Rare Isotope Formation in Complete Fusion and Multinucleon Transfer Reactions in Collisions of 48Ca +248Cm around Coulomb Barrier Energies postprint

Authors: Peng-Hui, Chen, Fei, Niu, Xin-Xing Xu, Zeng, Xiang-Hua, Feng, Zhao-Qing, Peng-Hui Chen, Feng, Zhao-Qing

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Abstract

Within the framework of the dinuclear system model, we thoroughly investigate the reaction mechanisms for synthesizing target-like isotopes from berkelium (Bk) to the compound nuclei livermorium (Lv) in complete and incomplete fusion reactions of ^{48}Ca + ^{248}Cm around Coulomb barrier energies. We evaluate the production cross sections of ^{292,293}Lv as a function of excitation energy in fusion-evaporation reactions and the isotopic yields of target-like fragments in multinucleon trans…

Full Text

Preamble

Within the framework of the dinuclear system model, we thoroughly investigate the reaction mechanisms for synthesizing target-like isotopes from berkelium (Bk) to the compound nuclei livermorium (Lv) in complete and incomplete fusion reactions of ^{48}Ca + ^{248}Cm around Coulomb barrier energies. We evaluate the production cross sections of ^{292,293}Lv as a function of excitation energy in fusion-evaporation reactions and the isotopic yields of target-like fragments in multinucleon transfer reactions, using a statistical approach to describe the decay process of excited nuclei. The available experimental data are reproduced well with reasonable model parameters. We systematically export all possible isotopic products formed during the dynamical pre-equilibrium process for collision partners at an incident energy of $E_{\mathrm{lab}} = 5.5$ MeV/nucleon, finding that quasi-fission fragments dominate the yields. The optimal pathway from the target to compound nuclei follows the valley of the potential energy surface. The effective impact parameter for two colliding partners leading to compound

nuclei ranges from head-on collision to semi-central collision with $L = 52\hbar$. The timescale boundary between complete fusion and multinucleon transfer reactions is approximately 5.7×10^{-21} s for effective impact parameters. We predict synthesis cross sections of unknown neutron-rich actinides from Bk to Rf to be around several nanobarns.

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Introduction

Nuclear physicists, both theoretical and experimental, are devoted to exploring the synthesis of exotic nuclei and superheavy elements (SHE) toward the drip lines and island of stability via heavy-ion collisions to find the limits of the nuclear landscape. Fusion-evaporation reactions have been widely used in laboratories worldwide to produce unknown superheavy elements. At the Flerov Laboratory of Nuclear Reactions (FLNR, Dubna), the synthesis of SHEs with atomic numbers up to $Z = 118$ has been claimed using reactions of actinides with a doubly magic ^{48}Ca beam [1, 2]. At the Gesellschaft für Schwerionenforschung (GSI), superheavy elements with $Z = 107 - 112, 114 - 117$ have been identified [3, 4]. The production of the new element nihonium ($Z = 113$) in collisions of ^{70}Zn + ^{209}Bi has been observed at RIKEN [5], while element flerovium ($Z = 114$) has been synthesized at Lawrence Berkeley National Laboratory (LBNL) [6]. The Chinese SHE group has synthesized superheavy isotopes of dubnium ($Z = 105$), bohrium ($Z = 107$), and darmstadtium ($Z = 110$) at the Institute of Modern Physics (IMP, Lanzhou) [7–9].

To produce exotic transuranium isotopes, multinucleon transfer (MNT) reactions are proposed for experiments with radioactive beams in various laboratories. These reactions offer the advantage that products are formed over a wide mass region due to broad excitation functions in MNT products. However, complete fusion reactions between two heavy partners at energies around the Coulomb barrier are strongly hindered by competing incomplete fusion reactions (quasi-fission and deep-inelastic reactions). Therefore, more insightful theoretical and experimental studies of the reaction mechanisms are required to make precise predictions for the probability of compound nucleus formation and MNT products in such reactions.

Quasi-fission and deep-inelastic heavy-ion collisions have been extensively investigated experimentally since the 1970s, when MNT reactions were initially proposed to synthesize superheavy elements. However, new neutron-rich projectile-like fragments and proton-rich actinide nuclei were observed in laboratories [10–16]. In particular, isospin-asymmetric collisions may provide valuable information on the production mechanism of exotic heavy nuclei. Reactions such as ^{136}Xe + ^{208}Pb [17, 18], ^{136}Xe + ^{198}Pt [19], ^{156,160}Gd + ^{186}W [20], and ^{238}U + ^{232}Th [21] have been performed worldwide to create unknown neutron-rich heavy nuclei near the neutron shell $N = 126$, with applications to understanding the origin of heavy elements in nuclear astrophysics.

