CHAPTER 4

THE $^{58}Ni(n, p)^{58}Co$ REACTION CROSS-SECTION: EXPERIMENTAL PROCEDURE

4.1 Introduction

In this chapter, we present the description of samples irradiated in the experiment to determine $^{58}Ni(n, p)^{58}Co$ reaction cross-section in Section 4.2. In Section 4.3, we present lithium foil preparation by rolling technique. The samples and the lithium foil were then used to prepare the target for irradiation, as presented in Section 4.4. The details of irradiation and counting measurements were presented in Section 4.5 and Section 4.6, respectively.

This chapter is based on section II of [Shivashankar et al., 2015].
4.2 Description of Samples

In the present work our aim was to determine neutron induced reaction cross-section for the $^{58}\text{Ni}(n,p)^{58}\text{Co}$ reaction at three different neutron energies. Hence our foil or sample of unknown cross-section ($\sigma_u$) is natural nickel foil (unknown sample or foil).

The experimental method adopted is relative measurement, that is the nickel foil has to be irradiated with a standard or monitor sample of accurately known cross-section ($\sigma_m$). So that $\sigma_u(E_n) = f(\sigma_m(E_n))$ can be determined.

We have employed two monitor foils (natural uranium (U) and natural thorium (Th) foils) in our work. The monitor reactions considered were $^{238}\text{U}(n,f)$ and $^{232}\text{Th}(n,f)$ fission reactions. In fission reaction $^{238}\text{U}$ and $^{232}\text{Th}$ splits into two nuclei of lower mass number called fission products. Out of many such fission products in $^{238}\text{U}(n,f)$ and $^{232}\text{Th}(n,f)$ fission reactions, we considered a particular fission product $^{97}\text{Zr}$ (fission product $^{97}\text{Zr}$ in $^{238}\text{U}(n,f)$ reaction and fission product $^{97}\text{Zr}$ in $^{232}\text{Th}(n,f)$ reaction).

On the basis of monitor reactions employed, the standard or monitor cross-sections employed in the present work were $\sigma_{mj} = Y_{fj}\sigma_j$ and $\sigma_{ml} = Y_l\sigma_l$, where $\sigma_{mj}$ is the cross-section for the formation of fission product ($Y_{fj}$) $^{97}\text{Zr}$ in $^{238}\text{U}(n,f)$ reaction, and $\sigma_{ml}$ is the cross-section for the formation of fission product ($Y_l$) $^{97}\text{Zr}$ in $^{232}\text{Th}(n,f)$ reaction [Shivashankar et al., 2015].

The basic idea is to irradiate Ni, U and Th foils in same neutron field and then to observe the activity of irradiated foils, by keeping each foil separately in a specified sample holder slot of HPGe detector. If irradiated Ni foil is placed in a specified sample holder slot of HPGe detector and if a $\gamma$-peak of 810.77 keV [Chu et al., 2014, NNDC, 2014] is registered by the detector, which is the indication that the $^{58}\text{Ni}(n,p)^{58}\text{Co}$ reactions have occurred. The $\gamma$-line of 810.77 keV is emitted from the product $^{58}\text{Co}$ in exited state. The same procedure is repeated for U and Th foils. The $\gamma$-peak of interest in this case is 743.36 keV [Chu et al., 2014, NNDC, 2014] emitted from the fission product $^{97}\text{Zr}$ in exited state. The decay schemes of $^{58}\text{Co}$ and $^{97}\text{Zr}$ are presented in Fig. 4.1.
Figure 4.1: Decay schemes of $^{58}\text{Co}$ and $^{97}\text{Zr}$ [Chu et al., 2014].
In the present work, we selected three sets of natural nickel (Ni), uranium (U) and thorium (Th) foils of dimension 1cm × 1cm for irradiation. Weight of each foil was measured using electronic physical balance.

