Chapter 3

Experimental Details

3.1 Introduction

An experiment with radioactive ion beam poses many problems compared to that with a normal beam because of the intrinsic properties of the RIB. For example, the intensity of RIB is only $10^3$ to $10^5$ pps while for normal beam it is $10^9$ pps or so. This leads to a very low reaction yield. Again the intrinsic energy spread of the RIB is in the MeV range while it is in the keV range for normal beam, and the angular spread of RIB is much more than that of a normal beam. In terms of beam spot, the size of the beam spot for RIB is one order of magnitude or so higher than that of the normal beam spot. So, one cannot expect a similar energy and angular resolution from an experiment involving RIB as that from a normal beam.
However, improvement in the instrumentations can lower these uncertainties. For the \(^7\)Be+\(^7\)Li elastic scattering a high efficiency detector system and other accessories have been developed to improve upon the data quality which will be described in later sections.

### 3.2 The Experimental Scheme:

The schematic of the experimental set up is as shown in fig. 3.1.

The primary \(^7\)Li beam from the 15UD Pelletron is allowed to reach the HIRA-RIB facility site and made to react with the primary target which is a polypropylene foil in rotary/linear motion placed at the entrance of HIRA. This produces radioactive \(^7\)Be in an inverse kinematic mode through \(^7\)Li(p,n)\(^7\)Be reaction. After energy and mass selection by HIRA the \(^7\)Be (having a half life of 53 days) is allowed to fall on the secondary \(^7\)Li target kept at the second and final focal plane of HIRA. The scattered particles are detected by a set of detectors installed behind the target. The next few sections describe the facilities, required for doing the experiment.

#### 3.2.1 The Pelletron

The 15UD Pelletron [1, 8] at NSC, dedicated for accelerator based research in physics, is an improved version of Van de Graaff accelerator. Fig. 3.1 shows the
Overall Plan

Chapter 3

Production target
Reaction target
detector setup

Figure 3.1: A schematic diagram of the experimental setup
schematic of the Pelletron while fig. 3.2 shows the principle of acceleration of ions in Pelletron.

![Diagram of Pelletron Accelerator](image)

Figure 3.2: Charging principle of pelletron (Courtesy to www.nsc.ernet.in)

The 15UD Pelletron is a tandem electrostatic accelerator, in vertical configuration, which can accelerate any ion from proton to uranium upto an energy of around 200 MeV or so depending on the ion and the charge state. The Pelletron accelerator consists of two main parts – ion source and the accelerating column with many other auxiliary parts in between.
There are three different ion sources, namely Alphatross, SINCS and Duoplasmatron, which can produce different negative ions to be injected into the Pelletron. The negative ions emerging from the ion source are first accelerated to 250 KeV by the high voltage deck potential and different optical elements focus and inject the same into the vertical accelerating tube. The injector magnet does mass selection by bending the ions by 90° and then injects them into the accelerating tube. The singly ionized negative ions then follow a vertical downward path and get accelerated through the accelerating tube.

The 26.5 meter long vertical accelerating tube includes a terminal, which gets charged by the Van de Graaff charging mechanism. It can hold potential from 4 MV to 15 MV. There are thirty units, 15 on either side which provide a positive potential gradient from the low energy end to the terminal and negative potential gradient from the terminal down to the high energy end at the bottom of the terminal. All the 30 units are provided with equipotential rings and a linear network. Rings are insulated from each other by ceramic rings in between. At the terminal there is a charge stripper which changes the incoming negative ions to positive ions (with different charge state). In a dead section on the higher energy side there is a second foil stripper which can further strip off electrons from the positive ions, to give a higher charge state and hence greater energy.

When the negative ion from the injector magnet feels the positive potential gradient it gets accelerated towards the terminal where some of its electrons get stripped in the stripper foil and the ion becomes positive. Then this positive ion sees a negative potential gradient further downwards and gets accelerated more. Thus the ion gets accelerated twice by the same terminal potential. The energy (E) gained by the ion in the accelerating tube at the end of the tube is given by,
where \( V \) is the terminal voltage and \( q \) is the effective charge of the ion.

The energetic beam, having different charge states, is then allowed to pass through the analyser magnet which is used to select ions of particular charge state and hence particular energy. Then the energy selected ions enter the switching magnet which bends the beam to any one of the seven different beam lines for experiment.

### 3.2.2 The HIRA-RIB facility

**HEAVY ION REACTION ANALYSER (HIRA)**

Heavy Ion Reaction Analyser (HIRA) [2] at NSC, is a recoil mass spectrometer (RMS) based on the principle of dispersion of ions in electric and magnetic fields. HIRA is a device to separate and reject beam like particles from the nuclear reaction products at forward angles (i.e., \( 0^\circ \)) and thus eliminates beam background from the reaction products. The reaction products are separated according to their \( M/q \) (mass/charge state) value and different masses are focused at different points at the focal plane.

