PHYSICAL REVIEW C **93**, 041604(R) (2016)

Examination of the fission time of the $Z = 120$ nucleus

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(Received 30 June 2015; revised manuscript received 30 November 2015; published 15 April 2016)

We show that the large difference in the measured lifetime for asymmetric fission of the highly excited ($T \approx 1.5$-MeV) $Z = 120$ nucleus as measured by the atomic techniques (crystal blocking and x-ray methods) with those measured by the nuclear techniques (mass-angle distribution and prefission neutron multiplicity) cannot be due to the different sensitivities of the atomic and nuclear techniques in different time domains. The claim of formation of a superheavy $Z = 120$ nucleus with a high fission barrier on the basis of an observed long fission time by the atomic techniques is in direct conflict with all other available measurements and calculations.

DOI: 10.1103/PhysRevC.93.041604

The search for superheavy elements with high fission barriers is a topic of current interest, and various attempts are being made to produce superheavy elements by fusion reactions between two heavy nuclei. However, a major obstacle for the formation of superheavy elements with $Z \geqslant 110$ is the dominance of the short-lived quasifission process [1] over fusion-fission (FF). Nuclear techniques, such as mass-angle distribution measurements [2,3], have been used earlier to measure a very short quasifission lifetime and distinguish it from fusion-fission. Recently, atomic techniques, such as the crystal blocking and x-ray methods [4–9], were being used to measure the fission lifetime of highly excited transuranium nuclei, and generally very long fission times ($\sim 10^{-18}$ s) have been seen. Recently, Fregeau *et al.* [9] reported a measurement of the characteristic x-ray fluorescence yield and obtained a long mean lifetime for $Z = 120$ (unbinilium) in agreement with their crystal blocking measurements [8]. Fregeau *et al.* [9] bombarded a ^{64}Ni target with a ^{238}U beam at 6.6 MeV/nucleon and detected fission fragments in the angular region of $15.9^\circ < \theta_{\text{lab}} < 69^\circ$ with respect to the beam axis. They detected characteristic x-ray photons from the compound $Z = 120$ nucleus, in coincidence with fission fragments and found that more than 53% of the mass-asymmetric fission fragments ($70 < Z < 80$) emitted in the angular region of $15.9^\circ < \theta_{\text{lab}} < 69^\circ$ came from a slow process of lifetimes much greater than that of the atomic K-orbital vacancy ($\tau_x = 2.8 \times 10^{-18}$ s), in agreement with an earlier crystal blocking experiment [8]. On the basis of these experimental results, it was concluded [8,9] that there is a large component of the long-lived ($>10^{-18}$-s) asymmetric fission process emitting fragments in the angular region of their study ($15.9^\circ < \theta_{\text{lab}} < 69^\circ$). The observed long fission time was thought [8,9] to be due to the high fission barrier of superheavy unbinilium decaying for a long time by neutron emission before undergoing predominantly asymmetric fission.

Using nuclear techniques, Toke *et al.* [2] and Hinde *et al.* [10] measured the fission time of the complex produced by the ^{238}U + ^{64}Ni reaction at the same or similar energy. Toke *et al.* [2] bombarded the ^{64}Ni target with ^{238}U at 6 MeV/nucleon and performed a mass-angle distribution measurement on the fission fragments detected in the angular region from 3° to 70°, which covers the angular region studied by Fregeau *et al.* [9]. They observed [2] a significant lack of reflection symmetry in the angular distribution of mass-asymmetric fragments, indicating that the fission time was comparable to or shorter than the time for one rotation of the composite ($\sim 10^{-20}$ s). For fission events with greater mass symmetry, the angular distribution showed a higher degree of reflection symmetry, indicating a longer lifetime of the composite. They found [2] that the fission time increased from 3.1×10^{-21} to 7.5×10^{-21} s with increasing fragment mass symmetry and that mass-asymmetric splitting was the dominant process.

