing theoretical models for nuclear reactions.

## 6.2 Charged Particle Induced Reactions for p-process

In this study, we analyze the uncertainties in proton capture reactions on heavy proton rich isotopes, specifically $^{92,94}$Mo and $^{74,76}$Se, within the energy range of 2 to 6 MeV. Through a comparative analysis of experimental data and theoretical predictions, we evaluate the accuracy of these models in predicting cross-sections. While certain datasets align well with theoretical models, others, particularly at higher energies, show discrepancies. These findings highlight the importance of conducting further experimental research and acquiring additional data to enhance global nuclear models, particularly in regions with limited data availability. The conclusions drawn from the present charged particle induced reactions are as follows:

- Comprehensive uncertainty analysis conducted for proton capture on heavy proton rich isotopes ($^{92,94}$Mo and $^{74,76}$Se) at astrophysically relevant energies.

- Comparison of experimental data with theoretical predictions shows general consistency but highlights discrepancies, especially at higher energies.

- Findings validate the reliability of current models, though the scarcity of data at relevant energies underscores the need for further experimental efforts.
- Future research should focus on acquiring new data for OMPs and NLDs to refine global nuclear models.
- The study enhances understanding of nucleosynthesis in the p-process, contributing to more accurate abundance predictions in astrophysical environments.

In conclusion, this study underscores the importance of rigorous uncertainty quantification in proton capture reactions on p-nuclei, specifically within the astrophysically relevant energy range. The comparison between theoretical predictions and experimental data reveals both agreements and discrepancies, particularly at higher energies, emphasizing the necessity for additional experimental data to refine the theoretical models. Enhancing the accuracy of OMPs and NLDs remains crucial for reducing uncertainties in nuclear reaction rates. These advancements are essential for improving our understanding of nucleosynthesis in stellar environments, particularly within the p-process, and for achieving more precise predictions of elemental abundances in the universe.

## 6.3 Future Plans

Future research should focus on expanding experimental measurements of neutron-induced reaction cross-sections over a wider range of energies and target nuclei to further validate and refine theoretical models. This includes enhancing measurement techniques and developing new semi-empirical formulas to improve accuracy. Additionally, further refinement of theoretical models such as TALYS and EMPIRE is needed to better align with experimental data. Emphasis should also be placed on incorporating advanced error propagation methods to minimize uncertainties in cross-section data, which is crucial for optimizing nuclear reactor safety, medical isotope production, and overall reactor performance and waste management.

A significant gap exists in experimental data at astrophysically relevant energies, especially concerning proton capture reactions on p-nuclei. Such data would help address the discrepancies observed between theoretical predictions and existing experimental results, especially at higher energies. Further theoretical investigations should explore alternative approaches to model proton capture reactions, particularly in regions where experimental data is scarce. This includes the exploration of semi-empirical methods and indirect approaches to cross-section estimation.

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