The schematic of HIRA is shown in the fig. 3.1. HIRA is 8.6 meter long and the ion optics is based on the electric (ED1) - magnetic (MD) - electric (ED2) dipole configuration as dispersive elements and two entrance (Q1, Q2) and exit quadrupole (Q3, Q4) doublets as focusing elements.
At the entrance of the HIRA, a sliding seal target chamber coupled to the 15° beam line, is installed, followed by the ion-optical elements Q1Q2-ED1-MD-ED2-Q3Q4, and then another chamber called focal plane chamber (FPC) at the end. FPC houses the detector system. The whole structure rests on a large rotatable platform such that it can be rotated to any desirable angle between -5° to 45°.

The electric dipoles ED1 and ED2 give rise to the energy dispersion while the magnetic dipole MD does the momentum dispersion and the net effect of ED1-MD-ED2 configuration is the M/q dispersion and the energy achromaticity of the reaction products. The beam of projectiles from Pelletron interacts with the target mounted in the sliding sealed chamber and different reaction products along with the beam like particles are focused by the magnetic quadrupoles Q1 and Q2 in the XZ and YZ plane (the beam direction is in the Z direction, say). ED1 is a large electric dipole consisting of cylindrical anode plate and a cathode plate. It disperses the reaction products according to their E/q (energy/charge state) value and rejects most of the beam-like particles. At the middle of the anode plate there is a horizontal slot leading to a Faraday cup where the non-interacting beam like particles which have much higher electric rigidity than the reaction products are collected.

Between ED1 and MD there is a magnetic multipole M (not shown in the fig. 3.1) which reduces the higher order aberrations.

The magnetic dipole MD gives rise to momentum dispersion according to the formula \( \frac{mu}{q} = B.R \) (where B is the magnetic field, R is the bending radius). The momentum dispersed ions now enters the second electric dipole ED2 which further rejects the beam like particles and does energy dispersion. In the symmetric configuration of ED1-MD-ED2, the energy dispersion caused in the first half (ED1 + half MD) is cancelled by the second (mirror) half (half of MD + ED2) to achieve the
energy achromaticity at the focal plane. So the whole ED1-MD-ED2 configuration causes $M/q$ dispersion and energy achromaticity of the ions. Now the ions further enter the fields of quadrupoles Q3 and Q4 which focus the ions at the focal plane where the detector system detects them.

All the HIRA fields are set and controlled by computer.

**THE RADIOACTIVE ION BEAM (RIB) FACILITY:**

In 1998, a new facility was added to HIRA by operating it in a different ion-optical mode as well as by adding some new hardwares, opening up a new frontier of research in nuclear physics in India, known as radio active ion beam (RIB) facility [3]. It is an in-flight separation facility and RIB is produced in the inverse kinematic mode.

The main features of the RIB here is a fine beam spot (3 mm diameter) and high purity (99.9\%) at low energy (1-3 MeV/nucleon).

The primary beam from the Pelletron is used in $(p,n)$, $(d,n)$ type of reactions in highly inverse kinematic mode to produce RIBs. The primary beam energy is kept in such a way as to avoid multi particle emission which can cause intrinsic impurity to the RIB species produced.

In the new optics for RIB, there is an intermediate focal plane (F1) at the mid plane of symmetry at the centre of the magnetic dipole (MD) and the final focal plane (F2) downstream of Q4. The first focusing elements Q1Q2 are chosen in such a way as to maximise the energy resolution at F1 and optimise the transmission of RIBs. At the first focal plane F1, the ions are both energy and mass dispersed. In this new optical mode, there is unit magnification both in horizontal and vertical
planes at F2 because of symmetry and many higher order aberrations vanish. Thus at the final focal plane F2, which is the site for secondary target, there is a 4-fold focusing - energy, mass, and spatial focus in horizontal and vertical direction.

The main hardware added to this facility are (1) a rotary/linear motion target assembly and (2) a momentum filter assembly.

The target assembly:

Two types of target assembly are used to produce RIBs... (1) rotating wheel assembly and (2) cryogenic gas cell.

As mentioned earlier, RIB can be produced in inverse kinematic mode in (p,n) or (d,n) type of reactions which need H₂ or D₂ targets for production of RIBs. In the rotating wheel assembly [4], (CH)₂ or (CD)₂ foils are used as target on a rotating frame which is also given a linear up and down motion in order to avoid the continuous hitting of the primary beam at the same place as these foils are prone to melting in the heat generated by the ion impingement. This target assembly gives a fine quality of beam but at the expense of beam intensity.