Hinde *et al.* [10] performed mass and total kinetic-energy gated prefission neutron multiplicity measurements for this reaction (^{64}Ni + ^{238}U) producing the same compound nucleus ($Z = 120$, $A = 302$) at the same excitation energy ($T \approx 1.5$ MeV) and detected fission fragments at similar center-of-mass angles as studied by Fregeau *et al.* [9]. They obtained [10] a prefission neutron multiplicity of (4.0 ± 0.8) which translates to an average fission lifetime of $(1.5 \pm 0.5) \times 10^{-20}$ s, again much shorter than the lifetime obtained in Refs. [8,9]. Moreover, Hinde *et al.* [10] stated that their measured prefission neutron multiplicity (4 ± 0.8) for the very fast fission of the $Z = 120$ nucleus produced by the ^{64}Ni + ^{238}U reaction probably contained very significant contributions from the postfission neutrons emitted by the accelerating fragments and the true prefission neutron multiplicity could be significantly lower, consistent with the measured splitting time on the order of 10^{-21} s of Toke *et al.* [2]. Both Toke *et al.* [2] and Hinde *et al.* [10] concluded that the quasifission process having a very short lifetime ($\sim 10^{-21}$ s) is the dominant reaction mechanism for the ^{238}U + ^{64}Ni reaction in the same angular region studied by Fregeau *et al.* [9] and Morjean *et al.* [8]. Explanations have been given [11,12] arguing that the fission process has a distribution of decay times extending from 10^{-21} to 10^{-15} s and nuclear techniques, such as mass-angle distribution and prefission neutron multiplicities are sensitive to the short fission time scale, whereas the atomic techniques (x rays and crystal blocking) are sensitive to the long fission time scale. We show below that this sensitivity argument

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cannot explain the observed large percentage of the long-lived fission component seen by the atomic techniques and the corresponding very short fission time observed by the nuclear techniques.

In the case of the $^{238}\mathrm{U}+^{64}\mathrm{Ni}$ reaction at $E_{\mathrm{c.m.}} = 332.8\,\mathrm{MeV}$, both the fast quasifission process and the fusion-fission process with a distribution of fission times might take place. The nuclear and atomic techniques measure the weighted averages of fission time distribution with different weighting factors in different time domains for the two techniques. So the comparison among the fission times obtained by the nuclear and the atomic techniques has to be performed carefully. The nuclear clocks are more sensitive and measure time with better precision compared to the atomic clocks. However they have a relatively short range and saturate earlier compared to the atomic clocks. The atomic clocks (x rays and crystal blocking) are less precise but can measure longer fission times in the range of 10^{-18}–10^{-16} s. Short fission times from 10^{-21} to 10^{-18} s do not produce any observable characteristic x-ray peaks, and blocking ratios remain below the thermal vibration limit. Hence the atomic clocks set fission times from 10^{-21} to 10^{-18} s in a single time bin designated as less than 10^{-18} s. So the atomic clocks cannot distinguish between fission times on the order of 10^{-21} s from fission times on the order of 10^{-19} s but can certainly distinguish unambiguously between short fission times on the order of 10^{-21} s and long fission times on the order of 10^{-18} s. Let N_K be the K-x-ray yield in coincidence with fissioning events (N_f). Let τ_X be the lifetime of the K-orbital vacancy, τ be the fission lifetime, $f(\tau)$ be the normalized fission time distribution, and P_K be the probability of producing a K-orbital vacancy. Then [6],

$$N_K = \frac{N_f P_K}{\tau_X}\int_{t=0}^{\infty}\int_{\tau=0}^{\infty} f(\tau)e^{-t/\tau}e^{-t/\tau_X}d\tau\, dt. \qquad (1)$$