Motivated by the need to predict exotic heavy and superheavy nuclei, several models have been developed, including the dynamical model based on multidimensional Langevin equations [22, 23], the time-dependent Hartree-Fock (TDHF) approach [24–27], the GRAZING model [28, 29], the improved quantum molecular dynamics (ImQMD) model [30, 31], Langevin-type dynamical equations [32, 33], and the dinuclear system (DNS) model [34–39]. These studies have emphasized interesting issues such as synthesis mechanisms, total kinetic energy spectra, and structure effects. However, open problems remain for strongly damped reactions, including the mechanism of pre-equilibrium particle emission, the stiffness of the nuclear surface during nucleon transfer, and the mass limitation of new isotopes with stable heavy target nuclides.

The three laboratories FLNR [40], GSI [41], and RIKEN [42] have obtained excitation functions for the 3n and 4n evaporation channels for production of superheavy element $Z = 116$ in ^{48}Ca-induced reactions with ^{248}Cm targets. In experiments synthesizing superheavy nuclei ($Z = 116$) with ^{48}Ca + ^{248}Cm [43–47], massive independent yields of target-like fragments have been observed, including new heavy isotopes. The production cross sections of all formed products provide an opportunity to investigate the interplay between equilibrium and dissipation in low-energy heavy-ion collisions as well as the decay properties of excited superheavy nuclei. This motivates our interest in exploring nuclear dynamics and reaction mechanisms in complete and incomplete fusion in terms of evolution time and dissipated energy.

In this work, we calculate the ^{48}Ca-induced complete and incomplete fusion reactions with ^{248}Cm using the DNS model. The aim is to study the dynamics affecting the synthesis cross sections of nuclides in complete and incomplete fusion of ^{248}Cm with a ^{48}Ca projectile. The article is organized as follows: In Sec. II we provide a brief description of the DNS model. Calculated results and discussions are presented in Sec. III. A summary is given in Sec. IV.

II. Model Description

The dynamical complete and incomplete fusion mechanisms are described as a diffusion process, in which the resulting distribution probability is obtained by solving a set of master equations numerically on the potential energy surface of the DNS. The time evolution of the distribution probability $P(Z_1, N_1, E_1, \beta, t)$ for fragment 1 with proton number Z_1, neutron number N_1, excitation energy E_1, and quadrupole deformation β is described by the following master equations:

$$\frac{dP(Z_1,N_1,E_1,\beta,t)}{dt} = \sum_{Z_1',N_1',\beta'} W_{Z_1,N_1,\beta;Z_1',N_1',\beta'}(t)\left[d_{Z_1',N_1'}P(Z_1',N_1',E_1',\beta,t) - d_{Z_1,N_1}P(Z_1,N_1,E_1,\beta,t)\right]$$

The sum is taken over all possible proton and neutron numbers that fragment (Z_1', N_1') may take, but only one-nucleon transfer is considered in the model with the relations $Z_1' = Z_1 \pm 1$ and $N_1' = N_1 \pm 1$. The $W_{Z_1,N_1,\beta;Z_1',N_1',\beta'}$ is the mean transition probability from the channel (Z_1, N_1, E_1, β) to $(Z_1', N_1', E_1', \beta')$, and d_{Z_1,N_1} denotes the microscopic dimension corresponding to the macroscopic state (Z_1, N_1, E_1).

The motion of nucleons in the interacting potential is governed by the single-particle Hamiltonian. The excited DNS opens a valence space in which the valence nucleons have a symmetrical distribution around the Fermi surface. Only particles in states within the valence space are active for nucleon transfer. The transition probability is related to the local excitation energy and nucleon transfer, which is microscopically derived from the interaction potential in the valence space as described in [48, 49].

The local excitation energy is determined by the dissipation energy from the relative motion and the potential energy surface of the DNS as $\varepsilon^*(t) = E_{\text{diss}}(t) - (U(\{\alpha\}) - U(\{\alpha_{EN}\}))$. The entrance channel quantities $\{\alpha_{EN}\}$ include the proton and neutron numbers, quadrupole deformation parameters, and orientation angles for projectile and target nuclei, denoted by $Z_P, N_P, Z_T, N_T, R, \beta_P, \beta_T, \theta_P, \theta_T$, respectively. The interaction time τ_{int} is obtained from the deflection function method [50]. The energy dissipated into the DNS increases exponentially [51].

