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Affirmation of transfer-breakup as a source for α-particle emission in ^{12,13}C + ^{232}Th fission reactions

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An enhancement in near-scission α-particle multiplicity was observed in the ^{12}C + ^{232}Th fission reaction at a beam energy of 69 MeV in a recent experiment [Y. K. Gupta *et al.*, Phys. Rev. C **86**, 014615 (2012)]. The excess α-particle emission was attributed to α-transfer induced fission, where α-particle transfer followed by breakup of ^{8}Be into two α particles in coincidence with fission fragments (FFs) was observed. In order to further verify this transfer-breakup source, α-particle energy spectra have been measured in coincidence with FFs in ^{12,13}C + ^{232}Th reactions at various relative angles with respect to the beam and FF directions at a beam energy of 74.5 MeV. The α-particle multiplicity spectra were fitted using a moving source disentangling analysis. The features of multiplicity spectra clearly demonstrate the presence of transfer-breakup events in ^{12}C + ^{232}Th fission. The contribution of α-particle multiplicity from transfer-breakup events in the ^{13}C + ^{232}Th reaction is seen to be negligibly smaller than that of the ^{12}C + ^{232}Th reaction. After taking into account the transfer-breakup source, the pre- and near-scission α-particle multiplicities follow the recently developed heavy-ion systematics for both reactions. These results conclusively affirm that transfer-breakup is a potential source of α-particle emission in fission reactions, induced by α-cluster projectiles such as ^{12}C.

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Characteristics of particle emission during fission, in particular, their multiplicities, provide crucial information for understanding the complex fission process, where a large-scale rearrangement of nucleonic degrees of freedom takes place. Neutron as well as α-particle emissions have been used quite extensively over the years for this purpose [1–5]. Using these particle emission probes it has been firmly established that fission is a slow process having a timescale of 20 to 70 zs (1 zs = 10^{-21} s) [6–9]. It is slow enough to consider fission as an adiabatic process to a first-order approximation, and indeed most theoretical studies have considered fission as an adiabatic process [10]. However, experimental observations of particle emission in fission cannot be explained fully based on pure adiabatic processes. In particular, at the time of actual tearing up of the neck, the adiabatic approximation is expected to break [11]. It is conjectured that a transition from an adiabatic to a nonadiabatic process takes place near the scission point [10]. Theoretical estimates for the actual tearing up of the neck (scission time) have been suggested to be in the range of 0.25 to 6 × 10^{-22} s [11]; however, these are not supported by any of the experimental evidence to date. It is to be noted that α-particle emission near the scission point, owing to the characteristic energy and angular distributions, might be used to estimate the scission timescale experimentally.

Recently, a systematic study has been carried out on pre- and near-scission α-particle multiplicities (α_{pre} and α_{nse}) for a variety of compound nuclear systems [4]. The features of α_{nse} in heavy-ion fission indicate that α particles emitted from the neck region near the scission point are due to the statistical emission process. This is contrary to the low-energy fission where it is a pure dynamical process. It seems that as the available excitation energy increases, statistical emission dominates over dynamical emission near the scission point as well. It has been inferred that the nuclear collective motion exhibits changeover from superfluid to viscous nature as the excitation energy is increased [4].

The α particles in heavy-ion induced fusion-fission originate from three sources: (i) pre-scission (compound nucleus), (ii) post-scission (fission fragments), and (iii) near-scission (neck region) emissions [3,4,8]. It is of utmost importance to unearth any other possible sources of α-particle emission than those mentioned above. Recently, an enhancement in the α-particle multiplicity has been observed in the ^{12}C + ^{232}Th fission reaction at a beam energy of 69 MeV [12]. The extra source of α-particle emission has been attributed to the transfer-breakup process, where one α-particle transfer makes the ^{8}Be to be produced in coincidence with fission fragments (FFs). Breakup of the ^{8}Be into 2α leads to an additional α-particle multiplicity. By including this transfer-breakup source in the moving source disentangling analysis (MSDA), the α-particle multiplicities follow the heavy-ion systematics [4,12].