It can easily be seen from Eq. (1) that if $f(\tau)$ is taken as a bimodal distribution with a very long time component ($\tau \gg \tau_x$, where $\tau_x = 2.8\times10^{-18}$ s) and a very short time component ($\tau \ll \tau_x$), one obtains the minimum percentage ($f_{\min}$) of a long-lived fission component given by the experimentally obtained ratio $f_{\min} = \frac{N_K}{P_K N_f}\times 100\%$. Any other fission time distribution $f(\tau)$ would produce a larger percentage of a long-lived fission component. Fregeau *et al.* [9] found $f_{\min} = 53\%$ for the emission of asymmetric fission fragments $70 < Z < 80$, implying that they experimentally obtained $\frac{N_K}{P_K N_f} = 0.53$ for these asymmetric fission fragments. Let us assume a bimodal distribution where only $f_L(\tau)\%$ of the total fission events with fission time τ contribute to the atomic K-x-ray yield and the remaining fission events have short fission times and do not significantly contribute to the K-x-ray yield. In Fig. 1, we have shown [using Eq. (1)] how $f_L(\tau)\%$ would decrease as a function τ in the context of the result of Fregeau *et al.* [9]. It is seen that for very large values of τ, $f_L(\tau)\to f_{\min} = 53\%$, as stated by Fregeau *et al.* [9]. As τ decreases, $f_L(\tau)$ must increase to reproduce the observed K-x-ray yield.

The prefission neutron multiplicity clock is a nonlinear high-precision clock with a relatively short range. Prefission neutron multiplicity (ν_{pre}) saturates at a value of ν_{satu} depending on the excitation energy of the compound nucleus. If ν_{pre} is close to its saturation value (ν_{satu}), the technique loses its precision because longer fission time scales do not yield significantly higher values of neutron multiplicity. Let us define a fission time $\tau_{\max}$ so that for $\tau \geqslant \tau_{\max}$, $\nu_{\mathrm{pre}}(\tau)\approx\nu_{\mathrm{satu}}$. Hence, the measured prefission neutron multiplicity could approximately be written as

$$[\bar{\nu}_{\mathrm{pre}}]_{\mathrm{exp}} \approx \int_0^{\tau_{\max}} \nu_{\mathrm{pre}}(\tau)f(\tau)d\tau + \nu_{\mathrm{satu}}\int_{\tau_{\max}}^{\infty} f(\tau)d\tau. \qquad (2)$$

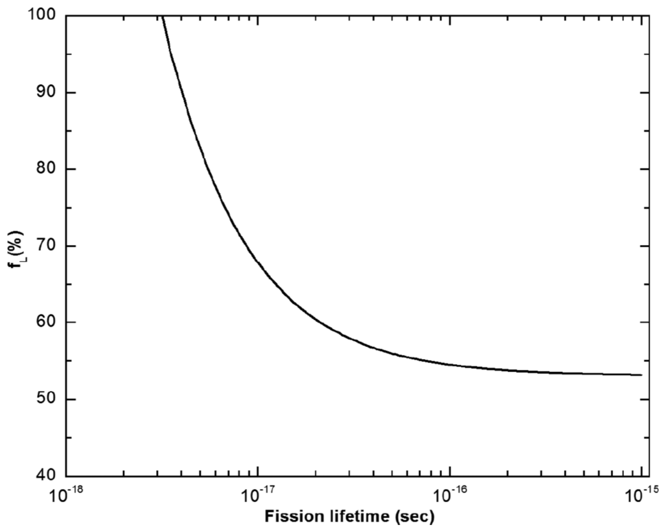

FIG. 1. Percentage of the long-lived fission component [$f_L(\tau)\%$] versus the fission time (τ) obtained from Eq. (1) using the data of Fregeau *et al.* [9].

A statistical model code, such as JOANNE2 [13], is used to determine the experimental fission time corresponding to $[\bar{\nu}_{\mathrm{pre}}]_{\mathrm{exp}}$. The deduced fission time is a weighted average and does not depend on any dynamical model of fission.

We have calculated prefission neutron multiplicities using the code JOANNE2 [13] with similar statistical model parameters as used by Hinde *et al.* [10]. The onset of fission was delayed, and the amount of delay was an input parameter while running the code. The number of prefission neutrons increases with fission delay. Thus, the measured prefission neutron multiplicity is a measure of the fission time. In Fig. 2, we present our calculations of ν_{pre} using the code JOANNE2 [13] for the $^{238}\mathrm{U}+^{64}\mathrm{Ni}$ reaction at $E_X(^{238}\mathrm{U})_{\mathrm{lab}} = 6.6\,\mathrm{MeV/nucleon}$ for various fission lifetimes of the composite nucleus. Following Hinde *et al.* [10], the effective excitation energy of the saddle to scission emitter has been increased to account for the high mean kinetic energy of the prefission neutron spectrum. Figure 2 shows ν_{pre} as a function of fission time showing the saturation of ν_{pre} at a value of $\nu_{\mathrm{satu}} \approx 7.7$ for the fission time $\geqslant 5\times10^{-19}$ s. It is clear from Fig. 2 that ν_{pre} measurements cannot distinguish among fission lifetimes longer than 5×10^{-19} s for this system. However, the technique can certainly tell us without any ambiguity