The other target assembly is the cryogenic gas cell where H₂ or D₂ gas is used as target gives a higher beam intensity (10^4 pps) but a poorer quality beam.

The momentum filter assembly:

At the first focal plane F1 where the RIB and normal beam are well separated a momentum filter assembly is used to cut out the normal beam and allow the RIB to pass unhindered ensuring a high purity of RIB.

The schematic of RIB production at NSC is shown in fig. 3.1.
3.2.3 The detection system

In experimental nuclear physics, detector system plays a very important role. The success of an experiment depends on the efficiency and good resolution of the detector system.

Elastic scattering experiment with $^7$Be beam has many difficulties. Firstly, the RIB, produced using in-flight technique as done at NSC, has intrinsic energy and angular spread caused by the production reaction and target thickness. These spreads are limited by the acceptance of the spectrometer as well as by the slits/apertures at various places along the flight path of the ions. But narrowing down these slits very tightly to reduce spreads further is not advisable as RIB intensity will fall. So a compromise is normally made between the required beam intensity and acceptable beam quality. Typically, it is operated with $\pm 30$ mrad angular and $\pm 2.5\%$ energy spread @ 5-10kHz flux. To compensate for this low beam intensity, high efficiency, discriminative detector systems are required. Secondly, the energy spectrum of $^7$Be beam shows a low energy tail. This is caused partly by the poor energy response of the large area detectors and also by scattering of beam from the slit systems mentioned earlier. Moreover, these scattered particles do not follow the mean ion optical trajectory and hence are not focused to a narrow spot and show up as tails in position spectra (beam halo). Typically, in an optimised settings, such events are of the order of 1%. Presence of these tails in elastically scattered events are undesirable as actual scattering events at any given angle will get contaminated by these random events. A kinematic coincidence technique can help in reducing these unwanted events.

To compensate for the low intensity of the $^7$Be beam and to reduce the effect of beam halo we have designed a detector system with high efficiency (50%) covering
an angular range of $3^\circ$ to $36^\circ$ and $54^\circ$ to $70^\circ$.

The detector system \cite{5} consists of two position sensitive annular silicon detectors (A1 and A2) obtained from MICRON, UK, a position sensitive 2-dimensional silicon detector (PSSD) from Eurisys Mesures, France and a compact transmission type ionization gas detector, fabricated at NSC.

**The annular detector**

![Front side of the annular detector](a) ![Back side of the annular detector](b)

Figure 3.3: Front side of the annular detector with 16 rings divided into 4 sectors for position read out (a) and the back side of the annular detector with 16 sectors for energy readout (b)

Both the annular detectors have identical dimensions: 96 mm outer diameter and 44 mm inner diameter and approximately 500 micron thickness. There are 16 concentric rings on p-side about the axis of the detector for obtaining the angular information. The p-side is again divided into 4 sectors to take the read outs. The n-side of the detector which gives energy information is divided into 16 sectors azimuthally. The number of position read out from the front side of each annular detector is $16 \times 4 = 64$ and that for energy read out from the back side is 16. So the total read out from each annular detector is 80 which are available via two
40 pin (20 pair) male FRC connector, one each for the two hemispheres of the detector. One FRC connector has readouts for 8 sectors and 32 quarter rings. One connector is placed on the upper side and one on the lower side of the PCB. In order to reduce this huge electronics involved with this large number of detector readouts, at the same time keeping the information from the detector intact, the number of detector readouts were minimised to the extent possible. The resistive charge division readout method was preferred for the concentric rings. Rings in each quadrant were separately interconnected by an external resistive chain. Thus we had 4 independent resistive chains for the rings, one for each quadrant. Readout electronics were connected to one end and the other end of the resistive chain was terminated with 50 ohm lemo terminator. Thus 64 position readouts were reduced to 4 readouts only. All the energy readouts from the back side of the detectors were shorted externally into one. Thus, there were only 4+1=5 read outs from each annular detector.

The external resistive chain is made on a 1.6 mm thick, 88 mm x 22 mm double sided PCB using 100 ohm surface mountable chip resistors and a PCB mountable 40 pin (20 pair) female FRC connector. The four sectors were also shorted on the same PCB. The female FRC connector mounted on the PCB is directly plugged onto the male FRC connector of the annular detector. Four such PCB, two each for one annular detector, were made. Each PCB had readouts for two quadrants i.e two resistive chains and corresponding 4 shorted sectors of the back side.

The maximum bias of the detector is +30V from the back side. 50 ohm termination on the resistive chain side completes the dc bias path.

