Understanding reaction mechanism from fragments yield in $^{14}N^{4+}$ + ^{159}Tb using 252 MeV beam from Superconducting cyclotron at VECC

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Introduction

At present, the Superconducting Cyclotron (SCC) at VECC is delivering beams in the energy range up to about 20 MeV/n. This energy domain is very much useful for the production and study of exotic nuclei, especially in the proton rich side of the nuclear chart, through multi fragmentation reaction. However, at this energy domain the multi-particle evaporation also plays a very significant role and competes with the multi-fragmentation. Therefore, information on fragment yields at this energy domain is extremely important for understanding the reaction dynamics and also for planning and carrying out meaningful experiments on nuclear structure and decay rate measurements.
However, experimental data on reaction cross section at and around 20 MeV/n is almost non existing [1,2]. Also, there are no standard theoretical codes that are known to be suitable for estimating fragment yields at this energy range. Such a code has been developed at VECC which needs rigorous testing with new experimental data. In addition, in any gamma spectroscopic measurement, the target backing plays an important role and depends on the ion beam and its energy. Therefore, it also becomes necessary to study the fragment yields from the prospective materials which are used as target backing.

Experiment

With above mentioned objectives, in the first experimental run, mono isotopic ^{159}Tb and ^{27}Al foils of 25 μm thickness were irradiated with 252 MeV beam of ^{14}N beam from SCC for 17 hours. The irradiated targets were counted with a 80% efficient single HPGe detector to study the beta-delayed gamma rays of the fragments produced in the reaction. The gamma ray spectrum from irradiated ^{159}Tb target is shown below in Fig. 1 with the observed and identified nucleus from the measurements of their decay half-lives of gamma-rays are marked in green. The gamma-ray counting experiment continued for about 45 days. Initially counting was 10 minutes duration which was increased to 1 day counting once in a week for identifying the long-lived nuclei in a particular mass-chain. The gamma ray spectrum from irradiated ^{27}Al foil showed the 1369 keV gamma ray as most prominent as shown in Fig. 2.

Results and Discussion

From the observed gamma-line signatures, the mass chains of A=155 and A=159 were confirmed. Since the sample counting started after ~2 hrs, calculations were performed to estimate the fragment yield at the end of irradiation using decay chain equilibrium relations.

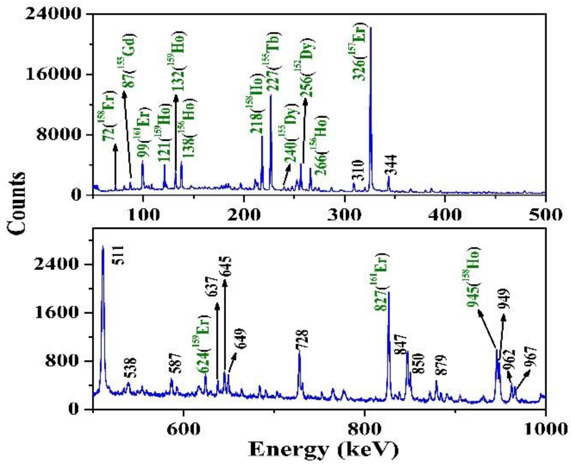

Fig. 1: Gamma ray spectrum obtained with irradiated ^{159}Tb target

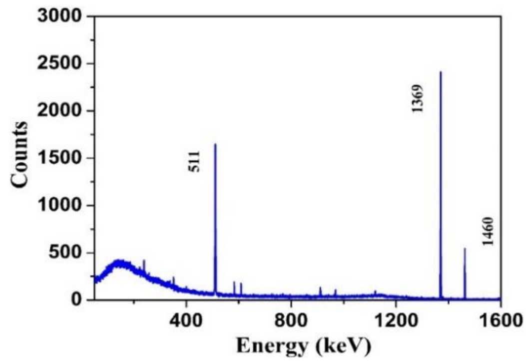

Fig. 2: Gamma ray spectrum obtained with irradiated ^{27}Al target

The gamma ray spectrum from irradiated ^{27}Al foil (Fig. 2) along with the decay half-life estimation for the 1369 keV gamma ray (Fig. 3) shows that ^{27}Al can be used as a target backing for gamma-spectroscopic measurements for cross section studies as only one nucleus (^{24}Na; $t_{1/2}$ = 14.956(3) hrs.) with considerable decay half - life is populated as a major contaminant.

In order to estimate the yield of a particular fragment it is important to estimate the number of nuclei present at the end of irradiation. This can be performed following procedures described in Ref.[3,4] by correcting the activity (N0) estimated for a characteristic gamma line of a nucleus by its abundance and detection efficiency. The efficiency curve used for the measurement is shown in Fig. 4.