It would be indeed interesting to confirm this transfer-breakup source with variation in the projectile (^{12}C) energy. Primarily, it stems from the fact that with varying beam energy, the grazing angle of transfer reaction products changes very rapidly [13]. Also, if ^{13}C is used as the projectile, where one α transfer will result in ^{9}Be having a high threshold

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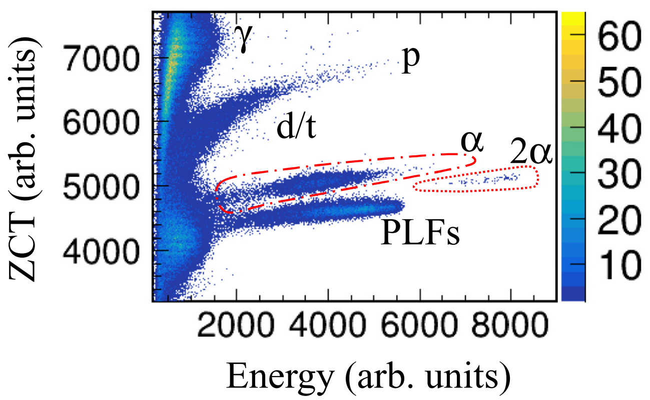

FIG. 1. Two-dimensional plot of zero crossover (ZCT) versus energy from a CsI(Tl) detector for different particles produced in the ^{12}C (74.5 MeV) + ^{232}Th reaction at a laboratory angle of 123° (see text).

for breakup, the α-particle multiplicity spectra should not mimic any significant contribution from this transfer-breakup source. With these motivations, a new experiment has been carried out, where the yield of α particles has been measured in coincidence with the FFs in ^{12,13}C (74.5 MeV) + ^{232}Th reactions at different relative angles with respect to the beam and FF directions. The results obtained further affirm that transfer breakup is a potential source of α-particle emission in the ^{12}C + ^{232}Th fission reaction.

The experiment was performed using ^{12,13}C (74.5 MeV) beams from the BARC-TIFR 14-MV Pelletron accelerator facility at Mumbai. A self-supporting metallic foil of ^{232}Th (∼1.6 mg/cm^2) was used as the target. The FFs from reactions were detected using a position sensitive ionization chamber (PSIC) consisting of $\Delta E_{\rm gas}$ followed by $E_{\rm gas}$ elements [14], and a hybrid detector telescope (HDT) [15]. The HDT consisted of $\Delta E_{\rm gas}$ and $E_{\rm gas}$ elements for the FFs, and additionally two CsI(Tl) detectors at the rear for the detection of light charged particles. The PSIC and HDT, having angular openings of ±15° and ±8.5°, were centered at +145° and −153° with respect to the beam direction, respectively. The gas pressure in both fission telescopes was kept the same and its value was chosen such that FFs were completely stopped in the ionization region ($\Delta E_{\rm gas}$ + $E_{\rm gas}$) of the HDT. The FFs in both fission telescopes were well separated from the projectile-like fragments (PLFs) in $\Delta E_{\rm gas}$ versus $E_{\rm gas}$ plots.

The α particles emitted in the reactions were detected by six collimated CsI(Tl)-Si(PIN) [16] detectors including two in the HDT. The CsI(Tl) detectors, having angular openings of ±3.40°, ±3.40°, ±3.75°, ±3.25°, ±2.05°, and ±2.05°, were placed at the angles θ_α of −73°, −83°, +105°, −123°, −151°, and −155°, respectively, with respect to the beam direction. The particle identification was achieved using the pulse shape discrimination (zero crossover) technique. The γ rays, light charged particles (p, d/t, α), and PLFs were well separated in the two-dimensional plot of zero crossover (ZCT) versus pulse height as shown in Fig. 1. A high-energy component is observed along the α-particle band in both reactions as shown for example in Fig. 1 for the ^{12}C + ^{232}Th reaction at θ_α = 123°. The intensity of this high-energy component varies depending on θ_α. In the case of CsI(Tl) detectors, the rise time for a given particle increases with particle energy [16]. The high-energy component in Fig. 1 is observed to have similar rise time as the lower energy α particles, suggesting that it is due to the summed energy of two lower energy α particles entering the detector simultaneously. Henceforth, this high-energy component is referred to as "2α events" as depicted in Fig. 1. The CsI(Tl) detectors were energy calibrated using a ^{228,229}Th source and in an in-beam experiment as in Ref. [12].

