# Fusion excitation function studies in the reactions forming $^{161,169}$Tm

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## Introduction

Heavy ion fusion near the Coulomb barrier region is a rich source of information on various aspects of quantum mechanical tunneling phenomenon. Fusion below the barrier is visualised as two inert spherical nuclei tunneling through a one dimensional potential barrier, considering only relative distance between them, to form the compound nucleus (CN). However an enhancement in the sub-barrier fusion cross section hinted to the role of other internal degrees of freedom in the fusion process. Heavy ion fusion exhibits a strong entrance channel dependence at near fusion barrier energies and could be reasonably explained by coupled channels formalism [1] that explicitly includes the effects of internal degrees of freedom. As an effect of this coupling, the one-dimensional single barrier will transform into a distribution of barriers [2], reducing the strength of the original barrier, which aids the fusion in sub-barrier region.

## Experimental Setup

The experiment was carried out at Inter University Accelerator Centre (IUAC), New Delhi, using the 15 UD Pelletron accelerator. Pulsed beams of $^{19}$F, with a pulse separation of 4 $\mu$s, was used to bombard the isotopically enriched $^{142}$Nd and $^{150}$Nd targets. The measurements were performed in the beam energy range of 66 to 96 MeV and 62 to 96 MeV, for the $^{19}$F+$^{142}$Nd and $^{19}$F+$^{150}$Nd reactions, respectively. The low energy ERs produced in the fusion reactions were separated from other possible scattered particles using the Heavy Ion Reaction Analyser (HIRA) [3] and are detected in the focal plane using a two-dimensional position-sensitive multi wire proportional counter (MWPC) with an active area of 150 mm x 50 mm. Two silicon surface barrier detectors were placed inside the target chamber to measure elastically scattered beam particles and to get absolute normalization of ER cross sections. The time interval between two successive pulses were slightly more than the time of flight (TOF) of ERs, from the reaction point to the focal plane of HIRA. The ERs were selected through the two-dimensional spectrum of ER energy loss ($\Delta$E) vs ER TOF.

## Results and discussion

The fusion cross sections is calculated from the measured ER yield using the standard expression [4]. Coupled channels code CCFULL has been used to analyse the measured fusion cross sections for the two reactions. Nuclear potential parameters $V_0$, $r_0$ and $a$ were first fixed using the Akyüz-Winther parameterisation [5]. The measured excitation function is found to be significantly enhanced rel-

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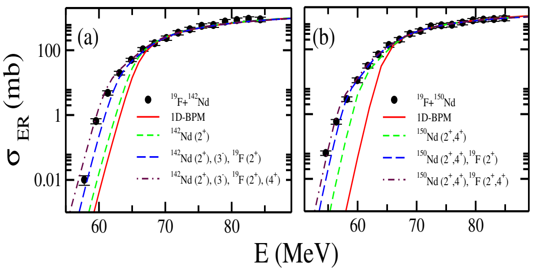


FIG. 1: The experimental fusion cross section for the $^{19}$F+$^{142}$Nd and $^{19}$F+$^{150}$Nd reactions along with CC calculations.

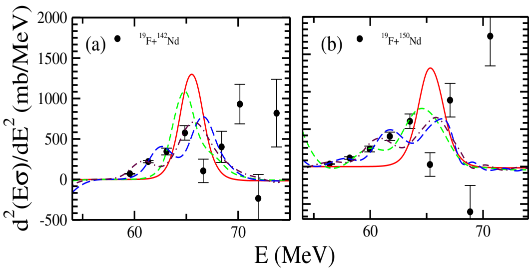


FIG. 2: The experimental barrier distribution for the $^{19}$F+$^{142}$Nd and $^{19}$F+$^{150}$Nd reactions along with CC calculations, same color and properties are used as in Fig.1.

ative to the one-dimensional barrier penetration model (1-DBPM).

Coupled channel calculations considering the projectile as inert and the vibrational coupling of $2^+$ state of $^{142}$Nd nucleus also underestimate the cross sections at sub-barrier energies. A similar calculation considering both the $2^+$ and $3^-$ state of $^{142}$Nd also fails to reproduce the sub-barrier cross sections in this case. So the effect of projectile's collective excitation is very clear in this reaction. So coupling to $^{19}$F rotational states are included in the CC calculations. The quadrupole ($\beta_2 =$ 0.43) and hexadecapole ($\beta_4 = 0.12$) deformation parameters are taken from Oyamada *et al.*,[6]. The first $(5/2)^+$ and second $(3/2)^+$ excited state lies at 0.197 MeV and 1.554 MeV respectively [6]. However, $^{19}$F nuclei is considered as a pure rotor and the calculations are performed considering the states corresponding to $J^\pi = 0^+$, $2^+$ and $4^+$. The energy of the first excited state ($2^+$) is taken to be 0.197 MeV and the next one ($4^+$) is computed to be 0.657 MeV. Significant enhancement in the cross section is observed by the inclusion of first excited state ($2^+$) of the $^{19}$F nuclei. Further enhancement in the cross section and a reasonable agreement with the experimental values have been noticed when both $2^+$ and $4^+$ states along with the target excitations are inluded in the calculation as shown in the Fig.1.

The degree of fusion enhancement is larger for the $^{19}$F+$^{150}$Nd reaction, compared to $^{19}$F+$^{142}$Nd. Even in this case the rotational couplings of ($2^+$ and $4^+$ states) of the deformed target alone could not reproduce the fusion cross sections in $^{19}$F+$^{150}$Nd reaction at sub- and near barrier energies. The rotational effects of the projectile is incorporated to explain the experimental data.

The barrier distribution (BD) is been extracted for both the reactions as shown in Fig.2. A broad BD with multiple peaks are obtained for both the reactions. The theoretical calculation incorporating the couplings could reproduce the shape to an extend as shown in the Fig.2.

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