The PSSD (Position Sensitive Silicon Detector)
The PSSD has a dimension of 50 mm x 50 mm and thickness of 300 micron. The front side of the detector is the resistive layer and the position information are collected from the four corners of the detector namely A,B,C,D as shown in fig. 3.4. The back side is the n-side which gives energy information. The X and Y positions can be obtained from

\[ X = Const \frac{(C + D) - (A + B)}{E} \]

\[ Y = Const \frac{(B + D) - (A + C)}{E} \]

**The Ionisation Chamber**
The ionisation detector consists of 3 wire planes as electrodes: first and third electrodes are grounded and act as cathodes while the middle one is raised to positive bias, acting as anode. The wire planes are perpendicular to the beam axis and separation is 9 mm each between the planes. This electrode geometry is chosen to optimise the detection efficiency (angular) of the annular detectors in the kinematic coincidence mode and to reduce the non-linearity of the electric fields of the gas detector arising from the very short gas length and large opening of the detector.

The schematic of the detector system is shown in the fig. 3.6. As shown in the figure, the first annular detector (A1) is at the front of the detector system, followed
Figure 3.6: A schematic of the detector system at the focal plane chamber.
by the ionisation chamber (IC) and then the second annular detector (A2). It is followed by the PSSD. A tantalum stopper of 8 mm diameter is hung in front of the PSSD to protect it from the direct beam exposure as it is in the beam direction. The whole detector assembly was housed in a stainless steel chamber. The front annular detector was mounted at the entrance of the chamber while the rest of the detectors were mounted inside the chamber. The chamber was isolated from the outer environment at the entrance window by a 6 micron polypropylene foil.

The design of the detector system has evolved through many iterations and more or less meets the basic design requirements mentioned earlier. All the distances/gaps were minimised to the extent possible. The first annular detector subtends an angle of 54° to 70° in the laboratory while the second annular detector covers an angular range from 20° to 36°. The PSSD covers angles from 3° to 20°. There are two ΔE-E telescope systems: the IC and the second annular detector and IC and PSSD. For the identical system like $^7\text{Be}+^7\text{Li}$ the first and the second annular detectors are operated in kinematic coincidence mode. For some inverse kinematic reactions like $^7\text{Be}+^2\text{H}$ the first annular detector and the PSSD may be used in kinematic coincidence mode.

**The Alignment of the Detector System**

The alignment of the centre of the detector system with the beam direction and alignment with respect to each other is very crucial for this detector system. Otherwise all the angle information given by the concentric rings of the annular detectors will be lost. So, to get proper angle information we have made a special arrangement to align the detector system which is briefly described below.

As shown in the fig. 3.7 the alignment arrangement consists of a centre aligning
Detector alignment arrangement

Figure 3.7: Alignment assembly for the detector system
Figure 3.8: (a) The CAC put in the back flange of the detector chamber through the mounting plates for PSSD and back annular detector
Figure 3.9: (b) The back annular detector and the PSSD mounted after alignment.
cylinder (CAC) of diameter \(= 60 \pm 0.25 \text{ mm} \) and a length of 110 mm, which has a small cylindrical extension of 20 mm diameter at the bottom which can be push fitted to a hole of a 10 mm thick plate. Three plates were made for mounting the three detectors, namely, first annular detector, second annular detector and the back PSSD with a centre hole of 60 mm such that all the mounting plates can be push fitted to the centre aligning cylinder. The CAC can also be push fitted to the centre hole (of diameter \(= 60 \text{ mm} \)) of the front flange of the detector chamber.

First, the 10 mm thick plate (90 mm x 50 mm) was fixed to the back flange of the detector chamber and then finding the centre of the flange mechanically, a 20 mm hole was made on the plate. The CAC was now fitted on the plate and then the detector chamber was put while the CAC was protruding through the window at the front flange of the detector chamber. In fact, the CAC is push fitted through the window too (with no window foil). Now at this position the whole chamber was aligned symmetrically with respect to the central line of the chamber and two dowels were made at the back flange of the detector chamber to make the alignment permanent. After this alignment, the mounting plates were push fitted through the CAC and tape holes at the back flange and the front flange and through holes at the plates to mount the plates were made making sure of the alignment of the plates mechanically, with respect to the central line of the detector chamber. The mount holes for the detectors at the plates were also made after mechanically ensuring the positions such that the detectors when put at the plates should be perfectly aligned to the plate's centre. This made the detectors aligned with respect to the central line of the detector system.

The detector chamber was put at the focal plane chamber of HIRA and aligned using telescope with respect to the secondary beam direction and at the aligned
position two dowels were put between the focal plane chamber and the detector chamber to make the alignment permanent such that one need not have to align the detector assembly each time it is put into the focal plane chamber. On the other hand, in the entire alignment process the detectors were not put in as even slight mechanical stress may break the detectors which are too thin (in the micron range) and very costly.

On-line, detector alignment could be monitored from the position spectra of the detectors.