The time correlations between the FFs and light particles were recorded using time-to-amplitude converters. During the data analysis, the 30° angular opening of the PSIC was divided into four (in the ^{12}C + ^{232}Th reaction) and three (in the ^{13}C + ^{232}Th reaction) equal parts for all the CsI(Tl) detectors excluding the two in the HDT where these were divided into two equal parts (for both reactions). Thus, a total of 26 and 22 combinations of α-particle spectra were obtained in ^{12}C + ^{232}Th and ^{13}C + ^{232}Th reactions, respectively, with each having different relative angles with respect to fission fragments ($\theta_{\alpha{\rm fd}}$) and the beam (θ_α). After correcting for random coincidences, the normalized α-particle multiplicity spectra were obtained by dividing the coincidence spectra with total number of fission single events. Figure 2 shows typical normalized α-particle multiplicity spectra in the ^{12}C + ^{232}Th reaction for eight combinations of θ_α and $\theta_{\alpha{\rm fd}}$ out of 26.

The MSDA was first carried out for the ^{12}C + ^{232}Th reaction including the usual fusion-fission sources, namely, the compound nucleus (pre-scission), both the FFs (post-scission), and the near-scission emission (NSE). The α particles are assumed to be emitted isotropically in the rest frames of pre- and post-scission sources and nonisotropic for NSE as given in Refs. [4,12]. The effective emission barrier heights calculated for compound nuclei ($V_B^{\rm pre}$) and FFs ($V_B^{\rm post}$) are 20.3 and 13.5 MeV, respectively. The temperatures $T_{\rm pre}$ and $T_{\rm post}$ values are calculated to be 1.35 and 1.40 MeV, respectively, using the recipe as given in Refs. [4,12].

The α-particle spectra calculated in rest frames of four sources were converted to laboratory frames using the appropriate Jacobians and finally summed up to fit the measured spectra. In the moving source fit, the parameters $T_{\rm pre}$, $T_{\rm post}$, $V_B^{\rm pre}$, and $V_B^{\rm post}$ are kept fixed, whereas the pre- and post-scission multiplicities and the parameters related to NSE, are varied. The mean fragment velocities are determined using Viola's systematics [17] for the total kinetic energy released in the fission process. The fitted spectra for the individual source and after summing are shown in Fig. 2 for the ^{12}C + ^{232}Th reaction at eight typical angular settings. The best fitted values of the parameters are found to be $\alpha_{\rm pre} = (7.1 \pm 0.2) \times 10^{-3}$, $\alpha_{\rm post} = (0.15 \pm 0.04) \times 10^{-3}$, $\alpha_{\rm nse} = (0.3 \pm 0.2) \times 10^{-3}$, $\epsilon_p = 20.9 \pm 0.9$ MeV, $\sigma_\epsilon = 1.9 \pm 0.6$ MeV, and $\sigma_\theta = 6.8^\circ \pm 3.1^\circ$ corresponding to a minimum χ^2/(degree of freedom) value of 25.3, where σ_ϵ and σ_θ are the standard deviations of the energy and the angular distributions, respectively, for near-scission emission.