After weighing, each foil was wrapped separately with 0.025 mm thick aluminum to prevent radioactive contamination from each other during irradiation. Foils in the first set were labeled Ni-1, U-1 and Th-1, and were together wrapped again with 0.025 mm thick aluminum. Same procedure is repeated for the remaining two sets. Foil weights are presented in Table 4.1, the foil weights were taken from [Shivashankar et al., 2015].

4.3 Lithium Foil Preparation by Rolling Technique

Neutron source employed in the present work is $^7$Li(p,n) reaction. Lithium foil required for the experiment is prepared by Rolling Technique [Gupta et al., 2014, Prajapati, 2012] at target laboratory of Tata Institute of Fundamental Research (TIFR), Mumbai.

Rolling Technique is cost effective method for the foil preparation, rolling machine of TIFR target laboratory is shown in Fig.4.2. In rolling technique, the Lithium\footnote{Lithium is a soft metal. It is also one of the highly reactive metals. To avoid exposure to air, it is usually stored in kerosene or paraffin wax.} foil (of arbitrary shape and thickness) to be rolled is placed between the sheet of Teflon (TS). The TS containing Lithium foil is then fed into the hard rollers of the rolling machine. After preliminary rolling, Lithium foil will be removed out of teflon sheets, and cut into rectangular shape of desired dimension and the fed again to the rolling machine. The

<table>
<thead>
<tr>
<th>Foil</th>
<th>Weight(g)</th>
<th>Foil</th>
<th>Weight(g)</th>
<th>Foil</th>
<th>Weight(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-1</td>
<td>0.4262 ± 0.0085</td>
<td>Th-1</td>
<td>0.2856 ± 0.0057</td>
<td>U-1</td>
<td>0.6970 ± 0.0139</td>
</tr>
<tr>
<td>Ni-2</td>
<td>0.1813 ± 0.0036</td>
<td>Th-2</td>
<td>0.3230 ± 0.0065</td>
<td>U-2</td>
<td>0.9917 ± 0.0198</td>
</tr>
<tr>
<td>Ni-3</td>
<td>0.1260 ± 0.0025</td>
<td>Th-3</td>
<td>0.3252 ± 0.0065</td>
<td>U-3</td>
<td>0.5795 ± 0.0116</td>
</tr>
</tbody>
</table>
procedure is repeated until the minimum possible thickness is achieved. In our work, Lithium foil thickness\(^2\) was \(~3.2\, mg/cm^2\).

![Figure 4.2: Rolling machine at TIFR target laboratory [Prajapati, 2012]](image)

### 4.4 Target Preparation

The lithium foil of thickness \(~3.2\, mg/cm^2\), is sandwiched between two tantalum foils of different thickness for mechanical support. The tantalum foil facing the proton beam should allow the protons to interact with lithium foil, and the other tantalum foil should stop the protons, which have not interacted with lithium.

The thin tantalum foil of thickness \(3.9\, mg/cm^2\) was used for proton facing, in which degradation of proton energy was about \(30\, keV\). The other tantalum foil thickness was \(0.025\, mm\), which is sufficient to stop the proton beam.

The tantalum-lithium-tantalum (Ta-Li-Ta) stack is mounted on the target holding assembly facing the proton beam. Ni-U-Th stack mentioned in Sec.4.2 is mounted at the

---

\(^2\)The quoted thickness of Li foil is average value, i.e. thickness was measured using screwgauge at different locations and average value is quoted. The Li foil was prepared by Dr. Mahdakar at target preparation laboratory of TIFR using rolling technique. The Li lump was immersed in kerosine, and rolled before it get dried. Just after rolling, the target was prepared (mounted on the target holder) and taken to 6 m pelletron irradiation facility.
other end of target holding assembly, at a distance of 2.1 cm from Ta-Li-Ta stack. Picture of target holding assembly is presented in Fig. 4.3. Target holding assembly can be installed at the 6 meter irradiation setup of BARC-TIFR Pelletron accelerator (irradiation setup is at 6 meter above the analyzing magnet). The BARC-TIFR Pelletron accelerator, 6 meter irradiation setup is shown in Fig. 4.3.
4.5 Irradiation

Tower view and schematic view of BARC-TIFR Pelletron accelerator (14 UD Model) is presented in Fig. 4.4. Pelletron accelerator working principle and proton acceleration is given in Sec. 3.3.