The decay curve for a particular candidate in the chain was inspected to identify the daughter product from the

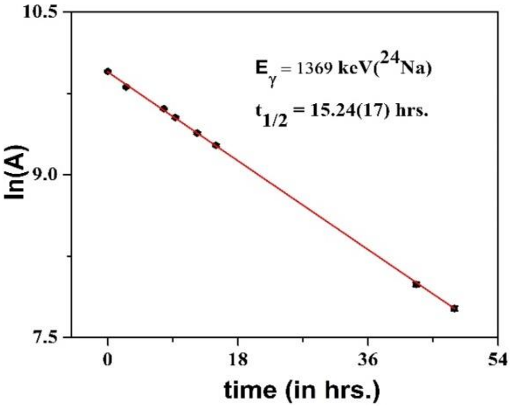

Fig. 3: Decay half life measured for ^{24}Na produced from irradiation of ^{27}Al target

half life values. The decay half life estimation for A = 155 mass chain is displayed in Fig. 5.

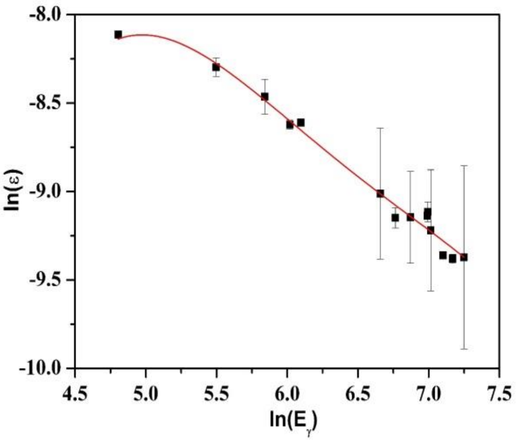

Fig. 4: Measured absolute efficiency of the HpGe detector used in the measurement

The growth and decay requires fitting considering contributions from (i) the feeding from parent and (ii) initial production during the nuclear reaction. The yield of each fragment in a mass chain, so determined, was added to estimate the summed production of all the nuclei in that particular mass chain. This was important as the decay of short lived fragments could not be detected as the counting was started after few hours of irradiation. As a result, yield for these short lived reaction products will be added to that of their daughters in a particular mass chain.

This is demonstrated in Fig. 5(b) where the decay curve of 227 keV (^{155}Dy → ^{155}Tb) has been fitted with the following equation considering feeding from ^{155}Ho.

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 \left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right) + N_2^0 e^{-\lambda_2 t}$$

(eqn. 1)

where N_2 is the area under 227 keV gamma ray, N_1^0 & N_2^0 are the number of ^{155}Dy and ^{155}Tb (decay gamma efficiency and abundance uncorrected), respectively, at t = 0. λ_1 and λ_2 are the half life values for parent (^{155}Dy) and daughter (^{155}Tb), respectively. Data fitting has been performed by considering λ_1 and λ_2 as both fix and free parameters.

PACE4 calculations have been performed to compare the experimentally determined yields of the products in a particular mass chain.

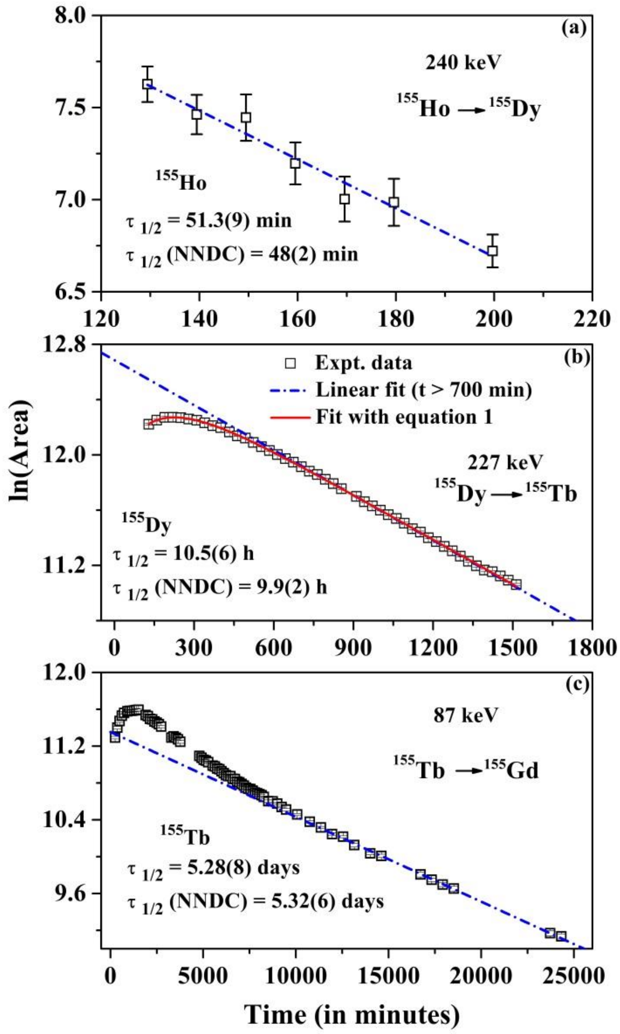

Fig. 5: Growth and Decay curves for gamma rays originating from A = 155 mass chain

Acknowledgement

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Reference

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