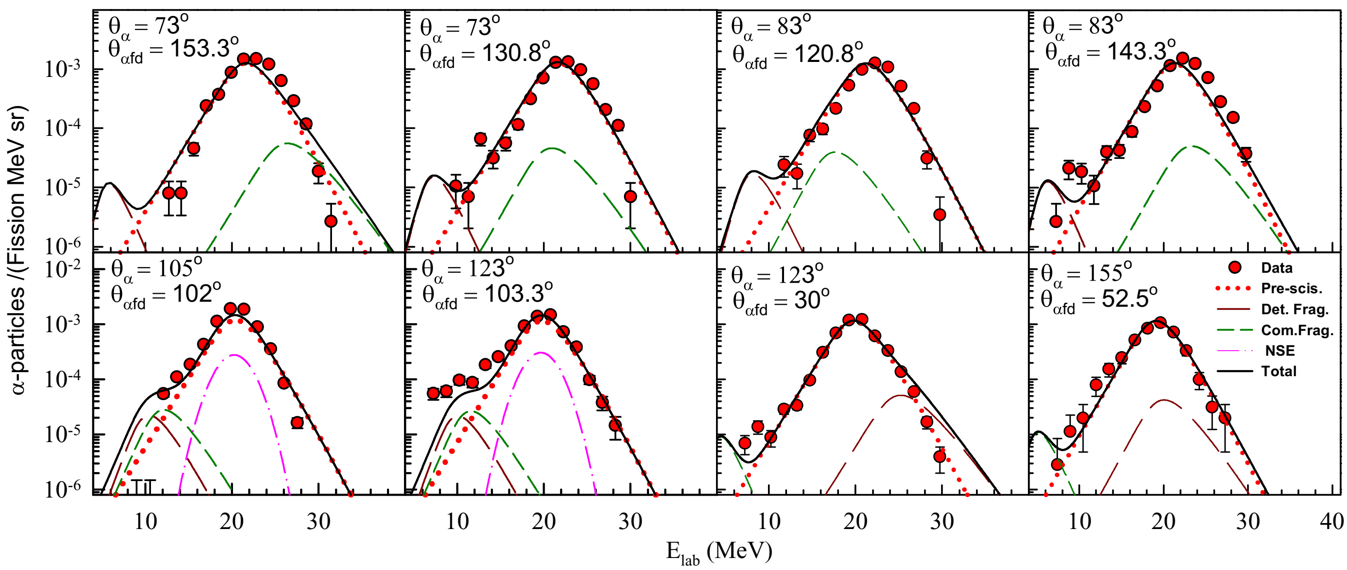

FIG. 2. α-particle multiplicity spectra along with fits of moving source model for different combination of laboratory angles of CsI(Tl) detectors with respect to the beam direction θ_α and detected FFs $\theta_{\alpha fd}$ in $^{12}C + ^{232}Th$ reaction. The dotted, long-dashed, short-dashed, and dash-dot curves are contributions from compound nucleus, detected fission fragment, complementary FF, and near-scission emission, respectively. The solid curve in each panel indicates total contribution from four sources.

One can notice from Fig. 2 that in the $^{12}C + ^{232}Th$ reaction, spectral fitting around the grazing angle ($\theta_\alpha \sim 75^\circ \pm 5^\circ$) is poorer than other angles, indicating the need for some other α source at these angles. Due to the α-cluster structure of ^{12}C, excess α particles around the grazing angle may originate from ^{8}Be breakup followed by α-transfer induced fission coincidence events. The folding angle between the two α particles produced from ^{8}Be breakup depends on their relative energy E_{rel} and kinetic energies, see Refs. [12,18,19]. For instance, for a kinetic energy of ^{8}Be (E_{Be}) to be 40 MeV, the maximum folding angle varies from 5.5° to 12.8° in going from $E_{rel} = 92$ keV to 500 keV. Therefore, in some of the coincidence events the angular acceptance of the each CsI detector (±3.5°) allows both α particles produced from ^{8}Be breakup to reach the detector simultaneously. The high-energy 2α events as shown in Fig. 1 correspond to these smaller folding angle events.

When only one of the α particles produced from ^{8}Be breakup enters the CsI detector, its kinetic energy E_α overlaps with that of other α particles produced from the fusion-fission process. Adopting the same method as discussed in Ref. [12], we carried out a reanalysis of the α-particle multiplicity spectra in the $^{12}C + ^{232}Th$ reaction including ^{8}Be breakup along with other fusion-fission sources in the MSDA. For simplicity in the moving source fit, the E_{rel} is neglected so that at a given θ_α, $E_\alpha = \frac{1}{2}E_{Be}$. The energy and angular distributions of one of the two breakup α particles are calculated in the rest frame of the compound nucleus using the following expression;

$$n(\epsilon^\alpha, \theta') \sim \alpha_{br} W_{c.m.}(\theta') \exp\left[\frac{-(\epsilon^\alpha - \epsilon_{br})^2}{2{\sigma_{br}}^2}\right], \qquad (1)$$