The potential energy surface (PES) of the DNS is evaluated by:

$$U_{\text{dr}}(t) = Q_{gg} + V_C(Z_1, N_1, \beta_1, Z_2, N_2, \beta_2, t) + V_N(Z_1, N_1, \beta_1, Z_2, N_2, \beta_2, t) + V_{\text{def}}(t)$$

which satisfies the relation $Z_1 + Z_2 = Z$ and $N_1 + N_2 = N$, with Z and N being the proton and neutron numbers of the composite system, respectively. The $B(Z_i, N_i)$ $(i = 1, 2)$ and $B(Z, N)$ are the negative binding energies of the fragment (Z_i, N_i) and the composite system (Z, N), respectively. The θ_i denotes the angles between the collision orientations and the symmetry axes of the deformed nuclei. $V_{\text{def}}(t)$ is the deformation energy of the DNS at moment t. The evolutions of quadrupole deformations of projectile-like and target-like fragments from the initial configuration are given by:

$$\beta_T'(t) = \beta_T \exp(-t/\tau_\beta) + \beta_1[1 - \exp(-t/\tau_\beta)]$$

$$\beta_P'(t) = \beta_P \exp(-t/\tau_\beta) + \beta_2[1 - \exp(-t/\tau_\beta)]$$

with the deformation relaxation time $\tau_\beta = 4 \times 10^{-21}$ s.

The total kinetic energy (TKE) of the primary fragment is evaluated by:

$$\text{TKE}(A_1) = E_{\text{c.m.}} + Q_{gg}(A_1) - E_{\text{diss}}(A_1)$$

where $Q_{gg} = M_P + M_T - M_{\mathrm{PLF}} - M_{\mathrm{TLF}}$ and $E_{\mathrm{c.m.}}$ is the incident energy in the center-of-mass frame. The masses M_P, M_T, M_{PLF}, and M_{TLF} correspond to the projectile, target, projectile-like fragment, and target-like fragment, respectively.

The cross sections of surviving fragments produced in MNT reactions and fusion-evaporation residue cross sections are evaluated by:

$$\sigma_{\mathrm{sur}}(Z_1, N_1, E_{\mathrm{c.m.}}) = \frac{2\mu}{E_{\mathrm{c.m.}}} \sum_{J=0}^{J_{\max}} (2J+1) \int f(B) T(E_{\mathrm{c.m.}}, J, B) \sum_s W_{\mathrm{sur}}(Z_1', N_1', E_1', J_1', B) dB$$

and

$$\sigma_{\mathrm{ER}}(E_{\mathrm{c.m.}}) = \frac{2\mu}{E_{\mathrm{c.m.}}} \sum_{J=0}^{J_{\max}} (2J+1) T(E_{\mathrm{c.m.}}, J) P_{\mathrm{CN}}(E_{\mathrm{c.m.}}, J) W_{\mathrm{sur}}(E_{\mathrm{c.m.}}, J)$$

respectively, where μ is the reduced mass of relative motion. The transmission probability $T(E_{\mathrm{c.m.}}, J)$ is calculated using the Hill-Wheeler formula in combination with the barrier distribution function. The E_1 and J_1 are the excitation energy and angular momentum for the fragment (Z_1, N_1). The maximal angular momentum $J_{\max}$ is taken to be the grazing collision of two nuclei. The survival probability W_{sur} of each fragment is evaluated with a statistical approach based on the Weisskopf evaporation theory [52], in which the excited primary fragments are cooled through evaporation channels $s(Z_s, N_s)$ by γ-rays and light particles (neutrons, protons, α particles, etc.) in competition with binary fission via $Z_1 = Z_1' - Z_s$ and $N_1 = N_1' - N_s$. The $P_{\mathrm{CN}}(E_{\mathrm{c.m.}}, J)$ is the fusion probability summed over all fragment probabilities located outside the Businaro-Gallone (BG) point. The transfer cross section is smoothed with the barrier distribution.

