

Chapter – 7

Final Summary and Conclusions of the Thesis

In the present thesis a major contribution comes in the form of neutron and photon induced nuclear reactions on various structural and other materials. The energy range covered in this work is between 1 to 20 MeV of neutron energy, and in the GDR energy region for photons, that are important for the reactor applications. In the present thesis, the targets used for the measurement of neutron induced reaction cross sections are the isotopes of W, Gd, Ni, V, Mn, Zn and As, which are of prime importance as structural materials. This work is important from the point of view of enhancing the nuclear data, as well as for the validation of present nuclear reaction models. The neutron induced reactions are studied on $^{182-184, 186}\text{W}$, $^{154,160}\text{Gd}$, ^{75}As , $^{64,66}\text{Zn}$, ^{55}Mn , ^{51}V , and ^{58}Ni isotopes. In the present work, the nuclear reactions (n, γ) , (n, p) and $(n, 2n)$ were studied. The reactions on W isotopes were done using ^{252}Cf spontaneous neutron source and accelerator based $^7\text{Li}(p, n)$ neutron source. The reactions on $^{154,160}\text{Gd}$ were studied using accelerator based $^7\text{Li}(p, n)$ neutron source. The remaining reactions on isotopes ^{75}As , ^{66}Zn , ^{64}Zn , ^{55}Mn , ^{51}V , and ^{58}Ni were studied using DT neutron source. The selection of the neutrons energies was done by keeping in view the fact that either there are very few or no cross section data or available data points are with large errors.

In addition to this, the present thesis, the giant dipole resonance mechanism for the photoneutron production was studied. A pure empirical formula has been derived from the first principal and used to explain the photonuclear reactions in the GDR energy range. The work is limited to the only (γ, n) nuclear reactions. The behavior of the nuclear quadrupole moment in deformation of the GDR peak has been demonstrated with the present empirical formula. It has been shown that the formula is applicable to the isotopes with $Z \geq 60$. The isotopes, which have experimental data available in the EXFOR library has been used to validate the presently developed empirical formula. Further, the nuclear modular codes were used as a tool to compare the results from the derived empirical formula. These nuclear models were also used to predict the neutron induced reaction cross section results at various selected incident energies. The models are based on an agreement with the nuclear data available in experimental data library EXFOR. The nuclear reaction codes TALYS –

1.6/1.8 and EMPIRE – 3.2.2, which are based on various well known standard nuclear models predictions, were used in the present thesis. The data produced from TALYS – 1.6 has been compared with the TALYS – 1.8, which is the new version of the code that was released during the course of this work. The data predicted from the both versions in the present work are found almost similar and no major differences were found, and hence the data listed with both the version were used. The photonuclear reaction data were predicted using TALYS – 1.6 and EMPIRE – 3.2.2 codes. The agreement was found consistent with the generated data obtained from the presently derived empirical formula.

(I) The summarized outcomes of this thesis are listed below.

1. The photon induced (γ , n) reaction cross section predictions have been done for isotopes with $Z \geq 60$ using the presently derived empirical formula discussed in this thesis.
2. Following reactions on tungsten and gadolinium isotopes were experimentally measured by using the $^7\text{Li}(p, n)$ reaction obtained from the BARC-TIFR Pelletron facility in Mumbai.
 - (a) The cross sections of $^{186}\text{W}(n, \gamma)^{187}\text{W}$ reaction are measured at 5.08 ± 0.165 , 8.96 ± 0.77 , 12.47 ± 0.825 and 16.63 ± 0.95 MeV.
 - (b) The cross sections of $^{182}\text{W}(n, p)^{182}\text{Ta}$ reaction are measured at 8.96 ± 0.77 , 12.47 ± 0.825 and 16.63 ± 0.95 MeV.
 - (c) The cross sections of $^{154}\text{Gd}(n, 2n)^{153}\text{Gd}$ and $^{160}\text{Gd}(n, 2n)^{159}\text{Gd}$ reactions are measured at 12.47 ± 0.825 and 16.63 ± 0.95 MeV.
3. The cross sections of $^{183}\text{W}(n, p)^{183}\text{Ta}$ and $^{184}\text{W}(n, p)^{184}\text{Ta}$ reactions are measured at 1.70 ± 1.35 MeV and 3.75 ± 1.26 MeV respectively using the ^{252}Cf spontaneous neutron source.
4. The cross sections of $^{75}\text{As}(n, p)^{75}\text{Ge}$, $^{66}\text{Zn}(n, p)^{66}\text{Cu}$, $^{64}\text{Zn}(n, p)^{64}\text{Cu}$, $^{55}\text{Mn}(n, p)^{55}\text{Cr}$, $^{51}\text{V}(n, p)^{51}\text{Ti}$ and $^{58}\text{Ni}(n, p)^{58}\text{Co}$ reactions are measured at 14.2 ± 0.2 MeV using DT neutron source.
5. The role of nuclear modular codes, as well as the nuclear transport codes, have been discussed.