where ϵ^α, α_{br}, ϵ_{br}, and σ_{br} are the α-particle energy, multiplicity, peak energy, and standard deviation of the energy distribution, respectively, in the rest frame. $W_{c.m.}(\theta')$ is the angular distribution of ^{8}Be in the rest frame which is deduced from $W_L(\theta_L)$ using the appropriate Jacobian [12], where $W_L(\theta_L)$ is the angular distribution of ^{8}Be in the laboratory frame at an angle of θ_L with respect to beam direction. Earlier, the angular distribution of Be transfer products produced in $^{12}C + ^{232}Th$ reaction was measured [13] at the same beam energy as the present one. It was observed [13] that the grazing angle of Be products in the $^{12}C + ^{232}Th$ reaction moves from around 120° to 80° while the beam energy changes from 69 to 74.5 MeV.

The fitted spectra for the individual source and after summing, obtained from reanalysis of the moving source fit, are shown in Fig. 3. The best fitted values of the parameters are now obtained corresponding to a minimum χ^2/(degree of freedom) value of 19.4. These extracted parameters along with temperatures and emission barriers are provided in Table I. The errors quoted in the extracted parameters include only statistical uncertainties. Thus, by including ^{8}Be as a source in the MSDA, the fitting of multiplicity spectra improves appreciably around the grazing angle shown in the Fig. 3. The α_{pre} follows the heavy-ion systematic, where it is shown that α_{pre} values, when normalized to $E_{CN}^{2.3\pm0.1}$, show a systematic linearly increasing trend with the α-particle emission Q value (Q_α). Similarly, the fraction of near-scission multiplicity has been observed to be $(6.5 \pm 2.5)\%$ which is also consistent with the systematic [4], where it is established that the fraction of α_{nse} remains nearly the same at around 10% of the total pre-scission multiplicity. Twice the breakup peak energy of the α particle (ϵ_{br}) represents the kinetic energy of the ^{8}Be in the c.m. frame, and its value of 46.8 ± 0.4 MeV is very much consistent with two-body kinematics including the optimum Q value (Q_{opt}) [13]. The breakup multiplicity α_{br} in the