III. Results and Discussion

In heavy-ion collisions that overcome the Coulomb barrier, the kinetic energy of relative motion rapidly transforms into internal excitation of the dinuclear system at the contact point. Figure 1 shows the interaction potential distribution as a function of distance, interaction time as a function of impact parameter, and internal excitation energy as a function of reaction time for the ^{48}Ca + ^{248}Cm system at $E_{\mathrm{lab}} = 5.5$ MeV/nucleon. The interaction potential is calculated as a function of surface distance between the two heavy partners. Panel (a) shows that the Coulomb barrier of the colliding system is about 185 MeV, while the quasi-fission barrier is several MeV. The potential pocket is located near the contact point. The reaction time, calculated by the deflection function and plotted as a function of angular momentum, decreases exponentially with increasing angular momentum. The internal excitation energy dissipated in the dinuclear system increases exponentially with evolution time. The existence of a pocket in the entrance channel is crucial for compound nucleus formation in fusion reactions and serves as an input physical quantity for calculating capture cross sections. The barrier is taken as the potential value at the touching configuration, and the nucleus-nucleus potential is calculated using the same approach as in fusion reactions [53].

According to Figure 1 [Figure 1: see original paper], we find that there is only a few MeV deep potential pocket for heavy systems due to the strong Coulomb repulsion between colliding partners with $Z_1Z_2 = 1860$. Lighter collision systems have relatively deeper potential pockets, which lead to correspondingly longer reaction times. For the ^{48}Ca + ^{248}Cm reaction with impact parameter $L = 50\hbar$, the timescale for reaching an almost equilibrium state with incident energy dissipated into internal excitation is about 5.7×10^{-21} s.

Nucleons can be transferred between collision partners, resulting in rapid rearrangement of the internal degrees of freedom characterizing nuclear states along the potential energy surface (PES) while dissipating kinetic energy and angular momentum. Calculating multi-dimensional adiabatic PES for heavy nuclear systems is a quite complicated physical problem that remains open. In this work, the PES for tip-tip collisions of ^{48}Ca + ^{248}Cm is calculated using Eq. (3) as a diabatic type with frozen distance, shown in Figure 2 [Figure 2: see original paper] (b). The solid black line, solid black circle, and solid red triangle indicate the valley value, projectile-target position, and compound nuclei, respectively. The valley value in the PES is listed as a function of mass in Figure 2 (a). The inner fusion barrier of the collision partners is $B_{\text{fus}} = 5.24$ MeV, meaning that 5.24 MeV of barrier energy must be overcome to fuse. The DNS fragments moving toward the mass-symmetric valley release positive energy that is available for nucleon transfer. The spectra exhibit a symmetric distribution for each isotopic chain, and the valley in the PES is close to the β-stability line, enabling diffusion of the fragment probability.

Figure 3 shows the calculated correlation between total kinetic energy (TKE) and mass distributions of reaction products, along with the mass distribution for the ^{48}Ca + ^{248}Cm reaction at near-barrier energy $E_{\text{lab}} = 5.5$ MeV/nucleon. These calculations agree reasonably well with experimental data [54] and are consistent with calculations using Langevin-type dynamical equations [55]. In most damped collisions, the interaction time is rather short (several units of 10^{-21} s). These fast events correspond to grazing collisions with intermediate impact parameters, shown by the areas around projectile-target points, where a large amount of kinetic energy is dissipated very rapidly (more than 45 MeV during several units of 10^{-21} s) at relatively low mass transfer. Other events correspond to much slower collisions with large nuclear surface overlap and significant nucleon rearrangement. In the TKE-mass plot, these events spread over a wide region of mass fragments. The fragments in the square areas indicate overcoming of the inner barrier (Businaro-Gallone point), meaning they can lead to compound nuclei within the DNS model framework.

Figure 4 [Figure 4: see original paper] shows predicted and experimental excitation functions for the 3n and 4n channels producing livermorium ($Z = 116$) in ^{48}Ca-induced reactions. Experimental data from FLNR (blue symbols), GSI (black symbols), and RIKEN (red symbols) are shown. The three laboratories obtained excitation functions for the 3n and 4n evaporation channels producing superheavy element $Z = 116$ in ^{48}Ca + ^{248}Cm collisions. At FLNR, three irradiations were performed at lower beam energies in Dubna during June-July and November-December 2000 and January and April-May 2001 [40]. At $E^* = 30.5$ MeV, a cross-section limit of 0.9 pb was reached. At $E^* = 33.0$ MeV, three decay chains were measured, resulting in a cross-section of $(0.5^{+0.5}_{-0.26})$ pb assigned to \$^{293}\$116. At the same excitation energy, a cross-section limit of 0.3 pb was obtained for the 4n channel. The highest energy studied was $E^* = 38.9$ MeV, where six decay chains were measured and assigned to \$^{292}\$116, yielding a cross-section of $(3.3^{+2.5}_{-1.4})$ pb for the 4n channel. Additionally, two chains from the 3n channel were measured at this energy, giving a cross-section of $(1.1^{+1.7}_{-0.7})$ pb. This experiment was performed in April-May 2004 [56], with four cross-section data points marked by solid blue symbols in Figure 4.

