Yrast and near-yrast spectroscopy of neutron-rich fission fragments using thermal neutrons from reactor

S. Mukhopadhyay[1],* L. S. Danu[1], D. C. Biswas[1], P. N. Prashanth[1], A. Goswami[2], A. Chatterjee[1], and R. K. Choudhury[1]

[1]*Nuclear Physics Division,* [2]*Radio Chemistry Division, Bhabha Atomic Research Centre, Mumbai - 400085*

* *email: somm@barc.gov.in*

Introduction

The spectroscopic studies of fission fragments provide direct information on the nuclear excited states, which are related to the shape and structure of the neutron-rich fragment nuclei [1,2]. Thermal neutron induced fission is one of the techniques which allows us to do spectroscopic investigation of such fragment nuclei with a higher neutron to proton ratio. These types of studies help to explore the new regions of nuclear deformations, and to extend the theoretical model(s) to regions which have hitherto been inaccessible. A lot of work has already been done on these set of nuclei by means of spontaneous fission of ^{252}Cf and ^{248}Cm sources [3,4], heavy-ion induced fusion-fission reactions [5], and also using deep-inelastic reactions. It is desirable to extend these measurements to thermal neutron induced fission as well, to investigate those nuclei whose yields in the above mentioned reactions are low, and also to obtain information on the mass regions accessible to all these fissioning systems and compare the results.

Here we report a comparative study in terms of yrast and near-yrast spectroscopy of the neutron-rich fragments that were produced in the thermal neutron induced fission of ^{235}U. It is to be noted that prompt online γ spectroscopy using γ-γ coincidence technique has been attempted for the first time using ^{235}U(n_{th}, *f*) reaction.

The experiment was done in CIRUS reactor facility in BARC, Mumbai. The details of the experimental set up in neutron beam line have been reported earlier [6]. A 3-mm thick, 17% enriched ^{235}U target, fully sealed in a Teflon disk type capsule, was bombarded by the thermal neutrons from the reactor. The front side thickness of the Teflon was measured 1 mm, and the base was 5-mm thick. The neutron-flux at the target position was ~10^7 neutrons/cm^2/sec. The de-exciting γ-rays from the fission fragments were detected by two Clover Ge detectors in coincidence mode, mounted in a vertical ring type mechanical structure with φ = 72^0. A total of 3×10^6 γ-γ coincident events were recorded for further off-line analysis.

Results and Discussions

In the off-line analysis, several complementary fragments were identified by γ-γ coincidence technique. The relative yield distribution (Fig. 1) was performed accurately, taking into account the amount of self-absorption of the emitted γ-rays, which of course depends on its energy and the thickness of the target material.

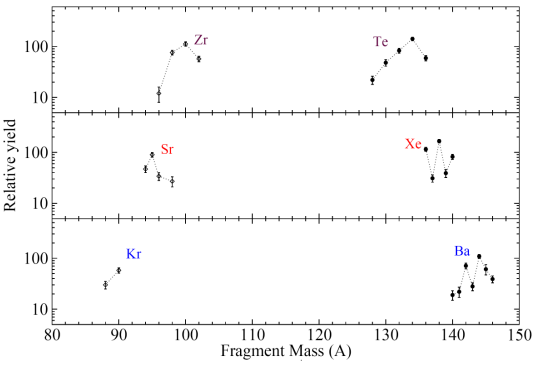

Fig 1: Relative yield distribution of fragment partners as obtained from ^{235}U(n_{th}, f) reaction.

In the thermal neutron induced fission of ^{235}U, the Sr isotopes are the fragment partners of Xe isotopes centered on ^{138}Xe. When gates were set on the lower lying strong transitions of ^{138}Xe, the strong γ lines of ^{94}Sr(4n), ^{95}Sr(3n) and ^{96}Sr(2n) were clearly seen (Fig. 2). Coincident rates of various Sr isotopes with ^{138}Xe nucleus were obtained. The rates were calculated from the relative intensities of the γ transitions (first

excited to the ground state) in these Sr isotopes from a single spectrum of ^{138}Xe, gated on 484-keV transition. It is very clear from the data that in case of Xe-Sr fragment pair, the 3-neutron evaporation channel is dominant. Similarly, in case of Ba-Kr fragment pair production, the 2-neutron evaporation channel dominates among others.