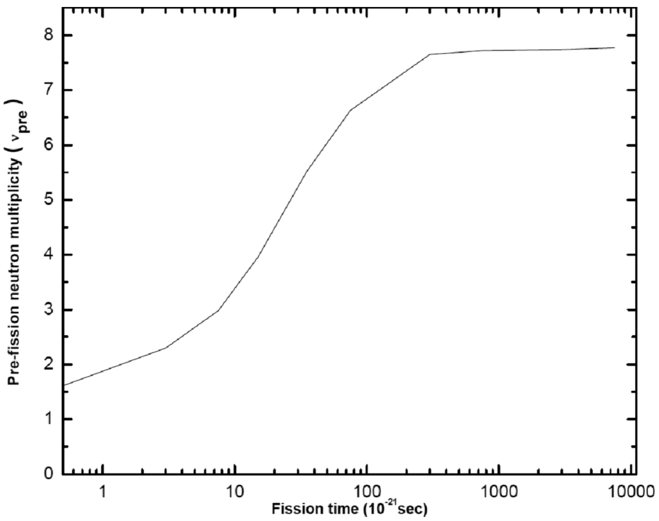

FIG. 2. Fission lifetime versus prefission neutron multiplicity (ν_{pre}) for the $^{238}\mathrm{U} + ^{64}\mathrm{Ni}$ reaction at $E(^{238}\mathrm{U})_{\mathrm{lab}} = 6.6$ MeV/nucleon as obtained from the JOANNE2 code calculations.

whether the fission time is on the order of 10^{-21} s or greater than 10^{-18} s. The experimental value $\nu_{\mathrm{pre}} = 4.0$ [10] for the $^{64}\mathrm{Ni} + ^{238}\mathrm{U}$ reaction has been reproduced with a fission delay of 2×10^{-20} s.

Let us now see if the results of Hinde *et al.* [10] could be made consistent with the x-ray data of Fregeau *et al.* [9] assuming that the fission time distribution function [$f(\tau)$] for $^{238}\mathrm{U} + ^{64}\mathrm{Ni}$ is similar to that shown by Cabrera *et al.* [14] for the $^{20}\mathrm{Ne} + ^{159}\mathrm{Tb}$ reaction ($E/A = 8$ MeV). Using Eq. (1) and the fission time distribution given in Ref. [14], we obtain $\frac{N_K}{P_K N_f} \approx 0.3$ rather than the experimentally obtained value of 0.53. Using the results from Fig. 2, the corresponding prefission neutron multiplicity comes close to 7 rather than the experimentally obtained value of 4. Hence neither the x-ray data [9] nor the prescission data [10] are consistent with a standard fission time distribution function [14]. On one hand, the x-ray data of Fregeau *et al.* require that $f(\tau)$ must contain a significantly larger percentage of long-lived fission component. On the other hand, the data of Hinde *et al.* [10] require that $f(\tau)$ must contain a significantly lower percentage of long-lived fission component. Using Figs. 1 and 2, we find that the only solution for these two contradictory requirements is an extreme bimodal distribution comprising 53% of very slow fission events with $\tau \geqslant 10^{-16}$ s and 47% of very fast fission events with $\tau \leqslant 10^{-21}$ s. We think such a fission time distribution is very implausible. If we think fast fission events (47% of the total fission events) are due to quasifission, then also it is implausible that the time distribution of the fusion-fission events would start at $\tau \geqslant 10^{-16}$ s. If the time distribution of the fusion-fission events would start at an early time before 10^{-16} s, then its percentage must increase above 53% (and the quasifission percentage must decrease below 47%) to be consistent with x-ray data [9], thus, contradicting the prefission neutron multiplicity data [10]. Even in the case of such an extreme bimodal distribution (47% fast fission of a lifetime of $\leqslant 10^{-21}$ s and 53% slow fission of a lifetime of $\geqslant 10^{-16}$ s), x-ray data and prefission data are inconsistent if we consider neutron emission from the accelerating fragments [10]. In the case of very short fission time comparable to the acceleration time of the fission fragments, it becomes very difficult [10] to distinguish between prefission and postfission neutrons from the accelerated fragments and ultimately whether these postfission neutrons coming from the accelerating fragments determine the minimum fission time that could be measured by the technique. Following Hinde *et al.* [10], we might consider that the minimum fission time that the experiment could measure for the $^{64}\mathrm{Ni} + ^{238}\mathrm{U}$ reaction was 1.5×10^{-20} s corresponding to $[\nu_{\mathrm{pre}}]_{\mathrm{exp}} = 4$. Hence, even for the extreme bimodal distribution, from Eq. (2) we obtain that the expected measured prefission neutron multiplicity should be $>(0.47 \times 4 + 0.53 \times 7.7) = 6$, thus contradicting the experimental result (4 ± 0.8) by more than two standard deviations.

