# Fission Fragment Spectroscopy of $^{232}$Th($^{9}$Be,f): Explicit pair-wise measurements for quantifying fusion suppresion

Krishna Debnath[1], Aniruddha Dey[1],* A.K. Mondal[1],† P.K. Nayak[2,3], A. Kundu[4], A. Sindhu[4], Biswajit Das[4], K. Mandal[1],‡ P. Dey[4], S. Biswas [1], Vishal Malik[4], B. Mukherjee[1], D. C. Biswas[2,3], R. Palit[4], S. Mukhopadhyay[2,3], and A. Chakraborty[1§]

[1]*Department of Physics, Siksha Bhavana, Visva-Bharati, WB 731 235, India*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400 094, India and*
[4]*Tata Institute of Fundamental Research, Mumbai 400 005, India*

## Introduction

$^{9}Be$ is a weakly-bound stable nucleus that exhibits several unusual features compared to the strongly-bound projectiles. It breaks up into the charged fragments: $^{9}Be \rightarrow \alpha + \alpha + n$, (Q = -1.57 MeV); $^{9}Be \rightarrow \alpha +\ ^{5}He$ (Q = -2.47 MeV) [1] which impacts the complete fusion-fission (CF) dynamics, and subsequently, the suppression of its cross section. This suppression factor is found to be nearly 30% as per the results presented in Ref.[3]. However, there is no reported value of complete fusion suppression contributions that arise due to the aforesaid two exclusive break-up channels of $^{9}Be$. In the present work, an attempt has been made to extract these values by using prompt $\gamma$ ray spectroscopic technique.

## Experimental Details

The experiment was carried out using the BARC-TIFR 14-MV Pelletron accelerator facility at Mumbai. A self-supporting $^{232}$Th target of thickness $\sim$ 25 mg/cm$^2$ was bombarded with $^{9}$Be beam at $E_{lab}$ = 46 MeV. The prompt $\gamma$-rays from fission fragments (FFs) were captured by the Indian National Gamma Array (INGA) spectrometer. The time-stamped list mode data were collected in $\gamma$-$\gamma$ and $\gamma$-$\gamma$-$\gamma$ coincidence by employing the digital data-acquisition system based on the PIXIE-16 modules of XIA LLC [2].

## Results and Discussions

The experiment, $^{232}$Th($^{9}$Be,f) will lead to the formation of the fissioning nucleus, $^{241}$Pu following the complete fusion-fission (CF) process. However, there exists a significant probability of the breakup of the projectile, $^{9}$Be thereby causing In-Complete Fusion (ICF) process [3]. The breakup channels will lead to the formation of the fissioning system, $^{233}$Th and $^{236}$U via the reactions, $^{232}$Th($n$,f) and $^{232}$Th($\alpha$,f), respectively. Therefore, three different fissioning nuclei were produced simultaneously at different excitation energies ($E_{ex}$). The corresponding $E_{ex}$ were calculated by taking into account the beam energy loss at the half-thickness of the target and respective Q-values (see Table.1). Considering only binary fragmentation, each of the aforementioned fissioning composite nuclei breaks into two complementary FFs such that the total proton number is conserved. The Fission Fragment Spectroscopy (FFS) measurement technique [4] has been utilized to measure the relative yields of complementary FFs produced through different fissioning channels. The nuclei, $^{100}$Zr and $^{104}$Mo were fixed as lighter fragment, and the corresponding yield from the heavier fragment with respect to each of fis-

*Presently at: Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia
†Also at: Department of Physics, Bolpur College, Bolpur, Birbhum, WB 731236, India
‡Also at: Department of Physics, Chandidas Mahavidyalaya, Khujutipara, Birbhum, WB 731215, India
§Electronic address: anagha.chakraborty@visva-bharati.ac.in