3.2.4 The secondary target

The enriched $^7$Li was our choice of target to perform the planned experiment. But $^7$Li is hygroscopic in nature. As soon as it comes in contact with air, it absorbs moisture and oxygen and forms hydroxide and oxide, thereby spoiling the target. Hence, for $^7$Li, we need an in-vacuum target transfer system from the target evaporation chamber to the scattering or reaction chamber. We have made an in-vacuum target transfer system [6] which can be easily coupled to both evaporation chamber and scattering chamber.

The details of the in-vacuum target transfer system are described below.

Fig. 3.10 shows the schematic of the in-vacuum transfer system while fig. 3.11 is the actual in-vacuum transfer system at the target evaporation chamber.

In the fig. 3.10, A is the neck with compatible flange to the target evaporation
Figure 3.10: In vacuum transfer system

(all dimensions are in mm)
chamber as well to the HIRA focal plane chamber. A is connected to the valve B whose other end is connected to the multi-port chamber C. The multi-port chamber has provision for pumping, measuring pressure and for viewing the target. The multi-port chamber is coupled to the magnetically driven shaft bought from MDC Ltd. for in-vacuum transportation. This magnetic drive allows the vacuum tight transportation of the target by pulling or pushing the target ladder which is attached to the shaft.

The working of the target in-vacuum transfer mechanism is very simple. The whole assembly is first fixed at the port of the target evaporation chamber and the valve is kept open. Then the target evaporation chamber is evacuated and the magnetically driven shaft is pushed inside the chamber such that the target ladder is in the substrate position. For making target like $^7$Li with thin Carbon backing, target holder with the thin carbon film is mounted on the target ladder before putting it into the chamber.

In this condition the multi-port chamber is also in the same vacuum state as the evaporation chamber. Now target material is deposited on the carbon film by evaporation and then by pulling the magnetically driven shaft, the target ladder is withdrawn into the multi-port chamber. Then the valve is closed and the transfer assembly is decoupled from the evaporation chamber. After this the whole system is taken to the HIRA focal plane chamber and fixed at the port meant for it. Now the focal plane chamber is evacuated and after it reaches the desired vacuum, the valve B is opened and the target shaft is pushed in so that the target is now at the beam height.
Evaporation of $^7$Li

The alignment of the detector system and target with respect to beam direction was very crucial for proper angular information. But as $^7$Li target is hygroscopic, alignment cannot be done with the targets exposed to air. Hence, the alignment of the target assembly was done before evaporation by putting the target holders in position.

On the bottom two target holder positions 10$\mu$g/cm$^2$ thick carbon foils were used as backing foil. On the top position holder one CD2 target of thickness 1mg/cm$^2$ (which was commercially available) was placed. CD2 target was used to do a scattering measurement of $^7$Be+$^2$H to test the kinematic coincidence mode of the detector system. The whole assembly was connected to the target evaporation chamber. A shutter was put to mask the CD2 target from getting exposed to
evaporated $^7$Li.

The metallic $^7$Li which was kept in a sealed argon atmosphere was opened by constantly blowing argon gas in a deep, long chamber. $^7$Li ribbon was then transferred to an air tight plastic bag which was first flushed with argon. While putting the ribbon, argon was constantly blown into the bag. Then it was sealed and kept in a chamber whose bottom surface was filled with CuSO$_4$ which absorbs moisture. CuSO$_4$ was slightly heated up to enhance the absorption of moisture. The chamber was also flushed with argon while putting the plastic bag containing $^7$Li ribbon. Then the chamber was closed and evacuated to rough vacuum.

The in-vacuum target transfer system was coupled to the evaporation chamber. A piece of $^7$Li was taken out from the plastic bag (while opening the chamber argon was constantly blown) and immediately put in the Mo boat in the evaporation chamber. Argon gas was constantly blown around and on the $^7$Li piece while placing it in the boat and closing the chamber. This way it was hardly in contact with moist air and was still shining. The target chamber was closed, isolation valve of in-vacuum target transfer system was opened, chamber was pumped out and kept in high vacuum for 8 hrs. Then the isolation valve was closed and current was applied for 20 minutes to the boat to get rid of the surface contamination from the $^7$Li piece. After that the current was stopped and the system was pumped out for another half an hour. Then the isolation valve was opened and the target holder was put at the substrate position.

In literature [7], we have found that by evaporation method, the optimum thickness of $^7$Li target made is generally not more than 200$\mu g/cm^2$, but our required thickness was more than 500$\mu g/cm^2$. It was difficult to evaporate $^7$Li of that thickness as it peels off beyond a certain thickness.
So, we started evaporating $^7$Li at a very low rate of 0.1 nm per sec and evaporated to the required thickness. Then the target ladder was pulled out and allowed to rest in the multi-port chamber and isolation valve was closed. During evaporation we found that in-spite of the masking some $^7$Li got deposited on the CD2 target.