In the case of the mass-angle distribution technique, the lack of reflection symmetry in the angular distribution of the fission fragments is observable when the fission time is less than or comparable to the time taken by the composite system to complete one rotation. Since typically the fissioning nucleus takes time ($\sim 10^{-20}$ s) to complete one rotation, this method is sensitive on the time scale of 10^{-21} s. If the fission time scale is much longer than 10^{-20} s, the composite system undergoes many rotations before fission, resulting in an essentially symmetric angular distribution of the fission fragments, implying a fission time $>10^{-20}$ s. The differential cross section ($\frac{d\sigma}{d\theta_{\mathrm{c.m.}}}$) versus the $\theta_{\mathrm{c.m.}}$ plot generally shows a peaklike structure at a small angle θ_p and then drops following a function that could be approximated by a decaying exponential function [1,15]. Let L be the orbital angular momentum, let I be the moment of inertia of a dinuclear system, and $f(\tau)$ is the normalized fission time distribution. Then the differential cross section at an angle $\theta_{\mathrm{c.m.}}$ in the center-of-mass frame for $\theta_{\mathrm{c.m.}} > \theta_p$ could be written as

$$\frac{d\sigma}{d\theta_{\mathrm{c.m.}}} = K \int_0^{\infty} f(\tau) \exp\left(-\frac{\theta_{\mathrm{c.m.}} I}{L\tau}\right) d\tau \approx K \int_0^{\tau_{\max}} f(\tau) \exp\left(-\frac{\theta_{\mathrm{c.m.}} I}{L\tau}\right) d\tau + K \int_{\tau_{\max}}^{\infty} f(\tau) d\tau. \quad (3)$$

Here K is a normalization constant and, for ($\tau > \tau_{\max}$; $\tau_{\max} \sim 10^{-20}$-s), the angular distribution could be considered isotropic. Considering an extreme bimodal distribution as discussed before, the second term of Eq. (3) should dominate for large values of $\theta_{\mathrm{c.m.}}$, contradicting the observed two-dimensional (2D) mass-angle distribution of the $^{238}\mathrm{U} + ^{64}\mathrm{Ni}$ reaction [2] that shows a steep decrease in the differential fission fragment cross section at large angles. Toke *et al.* [2] deduced the fission time for a mass split from the corresponding average angle of rotation of the intermediate complex. The average angle of rotation of the intermediate complex was determined by taking the weighted average over the entire angular distribution of the relevant fragment. Toke *et al.* [2] measured a rather small average angle of rotation of the $^{238}\mathrm{U} + ^{64}\mathrm{Ni}$ complex (61°) for the asymmetric splits, thus ruling out the presence of a large percentage of reflection symmetric component in the angular distribution and deduced a short fission time of $\tau = 3.1 \times 10^{-21}$ s [2]. Comparing with the 2D mass-angle spectra of $^{238}U + ^{27}Al$ (containing a 30% compound nuclear contribution), $^{238}U + ^{48}Ti$ (containing a 5% compound nuclear contribution) [2], etc., we conclude that the 2D mass-angle spectra of the $^{238}U + ^{64}Ni$ reaction cannot contain more than a 5% reflection symmetric compound nuclear component. The extraction of the fission delay from mass-angle correlation or prefission neutron multiplicity experiments [2,10] does not assume *a priori* that quasifission dominates as apparently contended in Ref. [9]. Even if the transient composite system rapidly splits into two fissionlike fragments that cannot be distinguished event by event from true FFs, the computed fission delays would be the same, although it would arise from a different reaction mechanism. Since shorter lifetimes are reported in Ref. [2] when the data are gated with asymmetric fission, it is clear that quasifission is indeed distinguishable from fusion-fission. Hence, these nuclear results [2,10] cannot be reconciled with a large saturation term (ν_{pre}) or isotropic term (in mass-angle distributions) arising from the presence of a large percentage of long-lived fission components [9].