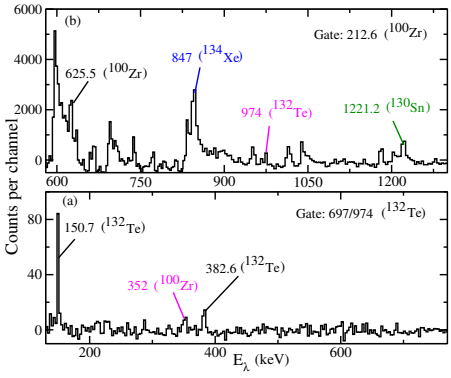


FIG. 1: Representative coincidence spectra obtained by applying : (a) double gate on the $4_1^+ \rightarrow 2_1^+$ (697 keV) and $2_1^+ \rightarrow 0_1^+$ (974 keV) transitions of $^{132}$Te; (b)single gate on the $2^+ \rightarrow 0^+$ (212.6 keV) transition of $^{100}$Zr. The FFs produced by three different fission channels are marked along with their corresponding $\gamma$ transitions.

Table 1: Experimentally extracted values of yield distributions from different complementary fission fragment pairs relevant to the three fusion-fission channels.

| Compound Nucleus | | E$_{ex}$ (MeV) | CFF Pair | Yield Ratio | Adopted Values |
|---|---|---|---|---|---|
| CF | $^{241}$Pu | 31.7 | $^{100}$Zr -$^{134}$Xe | 69 ± 9 | 66 ± 6 |
| | | | $^{104}$Mo -$^{128,130}$Te | 63 ± 8 | |
| ICF | $^{233}$Th | 31 | $^{100}$Zr -$^{130}$Sn | 18 ± 4 | 19 ± 3 |
| | | | $^{104}$Mo -$^{114}$Cd | 20 ± 4 | |
| | $^{236}$U | 15 | $^{100}$Zr - $^{132}$Te | 13 ± 3 | 15 ± 3 |
| | | | $^{104}$Mo -$^{130}$Sn | 17 ± 4 | |

sioning nuclei were measured as shown in Table.1. The ratio of the yield for a FF pair following a specific fissioning channel with that of the total summed yield provide the relative contributions of different ICF channels explicitly as shown in Table.1.

The experimentally observed relative isotopic yield distribution profile has been compared with the predicted values from the theoretical GEF model [5] (see Fig.2). The measured relative contributions of the three different fissioning channels were incorporated into the GEF model calculations. A good agreement has been found between the theoretical and experimental values of the relative isotopic fission fragment yield distribution for the element, Xe$_{54}$. It is expected that the newly presented results would have significant consequences for fusion-fission dynamics, as well as in synthesizing super heavy elements.

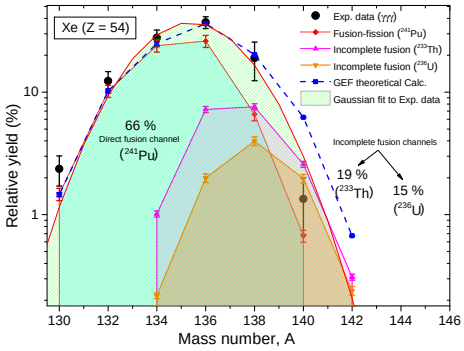


FIG. 2: Comparative depiction of relative isotopic yield distribution between experimental results and GEF calculations for even-even Xe isotopes considering the extracted ICF ratios as obtained from the present work.

## Acknowledgments

Thanks are due to the PLF staff of TIFR, Mumbai for smooth running of the accelerator. The author, K. D. would like to thank UGC, New Delhi for providing financial support under the scheme, NET-JRF. The author, A. C. would like to acknowledge the financial assistance received from SERB (File No. CRG/2021/004680), IUAC (Project No.71344), and UGC-DAE CSR (Project No. CRS/2021-2/02/472).

## References

[1] D. J. Hinde *et al.*, Phys. Rev. Lett. **89**, 272701 (2002).
[2] R. Palit *et al.*, Nucl. Instrum. Methods Phys. Res. A **680**, 90 (2012).
[3] T. Banerjee *et al.*, Phys. Rev. C. **102**, 024603 (2020).
[4] A. Dey *et al.*, Phys. Rev. C. **103**, 044322 (2021).
[5] K. H. Schmidt *et al.*, Nucl. Data Sheets **131**, 107 (2016).