6. The reproduction of experimental reaction cross sections has been done by using the standard modular codes EMPIRE and TALYS.

(II) Following conclusions can be made from the entire work done here:

1. The prediction of GDR cross section from the new empirical formula is in general in agreement with the experimental data from several authors and the theoretical codes TALYS and EMPIRE.
2. The empirical formula derived in this thesis for (γ, n) reaction is limited to validity for $Z \geq 60$ and $N - Z \geq 22$, where Z and N are proton and neutron numbers of the isotope respectively.
3. The deformation and double peak are due to the nuclear quadrupole deformation.
4. In the case of the neutron induced reactions, the offline gamma ray spectroscopy and neutron activation analysis (NAA) techniques have been explored for the cross section evaluations.
5. The cross section measured for neutron induced reactions are in general agreement with the nuclear modular code predicted data for all the three experiments.
6. The different parameters, which can affect the results of the experiment were optimized and corrections have been demonstrated using the MCNP code.
7. The cross sections for $^{183}\text{W}(n, p)^{183}\text{Ta}$ and $^{184}\text{W}(n, p)^{184}\text{Ta}$ reactions using ^{252}Cf neutron source were relatively small.
8. The measured cross sections of $^{186}\text{W}(n, \gamma)^{187}\text{W}$ at 5.08 ± 0.165 MeV, 8.96 ± 0.77 MeV, 12.47 ± 0.825 MeV and 16.63 ± 0.95 MeV, $^{182}\text{W}(n, p)^{182}\text{Ta}$ at 8.96 ± 0.77 MeV, 12.47 ± 0.825 MeV and 16.63 ± 0.95 MeV, $^{154}\text{Gd}(n, 2n)^{153}\text{Gd}$ and $^{160}\text{Gd}(n, 2n)^{159}\text{Gd}$ at 12.47 ± 0.825 MeV and 16.63 ± 0.95 MeV are in agreement with the code evaluated data. In the case of the cross section of $^{160}\text{Gd}(n, 2n)^{159}\text{Gd}$ reaction at 16.63 ± 0.95 MeV, the value is under estimated.

9. The present results of (n, p) reaction cross section for ^{75}As , ^{66}Zn , ^{64}Zn , ^{55}Mn , ^{51}V and ^{58}Ni at 14.2 ± 0.2 MeV are in good agreement with the previous measurements and theoretical calculations.

Future Outlook

The present thesis discusses the cross section measurement of those isotopes having very few and scarce data using the standard neutron activation analysis. In the future proposal, accelerator based neutron sources will be employed for the cross section measurement for those isotopes have wide prospects in reactors, but there is a complete lack of cross section data. There are several structural materials still have data shortage, which needs to be completed. The isotopes of tungsten will be taken for further measurements. The empirical formula, which is still applicable to the isotopes with $Z \geq 60$ will be extended to the whole periodic table. The present formula must be extended for the entire energy range and other photoneutron production channels too. Overall the present work has plenty of future scopes.