The in-vacuum target transfer assembly was dismantled from the evaporation chamber and was put in the HIRA focal plane. The multi-port chamber was connected to a roughing pump and pumped out constantly.

From the view port we found that there was no peeling off of $^7$Li.

The thickness of the targets were determined from the energy loss of alpha particle (taking an alpha source run with PSSD detector, and putting a mask with a 3 mm central hole at its front) and the thickness of the targets found were as follows...

<table>
<thead>
<tr>
<th>position</th>
<th>target</th>
<th>thickness($\mu g/cm^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$^7$Li</td>
<td>628.19</td>
</tr>
<tr>
<td>2</td>
<td>$^7$Li</td>
<td>593.22</td>
</tr>
<tr>
<td>4</td>
<td>CD2+$^7$Li</td>
<td>10000 +420.88</td>
</tr>
</tbody>
</table>

**Table 3.1: Thickness of the targets as obtained from alpha particle energy loss**

**Attempt to prepare target by rolling method**

Before evaporation method, rolling method was also tried to roll the $^7$Li to 500 $\mu g/cm^2$ in an argon atmosphere. Literature says by rolling method $^7$Li can be rolled to 1 mg $/cm^2$ easily.
A piece of $^7\text{Li}$ was put in liquid paraffin which prevents air or water molecules to come in contact with $^7\text{Li}$ and then placed in a plastic bag to which argon gas was constantly circulated. The piece was cut into two and one piece was placed in between two Teflon sheets and rolled slowly manually with a SS cylinder. But it was found that around $1 \text{ mg/cm}^2$ thickness, it forms pin holes. It was due to the "not very smooth surface" of the Teflon. So next we put the other piece between two transparency sheets and tried in the same way. But around $500 \mu\text{g/cm}^2$ of thickness it also formed pin holes. Several attempts ended with same result. Moreover, in-spite of the constant flow of the argon, the target got blackened indicating the formation of oxides.

So ultimately this method was discarded and we opted for the evaporation method.

### 3.2.5 Data Acquisition System

For data acquisition and analysis we needed hardware which processed the analog signals from the detectors and then converted it to a digital signal which was then fed to the computer via a computer interface for storage and analysis.
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Hardware Part:

The nuclear electronics:

The signal from the detector is processed through a preamplifier which is used for impedance matching and some amplification of the signal from the detector. It drives the signal to the amplifier which is kept far away from the detector. The amplifier amplifies and shapes the signal to a nearly Gaussian shape for improved signal to noise ratio. This analog signal is then fed to the Analog to Digital Converter (ADC) or Time to Digital Converter (TDC). The ADC or TDC needs a strobe or trigger to process the signal which is usually generated either from the timing signal from the preamplifier via Timing Fraction Amplifier (TFA), Constant Fraction Discriminator (CFD), Gate and Delay Generator (GDG) or from the bipolar output of the amplifier and then processed through Timing Single Channel Analyser (TSCA) and GDG.

At Nuclear Science Centre, the nuclear modules used are CAMAC (Computer Automated Measurement And Control) or NIM (Nuclear Instrumentation Modules) modules interfaced to CAMAC.

As for this detector system, there are a large number of signals from the detector output, a large number of preamplifiers, amplifiers etc. are required. Along with reducing the detector output from 186 to 16 by resistive chain for the position signals and external shorting of the energy signal while keeping the detector information intact, some high density electronics like quad and octal preamplifiers and amplifiers were also indigenously made whose performance were comparable to the commercial ones. In fact they sometimes behaved better than the commercial ones with respect to signal to noise ratio.
Table 3.2: The commercial modules used in the experiment

<table>
<thead>
<tr>
<th>Module</th>
<th>Company</th>
<th>Model number</th>
</tr>
</thead>
<tbody>
<tr>
<td>preamp</td>
<td>Ortec</td>
<td>142 IH</td>
</tr>
<tr>
<td>preamp</td>
<td>CEAN</td>
<td></td>
</tr>
<tr>
<td>amp</td>
<td>Ortec</td>
<td>571</td>
</tr>
<tr>
<td>amp</td>
<td>Canberra</td>
<td>2022,2011</td>
</tr>
<tr>
<td>ADC</td>
<td>Ortec</td>
<td>AD811</td>
</tr>
<tr>
<td>TSCA</td>
<td>Canberra</td>
<td>2037</td>
</tr>
</tbody>
</table>

The schematic of the electronic set up is shown in the fig. 3.12.