We conducted three experiments at three different proton beams of energy 7.8, 12 and 18 MeV. The irradiation period was for 15 h, 6 h and 5 h respectively. The proton current during the irradiation was in the range of 100 — 400 nA. The energy spread for the proton beam at 6 meter irradiation setup was in the range of 50-90 keV. At this port, the terminal voltage was regulated using a terminal potential stabilizer. Further, we used a beam collimator of 6 mm diameter before the Ta-Li-Ta stack [Shivashankar et al., 2015].

The proton beam energy considered in our experiment is greater than the required threshold energy (∼1.8 MeV) for the $^7$Li$(p, n)$ reaction. The protons which do not interact with lithium foil will be stopped in the thick tantalum foil of Ta-Li-Ta stack. The neutron beam produced in the $^7$Li$(p, n)$ reaction will irradiate the Ni-U-Th stack.

After irradiation, the samples were cooled for one hour. Then the irradiated Ni, U and Th foils were separated from the stack. Each of the irradiated foil along with Al wrapper were mounted on perspex plate and taken for γ-ray spectrometry to check the activity of irradiated foils.

4.6 Counting Measurement and Counting Data

FIGURE 4.5: Liquid nitrogen plant and Ortec HPGe detector facility of radio chemistry lab, TIFR.
The Canberra HPGe detector system (coupled to a PC-based 4 K channel MCA) used in our work is presented in Fig. 4.5. The high purity germanium crystal present in the HPGe detector has to be maintained at liquid nitrogen temperature, before turning on the high voltage power supply. The power supply employed was Canberra portable bin/power supply, model 1000. Voltage is adjusted in small steps to -3200 V, coarse gain of 100 and sharpness of 3 µs were employed [Shivashankar et al., 2015].

The detector efficiency was 20% at 1332.5 keV relative to 3’’ diameter × 3” length NaI(Tl) detector and The energy resolution of the detector system was 1.8 keV at 1332.5 keV γ-ray energy of $^{60}$Co (specifications as given by the manufacturer).

The efficiency calibration of the detector was done using standard $^{152}$Eu point source. We selected standard $^{152}$Eu source, because the γ-lines emitted covers wide energy range. We kept the $^{152}$Eu point source at 10th shelf of the sample holder, which is approximately 10 cm from the detector. Further details on efficiency calibration is discussed in Chapter 6.

The above mentioned process of detector calibration was done much before the irradiation of the foils, so that detector system is ready for the counting measurements.

After the irradiation and subsequent cooling process, each of the Ni, U and Th foils mounted on perspex plate are kept at 10th shelf of the detector sample holder, separately. Initially the observation was done for very short time, just to check the activity.

We observed the photo peak at 810.77 keV from the irradiated Ni sample. 810.77 keV γ-line is emitted from the reaction product $^{58}$Co in exited state. The γ-ray spectra of $^{58}$Co from 503.4 h cooled sample (Natural Nickel), showing photopeak at 810.77 keV is presented in Fig. 4.6. Similarly, we observed photo peak at 743.36 keV from irradiated U and Th samples. The 743.36 keV γ-line is emitted from the fission product $^{97}$Zr in exited state.

Counting data (raw data) obtained from the irradiated Ni, U and Th are presented in Table 4.2. Wherein the γ-ray counts (γ-counts) mentioned in the last column, are the center and spread of the photo peaks at $E_\gamma = 810.77$ keV in case of Ni foils, and at $E_\gamma = 743.36$ keV in case of Th and U foils, respectively.
Chapter 4. Experimental procedure

4.7 Conclusion

The specifications of proton energy and its energy spread, presented in Section 4.5 and thickness of the samples presented in Section 4.2, all play very important role in the estimation of effective neutron energies, presented in chapter 5. The weight of the samples and counting data of the irradiated samples are the necessary information required for the covariance analysis presented in chapter 7.