At GSI, at energy $E^* = 40.9$ MeV, six decay chains were detected, with four events assigned to the 4n channel resulting in a cross-section of $(3.4^{+2.7}_{-1.6})$ pb and one of the other two events to the 3n channel, giving a cross-section of $(0.9^{+2.1}_{-0.7})$ pb for the event definitively assigned to \$^{293}\$116. No event was observed in the second part of the experiment at $E^* = 45.0$ MeV, resulting in a one-event cross-section limit of 1.6 pb. Three cross-section data points are marked by solid black symbols in Figure 4.

At RIKEN, the fusion reaction ^{48}Ca + ^{248}Cm → ^{296}Lv* was investigated using the gas-filled recoil ion separator GARIS at excitation energies of 41.3 and 38.2 MeV. A total of seven decay chains were observed, with three assigned to ^{292}Lv and three to ^{293}Lv. The resulting cross sections are $\sigma_{3n} = (1.0^{+2.4}_{-1.8})$ pb and $\sigma_{4n} = (3.1^{+2.8}_{-0.9})$ pb at $E^* = 41.3$ MeV, and $\sigma_{3n} = (1.8^{+2.3}_{-1.1})$ pb at $E^* = 38.2$ MeV. For unobserved decay chains, one-event cross-section limits are 1.9 pb and 1.6 pb at $E^* = 41.3$ and 38.2 MeV, respectively. Three cross-section data points are marked by solid red symbols in Figure 4. In theoretical calculations, the Q-value for ^{48}Ca + ^{248}Cm → ^{296}Lv* is -166.57 MeV, and the V_{Bass} potential is 197.12 MeV, indicated by the solid black arrow. The dashed and solid lines are calculated excitation functions corresponding to the 3n and 4n evaporation channels. Figure 4 shows that the calculated excitation functions agree well with all available experimental data [40–42].

In ^{48}Ca + ^{248}Cm collisions at energies around the Coulomb barrier, MNT products dominate all isotopic yields. In the 1980s, to study the role of the neutron-rich projectile ^{48}Ca in enhancing yields of neutron-rich actinides and to determine the effect of eight fewer neutrons in ^{48}Ca on the mass distribution, two series of experiments were performed at LBL and GSI using radiochemical methods and on-line gas-jet transport of short-lived reaction products combined with electronic detection systems [44]. Above-target isotopes from Bk to Fm, and below-target isotopes of Rn, Ra, Ac, Th, U, Pu were observed in ^{48}Ca + ^{248}Cm reactions at incident energies $E_{\rm lab} = 223 - 239$, $248 - 263$, $247 - 263$, $272 - 288$, and $304 - 318$ MeV. The maximum yields of above-target isotopes occur around $E_{\rm lab} = 248 - 263$ MeV. This paper reports only on the production of Bk, Cf, Es, and Fm; production of below-target isotopes is discussed in [57].

In 2000, experiments on ^{48}Ca + ^{248}Cm at $E_{\rm lab} = 265.4$, 270.2 MeV were performed at GSI [47]. Fusion products and target-like transfer reaction products were measured on SHIP. Due to short detection time (two days) and limited separation methods, several above-target isotopes were obtained: ^{252,254}Cf, ^{254,256}Es, and ^{254,256}Fm, listed in TABLE I. Cross sections measured in [46] for the same isotopes and collision system are also listed for comparison. Results from both experiments are in quite good agreement despite different experimental techniques and systematic uncertainties. For example, cross sections for directly populated nuclides ^{254}Cf and ^{254}Es agree within factors of approximately 1.8 and 1.5, respectively, compared to cross sections presented in [46]. For the same reaction system, different separation methods can result in discrepancies of several orders of magnitude.

Figure 5 [Figure 5: see original paper] presents predicted and identified MNT products from Bk to Fm along with measured cross sections. The calculations agree reasonably well with experimental data. Both calculations and experimental data reveal a trend where the cross section of a given MNT product decreases on average by one order of magnitude with each proton transferred from the projectile to the target nucleus, due to heavier above-target isotopes having smaller fission barriers. Predictions have been made for unknown isotopes ^{254}Bk, ^{257}Cf, ^{259}Es, ^{260}Fm, ^{263}Md, ^{264,265}No, ^{266}Lr, and ^{268}Rf, with cross sections of 0.4, 0.2, 0.1, 0.2, 0.2, 0.9, 0.6, 0.2, and 1 nb, respectively.