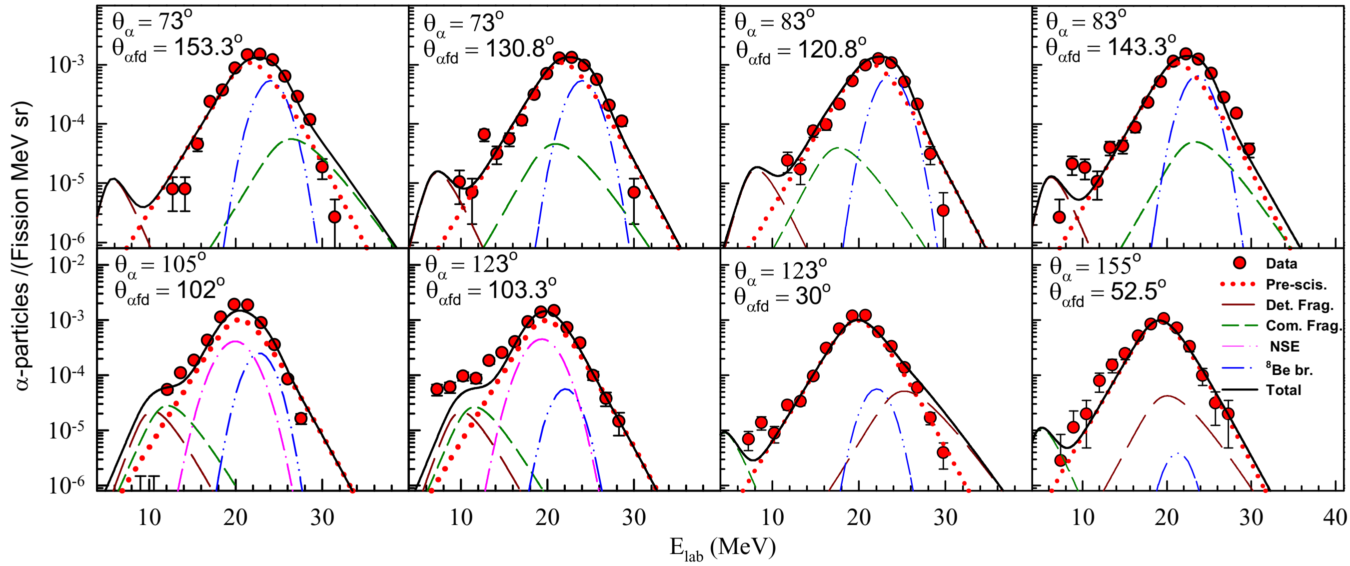

FIG. 3. α-particle multiplicity spectra along with fits of MSDA for different combination of laboratory angles of CsI(Tl) detectors with respect to the beam direction, θ_α, and detected FFs, $\theta_{\alpha\text{fd}}$. The solid curve indicates total contribution from five sources. The dotted, long-dashed, short-dashed, dash-dot, and dash-dot-dot curves are contributions from compound nucleus, detected fission fragment, complementary FF, near-scission emission, and ^{8}Be breakup, respectively.

present work at 74.5 MeV is observed to be significantly less than that of 69 MeV from our earlier work [12], where $\alpha_{\text{br}} = (2.1 \pm 0.1) \times 10^{-3}$. The α_{br} provides a measure of the dominant part of the transfer induced fission probability through the α-transfer channel. In fact, we can estimate the transfer induced fission cross section of this particular channel (α transfer) with knowing the total fission cross section from Ref. [20]. The fission cross sections at 69 and 74.5 MeV beam energies are 250 and 540 mb, respectively (see Ref. [20]) which yield the α-transfer induced fission cross section to be around 0.5 mb for both the energies.

TABLE I. Quantities relevant for α-particle emission and parameters extracted from MSDA. E_{CN} is initial compound nucleus excitation energy. Q_α and S_n are the Q value for α-particle emission and the neutron separation energy from the compound nucleus.

Parameter	$^{12}\text{C} + {}^{232}\text{Th}$	$^{13}\text{C} + {}^{232}\text{Th}$
E_{CN}	47.8 MeV	48.1 MeV
Q_α	5.902 MeV	5.623 MeV
S_n	6.801 MeV	5.520 MeV
α_{pre}	$(6.1 \pm 0.2) \times 10^{-3}$	$(3.3 \pm 0.3) \times 10^{-3}$
T_{pre}	1.35 MeV	1.35 MeV
V_B^{pre}	20.3 MeV	20.3 MeV
α_{post}	$(0.15 \pm 0.04) \times 10^{-3}$	$(0.15 \pm 0.04) \times 10^{-3}$
T_{post}	1.4 MeV	1.4 MeV
V_B^{post}	13.5 MeV	13.5 MeV
α_{nse}	$(0.42 \pm 0.16) \times 10^{-3}$	$(0.27 \pm 0.06) \times 10^{-3}$
ϵ_p	20.6 ± 0.6 MeV	17.7 ± 0.50 MeV
σ_ϵ	1.9 ± 0.6 MeV	2.0 ± 0.40 MeV
σ_θ	$6.8^\circ \pm 3.1^\circ$	$4.7^\circ \pm 1.0^\circ$
Fractional α_{nse}	$(6.5 \pm 2.5)\%$	$(7.6 \pm 1.8)\%$
α_{br}	$(0.90 \pm 0.09) \times 10^{-3}$	$(0.28 \pm 0.14) \times 10^{-3}$
ϵ_{br}	23.4 ± 0.2 MeV	21.8 ± 0.5 MeV
σ_{br}	1.5 ± 0.2 MeV	1.4 ± 0.2 MeV

It is to be noted that the fraction of breakup multiplicity (α_{br}) with respect to total pre-scission multiplicity ($\alpha_{\text{pre}} + \alpha_{\text{nse}}$) is observed to be $(13.9 \pm 1.5)\%$ in the present work at 74.5 MeV beam energy. It is much smaller than that observed at 69 MeV [12], where this fraction is around 33%. The reduction in the breakup multiplicity fraction with increasing beam energy is also consistent with transfer systematics [13]. Consistency in most of the observations establishes the fact that transfer breakup is indeed a potential source of α-particle emission in the $^{12}\text{C} + {}^{232}\text{Th}$ reaction which overlaps with the fusion-fission process.