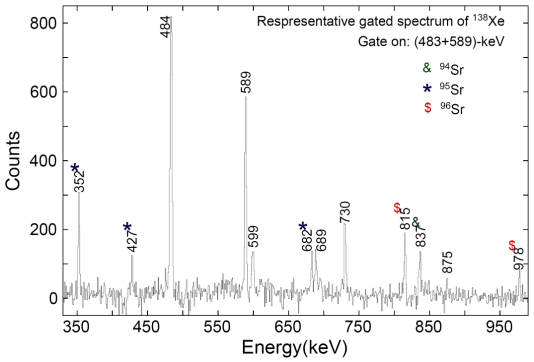

Fig 2: Representative gated spectrum of ^{138}Xe.

The medium and high-spin states of several isotopes were clearly observed from the present data set, and level schemes were constructed based on coincidence relationship and intensity arguments. The Ba chain of isotopes ($^{140\text{-}146}$Ba) was seen to be the longest among the observed chain of isotopes of all elements in the present data set. The coincidence data have proved to play a crucial role in justifying earlier assignments of the level schemes.

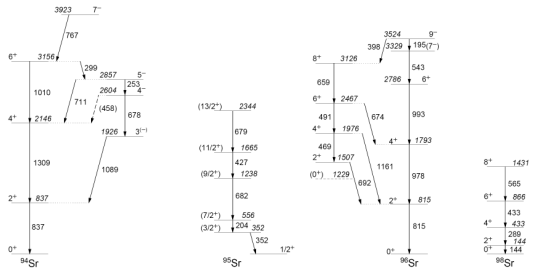

Fig 3: Partial level schemes of Sr isotopes, as obtained in the present measurement.

Among the Sr chain of isotopes, we could see the γ lines clearly up to $I = (7^-)\hbar$ (E_x = 3.923 MeV), $I = (13/2^+)\hbar$ (E_x = 2.344 MeV), $I = (9^-)\hbar$ (E_x = 3.524 MeV) in ^{94}Sr, ^{95}Sr and ^{96}Sr, respectively. The level schemes (Fig. 3) obtained agree well with the previous works. In ^{96}Sr, we did not see the excited 0^+ levels at 1229 keV and at 1465 keV, similar to the ^{248}Cm data. Although we could see the quasirotational structure built on a possible 0_2^+ excitation, subsequent experimental non-observation of 0_2^+, 0_3^+ (at 1465 keV) and the proposed deformed band built on 0_3^+ render their existences doubtful.

Among the complementary fragments of Sr isotopes, ^{138}Xe was seen to have the highest yield. We could see up to spin $I = (12^+)\hbar$ (E_x = 3.572 MeV) in its yrast sequence. We could see the first few levels that constitute the proposed gamma vibration band in this nucleus. In ^{140}Xe, levels up to spin $I = (12^+)\hbar$ (E_x = 3.270 MeV) were observed. This ^{140}Xe happens to be the only nucleus among the Xe isotopes where we could see the first few levels of the octupole band proposed and observed earlier.

Among the Ba chain of isotopes, ^{144}Ba was seen to have the highest yield. The first few levels of the octupole band in ^{144}Ba and ^{146}Ba were seen very clearly. In ^{142}Ba, certain level sequences in the yrast and the octupole band were not agreed by Urban *et al.* Our data corroborates the sequence proposed from the ^{248}Cm data set.

Among the Zr chain of isotopes, ^{98}Zr and ^{100}Zr were seen to have maximum yield. We could see up to spin $I = (12^+)\hbar$ (E_x = 4.821 MeV) and $I = (10^+)\hbar$ (E_x = 2.426 MeV) in their level sequences, respectively. Although we could not see the 0_2^+ and 2_2^+ states as observed earlier, we could see some notable discrepancies with respect to the ^{252}Cf data set. The proposed 0_3^+ level remain elusive like all previous SF data.

Detailed analysis of yrast and near-yrast structures of all the fission fragment isotopes are in progress and will be presented.

References

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