Collisions of atomic nuclei are ideal for investigating equilibration and dissipative processes in quantum many-body systems [58, 59]. Exploring nuclear dynamics in complete and incomplete fusion for heavy-ion collisions can help understand the interplay between equilibrium and dissipation in quantum systems. During the collision process, nucleons can diffuse from the target to compound nuclei, with probabilities of all formed fragments exported at every moment. The dynamical process of isotopic yields from pre-equilibrium to equilibrium can reveal a boundary line between complete fusion and multinucleon transfer reactions. The timescale for mass equilibrium ($\sim 10^{-20}$ s) is found to be larger than the timescale for kinetic energy dissipation, which is on the order of 10^{-21} s. In our approach, for collisions of ^{48}Ca + ^{248}Cm at $E_{\rm lab} = 5.5$ MeV/nucleon with impact parameter $L = 25\hbar$, dynamical nucleon transfer between projectile and target is exhibited by plotting graphs for all fragment production at different timescales: 2×10^{-22} s, 4×10^{-22} s, 1×10^{-21} s, 2×10^{-21} s, 4×10^{-21} s, and 5.7×10^{-21} s, corresponding to panels (a), (b), (c), (d), (e), and (f) of Figure 6 [Figure 6: see original paper], respectively. The composite system begins to fuse into compound nuclei at 5.7×10^{-21} s, which we consider as the boundary between complete and incomplete fusion. The moments when collision partners fuse to form compound nuclei are identified in the diffusion process, and we calculate all these moments corresponding to all impact parameters. Plotting all these moments yields the red dashed line shown in Figure 1(b).

We find that the upper limit of impact parameter for synthesis of superheavy element $Z = 116$ is $L = 56\hbar$, primarily because the dissipated energy of the colliding system reaches equilibrium almost completely. The boundary line between complete fusion and MNT is found to be around 5.7×10^{-21} s. It is worth mentioning that our calculations for equilibrium timescales of fragment mass asymmetry and kinetic energy dissipation are consistent with those from TDHF and TDRPA [60].

IV. Conclusions

In summary, we have investigated production of above-target isotopes and compound nuclei within the DNS model through complete fusion-evaporation and multinucleon transfer reactions, focusing on MNT products of Bk, Cf, Es, Fm and fusion-evaporation products of ^{292,293}Lv. In the collision process, kinetic energy dissipated into internal excitation heats the composite system. Nucleon transfer occurs at the touching configuration of two colliding nuclei under the PES. The valley shape of the PES influences the formation of primary fragments and leads to production of quasi-fission isotopes. The PES used here is of diabatic type, derived from the Q_{gg} value, double-folding nuclear potential, and Coulomb potential. The TKE-mass distribution of multinucleon transfer products reveals important quantities including reaction mechanisms, dissipated energy, and shell and structure effects. The calculations can reasonably explain both experimental results of complete fusion-evaporation products and multinucleon transfer fragments for ^{48}Ca + ^{248}Cm. Available experimental data have been obtained successively from laboratories worldwide. In our calculations, the diffusion pathway from target to compound nuclei has been identified, derived from dynamical competition with deep-inelastic and quasi-fission processes for two heavy systems. The excitation functions for producing superheavy isotopes ^{292,293}Lv are composed of experimental data from three different laboratories: GSI, FLNR, and RIKEN.

We compare experimental data from two groups for target-like fragments in ^{48}Ca + ^{248}Cm collisions performed at GSI & LBL in 1986 and 2010, respectively. We find that the obtained isotopic cross sections are highly dependent on the identification method. In particular, for below-target isotopes ($Z < 96$), cross sections obtained by radiochemical methods are three orders of magnitude larger than those obtained by decay spectroscopy. However, cross sections of above-target nuclei ($Z > 96$) from both experiments are quite consistent despite different experimental techniques and systematic uncertainties. The effective impact parameter for these colliding partners leading to compound nuclei ranges from central collision to $L = 52\hbar$. The timescale between complete and incomplete reactions is about 5.7×10^{-21} s for effective impact parameters. We predict that synthesis cross sections of unknown rare isotopes ^{254}Bk, ^{257}Cf,

^{259}Es, ^{260}Fm, ^{263}Md, ^{264,265}No, ^{266}Lr, and ^{268}Rf are around the nanobarn level in ^{48}Ca + ^{248}Cm collisions near Coulomb barrier energies.

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