Employing the same procedure and including five sources as used for the $^{12}\text{C} + {}^{232}\text{Th}$ reaction, the MSDA was performed for the $^{13}\text{C} + {}^{232}\text{Th}$ reaction. T_{pre}, T_{post}, V_B^{pre}, and V_B^{post} in the $^{13}\text{C} + {}^{232}\text{Th}$ reaction are obtained to be the same as the corresponding values in the $^{12}\text{C} + {}^{232}\text{Th}$ reaction as shown in Table I. Angular distribution of Be transfer products in the $^{13}\text{C} + {}^{232}\text{Th}$ reaction, needed for the MSDA, was measured separately in an auxiliary experiment as shown in Fig. 4. The fitted spectra for the individual source and after summing are shown in Fig. 5 for some typical angle settings. The best fitted values of the parameters are obtained corresponding to a minimum χ^2/(degree of freedom) value of 12.4. These extracted parameters are provided in Table I. The α_{pre} value in the $^{13}\text{C} + {}^{232}\text{Th}$ reaction, however, is less than the corresponding value in the $^{12}\text{C} + {}^{232}\text{Th}$ reaction, but it is grossly consistent with heavy-ion systematics. The compound nucleus excitation energy E_{CN} and Q_α values are provided in Table I for both reactions. The fraction of near-scission multiplicity in the $^{13}\text{C} + {}^{232}\text{Th}$ reaction has been observed to be $(7.6 \pm 1.8)\%$ which is consistent with systematics [4].

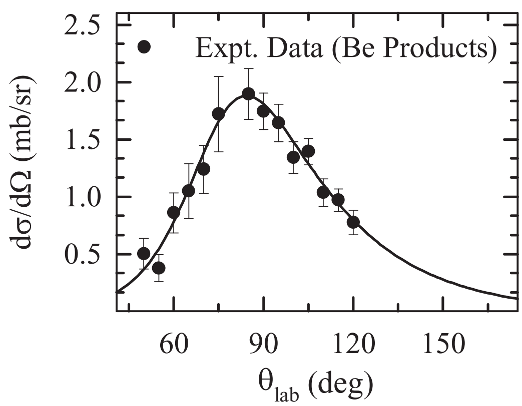

FIG. 4. Measured transfer angular distributions for Be products in ^{13}C (74.5 MeV) + ^{232}Th reaction. Solid line is the least-squares fitting assuming appropriate polynomial shape.

The 2α events in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction at $\theta_\alpha = 123^\circ$ are observed to be 1.2×10^{-4}/fission/sr which is around 3.5 times less than the corresponding value for $^{12}\mathrm{C} + ^{232}\mathrm{Th}$. As shown in Table I, the breakup multiplicity α_{br} in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction is also less than the $^{12}\mathrm{C} + ^{232}\mathrm{Th}$ reaction by almost the same factor. Two possibilities can lead to 2α events in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction: (i) α transfer ($Q = -15.22$ MeV) followed by breakup of ^{9}Be into two α particles and one neutron and (ii) $n\alpha$ transfer ($Q = -11.76$ MeV) followed by breakup of ^{8}Be into two α particles. The α-transfer channel in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ would be less probable owing to its unfavorable Q value. Also, the threshold of 1.573 MeV would hinder the breakup of ^{9}Be into two α particles and one neutron. The Q value for $n\alpha$ transfer in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ is very close to the α transfer in $^{12}\mathrm{C} + ^{232}\mathrm{Th}$ (-11.94 MeV), but one additional nucleon transfer in the former reaction would have an order of magnitude smaller probability than the latter reaction [21,22]. Thus, both $n\alpha$- and α-transfer channels lead to significantly lower breakup multiplicity in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction than the $^{12}\mathrm{C} + ^{232}\mathrm{Th}$ reaction.