The commercial modules used are tabulated in table 3.2

The interface

:CAMAC:

CAMAC is one of the internationally accepted modular standard for interfacing devices to a computer. In simple words it is the gateway between the analog nuclear electronics and the digital computer. It generally consists of a trigger generator (TG), list processor (LP, Hytec LP1340), plugged into one CAMAC Crate and does the collection of data from the ADCs or TDCs, to store it in the buffer memory of LP and transfer the data to the computer memory simultaneously and thus handles a high event rate.
Figure 3.12: Schematic of electronic set up for the experiment
The software: FREEDOM [9]

The Linux based program called FREEDOM developed at NSC was used for data acquisition as well as for analysis of the data.

Later the same has been upgraded to 'CANDLE' which has larger capacity of accommodating more number of ADCs (both soft and hard ADCs) and can handle a multipole number of CAMAC Crates.

3.2.6 Calibration of the detector system:

The calibration of the detector system was done with $^{241}$Am $\alpha$ source of known energy of 5.486 MeV for each individual detector.

$^{241}$Am was placed in front of the annular detectors in a vacuum chamber of vacuum of the order of $10^{-6}$ mbar. The position and energy signals were processed through the associated nuclear electronics described above and collected and analysed through CANDLE. Fig. 3.13 shows the position and energy spectrum of the same. The 16 peaks in the position spectrum correspond to the 16 rings in the front side of the detector which were externally connected by a resistive chain. The energy resolution of the front annular detector is found to be 368 keV while for the back annular detector it is 302 keV without gas in the chamber and 515 keV with isobutane gas of pressure 95 mbar in the chamber.

Similarly, energy calibration was done for IC and the PSSD. The energy calibration
Figure 3.13: Position spectrum of the annular detector from calibration run
A PC board mask with $5 \times 5$ $1 \text{ mm}$ holes in 5 rows and columns with 1 cm distance between them was put in front of the PSSD for determination of position resolution. $^{241}\text{Am }\alpha$ source was placed in front. The calibration run gave the position resolution of the PSSD to be 0.06 mm/channel ($46 \text{ mm} = 728 \text{ ch}$ for X, Y & R calibration in a range of 2k channels).

### 3.2.7 The performance test of the detector system

The first beam test of the detector system was taken in General Purpose Scattering Chamber (GPSC) to see the Z-resolution of the telescope system and the annular detector signals, with commercial preamplifiers, amplifiers and indigenously made high density electronics. The experimental set up is shown in fig. 3.14.

As we wanted to see the Z-resolution of the detector telescope at lower mass region at low energy, of which the $\Delta E$ detector is the gas detector with large area (100 mm diameter) and short axial length (18 mm) in an axial field geometry, we
Figure 3.14: Schematic of the experimental setup to test the Z-resolution of the detector system.
only used the 50x50-300 Eurisys SSB (Silicon Surface Barrier) detector as the E
detector as this was used several times before and we are quite familiar with its
performance. We did not use the second annular detector during this test. The first
annular detector (which was subtending a small angle of 3° at the scattering plane)
was used to see its performance with beam.

30 MeV $^7$Li beam was used for this test run and targets were $^{12}$C, $^{27}$Al and
$^{197}$Au of thicknesses 0.034 mg/cm$^2$, 0.55 mg/cm$^2$ and 2.06 mg/cm$^2$, respectively.
The thickness of the targets were measured by the conventional method of the energy
loss of alpha particles in the targets. The choice of the beam target combination
was made to see the Z-separation in the $\Delta$E-E spectrum for various reaction prod-
cucts at the low energy and low-medium mass region. Carbon target was made by
the evaporation method while aluminium and gold targets were made by rolling
method. The targets were put on a target holder and placed at the centre of the
GPSC chamber which is 150 cm in diameter and the detector assembly was mounted
on one of the 30° port of the GPSC. Thus the detector assembly was at a distance
of 735 mm from the target subtending an angle of 7° only.

A new gas handling system was installed for the smooth operation of the de-
tector system.

The detector pressure foil (1.5 $\mu$m polypropylene) was tested for leak and it
could hold a pressure of 260 mbar while GPSC pressure was of the order of low $10^{-6}$
mbar.

The pressure (p) as well the field (E) of the ionisation chamber were varied
to get best resolution and it was found that best results were obtained for $E/p =
7-8$ Volt/mbar and while at the same $E/p$ value the best resolution was for lower
pressure (140 mbar, corresponding to less than 1/3 of the total energy loss in the ΔE part).

In case of annular detector, where the large number of readouts (80) were reduced to 12 (4 energy from four quadrants and 8 positions from 4 quadrants) by resistive chain network, we terminated one side of each position quadrant and got the signals from 16 rings of each quadrant. Then we tried to take the position signal from both the ends which apparently did not show up any advantage, but made the number of read outs more. Hence, we went back to the previous position, reading from one end with termination at the other end. Effectively, there were only 8 read outs required for complete energy and position information from the annular detector.