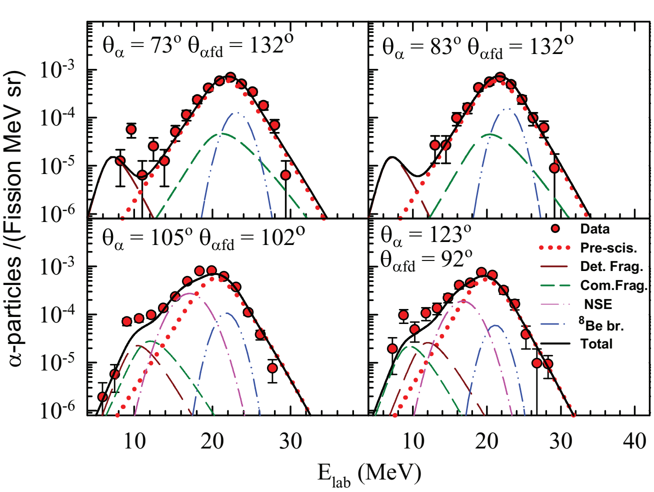

FIG. 5. Same as Fig. 3, but for $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction.

According to two-body kinematics including Q_{opt} [13], the kinetic energy of ^{8}Be in the center-of-mass frame produced through $n\alpha$-transfer in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ is 46.9 MeV, and hence the peak energy of the α particle ϵ_{br} should be around 23.5 MeV. But the experimental value of ϵ_{br} in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction is 21.8 ± 0.5 MeV. Whereas the kinetic energy of ^{9}Be in the center-of-mass frame produced through α transfer in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction is 46.3 MeV and it gives $\epsilon_{\mathrm{br}} = 20.6$ MeV. The experimental value of ϵ_{br} is 1.7 MeV lower and 1.2 MeV higher than the expectations of $n\alpha$-transfer and α-transfer channels, respectively. An average of expected values of ϵ_{br} from $n\alpha$-transfer and α-transfer channels is 22 MeV, which is very close to the experimental value, indicating that breakup α particles in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction might be produced, though very negligible, through both $n\alpha$- and α-transfer channels. It would be of further interest to perform exclusive measurements for α and $n\alpha$ transfer in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction.

It is interesting to note how an extra neutron in the entrance channel makes pre-scission α-particle multiplicity in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ smaller than the corresponding value in $^{12}\mathrm{C} + ^{232}\mathrm{Th}$. It might be attributed to the differences in key statistical parameters which are the initial compound nucleus excitation energy (E_{CN}), Q values for α-particle emission (Q_α), and neutron separation energy from the compound nucleus (S_n) for both reactions. As noted in Table I, the values for E_{CN} and Q_α are very similar for both reactions, but S_n is 1.3 MeV lower in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ than in $^{12}\mathrm{C} + ^{232}\mathrm{Th}$. A lower value of neutron separation energy in the $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ reaction would favor more neutron than α-particle emission during compound nuclear de-excitation. These results firmly establish the fact that projectile structure can influence the study of fission dynamics using particle emission as a probe.

In summary, we have measured the α-particle energy spectra in coincidence with the FFs in the $^{12,13}\mathrm{C} + ^{232}\mathrm{Th}$ reactions at different relative angles with respect to the FF direction at a beam energy of 74.5 MeV. The α-particle multiplicity spectra are fitted with moving source disentangling analysis to determine different components of α-particle emission. Excess α-particle emission has been observed in the $^{12}\mathrm{C} + ^{232}\mathrm{Th}$ reaction at 74.5 MeV projectile energy. It is identified as being caused by the same transfer-breakup source of excess α particles that was observed earlier at 69 MeV projectile energy. The breakup component in $^{13}\mathrm{C} + ^{232}\mathrm{Th}$ fission has been observed negligibly smaller than the $^{12}\mathrm{C} + ^{232}\mathrm{Th}$ fission. Results so obtained for pre- and near-scission multiplicities after taking into account the transfer-breakup source follow the heavy-ion systematics very well for both reactions. These results conclusively establish that transfer breakup is an undeniable source of α-particle emission in fission reactions, induced by α-cluster projectiles such as ^{12}C.

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