Then we replaced the commercial preamplifiers by the indigenous 16 channel preamplifiers and got the similar result.

Fig. 3.15, 3.16 and 3.17 are the preliminary result from the first detector testing.

Fig. 3.15 shows the position read out from one quadrant of the annular detector. The peaks from the left correspond to the rings from the outer edge as the inner side of the read out was terminated. Fig. 3.16 is the energy normalised position spectrum of the annular detector.

Fig. 3.17 shows the ΔE-E spectrum, which shows the clear separation between the reaction products.
Figure 3.15: Position spectra of the annular detector from the first beam test
Figure 3.16: Energy normalised position spectra of the annular detector from the first beam test
Figure 3.17: DE-E spectrum from the first beam test
3.2.8 Channel Calibration

All the ADC channels were calibrated by using high precision Ortec pulse generator. Later in the software, the channel offset was taken into account.

3.3 The main experiment

For the $^7$Be+$^7$Li experiment, the detector system was mounted in the HIRA focal plane Chamber (FPC) taking care of proper alignment. The in-vacuum target transfer system was also installed there after making the $^7$Li target by evaporation. The target ladder contained 3 targets, the bottom two were $^7$Li target and the top most was CD2 (see section 3.2.4). A $^{241}$Am $\alpha$ source was also mounted from the side of the FPC using an MDC linear drive which could be put in the beam direction or pulled out and kept behind a mask whenever required. This arrangement was to check the consistency of the detector system throughout the experiment.

On the same linear drive, where $\alpha$ source was put, a 100 mm$^2$ Si detector was also mounted for normalisation purpose. In the production chamber, another 300 mm$^2$ Si detector (monitor detector) with a 1 cm hole mask in front was placed at 30° in the forward direction to detect the scattered protons from the elastic $^7$Be+p reaction from the polypropylene foil. This was to check if the transmission of $^7$Be through HIRA was at a constant level. Any power glitch during the experiment may cause hysteresis in the HIRA magnetic fields which could change the transmission of the beam through HIRA. The protons detected in the monitor detector and $^7$Be detected at the normalisation detector were mutually exclusive events, but for a
given experimental condition like beam current, target thickness, their ratio should always be same. The transmission of $^7$Be through HIRA is constant if the ratio of the proton counts to $^7$Be counts is also a constant.

After achieving all desired vacuum in the HIRA, gas pressure in the IC was set at 95 mbar and detectors were biased. HIRA fields were set for 20.0 MeV $^7$Be. 25.0 MeV $^7$Li from Pelletron was focused on a quartz in the production chamber which was mounted on a linear drive and brought in the beam direction. After maximisation of $^7$Li on quartz, the quartz was pulled out from the beam direction, allowing the beam to fall on the rotating polypropylene target. Now the HIRA fields were finally set for 20.25 MeV $^7$Be, it being the optimum energy setting found through energy grid search. Fields were tuned to put the beam on the target and the Ta stopper. The position spectrum of PSSD was monitored online. Fig. 3.18 shows the position spectrum of PSSD. The empty circle at the middle of the spectrum is because of the shadow cast by the stopper on the PSSD.

First, the CD2 target was put in the beam direction. The recoiling deuterons were collected by the first annular detector while the ejected $^7$Be were registered in the PSSD. When an energy gate from PSSD was put on the position spectra of first annular detector all the four quadrants gave same counts within the statistical error. Later in offline analysis, the PSSD position was divided into 4 quadrants and energy gate was put from front annular detector. This time also all the four quadrants showed equal counts within the statistical error. Fig. 3.19 shows the ratio of the top to bottom half of the PSSD and that of right to left half of the PSSD for different runs. Both the ratios fall in a horizontal line implying the proper alignment.

For $^7$Be+$^7$Li runs, $^7$Li target of thickness 628$\mu$g/cm$^2$ was put in the beam
Figure 3.18: Position spectrum of PSSD with stopper at the front.
Alignment verification from PSSD position

Figure 3.19: Alignment verification of the detector system from the PSSD counts
direction and the scattered and recoiled $^7$Be and $^7$Li were registered in the first and second annular detectors. The run sequence was as follows:

(1) A short alpha run was taken by putting the alpha source in the beam direction, with beam off.

(2) Normalisation detector was put in the beam direction and beam run was taken.

(3) CD2 target was put in the beam direction and $^7$Be+CD$_2$ run was taken.

(4) Target ladder was pulled up and a short run with no target was taken. This blank run was taken to eliminate any background counts later in the offline analysis.

(5) $^7$Li target was put in the beam direction and long $^7$Be+$^7$Li runs was taken.

Step (1)-(5) were repeated many times in the whole experiment.
Bibliography