Toke *et al.* [2] performed measurements at $E_{c.m.} = 302.6$ MeV, whereas Fregeau *et al.* [9] and Hinde *et al.* [10] performed measurements at $E_{c.m.} = 332.8$ MeV. The Coulomb barrier for the $^{64}Ni + ^{238}U$ reaction from the Bass model is about 267 MeV [16] in the center-of-mass frame. Kozulin *et al.* [16] found that the total capture cross section (the sum of the quasifission and compound nucleus fission cross sections) for the $^{64}Ni + ^{238}U$ reaction tended to saturate around $E_{c.m.} = 300$ MeV and the compound nucleus fusion cross section was negligible compared to the quasifission cross section. The compound nucleus fusion excitation function generally tends to show saturation at 1.1–1.15 times the Coulomb barrier energy in the center-of-mass frame. So the available evidence suggests that the emitted fission fragments at $E_{c.m.} = 302.6$ and 332.8 MeV should essentially all be from the quasifission process. Both Toke *et al.* [2] and Hinde *et al.* [10] determined the fission time of the strongly damped fission fragments by cutting out the quasielastic regions and gating on the strongly damped regions as seen from their 2D total kinetic energy versus fragment mass plots. On the other hand, Fregeau *et al.* [9] gated on the Z bin ($70 < Z < 80$) and fragment energy bin from about 300 to 1100 MeV. Assuming detected fragments in the Z bin ($70 < Z < 80$) approximately correspond to a fragment mass bin in the range of ($160 < A < 200$), the total kinetic energies of the fragments in the center-of-mass frame were similar to what Toke *et al.* [2] and Hinde *et al.* [10] had observed in this mass region. Hence, the fission lifetime measured by Toke *et al.* [2] in an asymmetric mass bin around $A = 180$ should be consistent with the measurements of Fregeau *et al.* [9]. Although the mass-angle distribution measurements of Toke *et al.* [2] and du Rietz *et al.* [15] cannot rule out the possibility of late-chance fission (fission time of $\sim 10^{-18}$ s) at some low level [17] consistent with the experimental uncertainty, they certainly contradict the presence of a long-lived fission component for a large percentage of the fission fragments as found by Fregeau *et al.* [9] and Andersen *et al.* [7].

The conclusion [8,9] that fusion-fission (rather than quasifission) dominates and that the fission barrier is high resulting in rapid cooling by neutron emission is also in conflict with the theoretical prediction [18] of a low fission barrier of ≈ 6 MeV compared to the neutron binding energy of ≈ 7.2 MeV. Recent attempts [19,20] to detect the $Z = 120$ nucleus as an evaporation residue using the same reaction ($^{238}U + ^{64}Ni$) at an energy near the Coulomb barrier ($E_{c.m.} \approx 270$ MeV) obtained a negative result (upper limit of evaporation residue cross section of <94 fb), implying the dominance of quasifission and/or a low fission barrier of $Z = 120$, contradicting the conclusion of Refs. [8,9]. The compound nucleus fusion cross section of the $^{64}Ni + ^{238}U$ system (Coulomb barrier = 267 MeV [16]) is expected to saturate before $E_{c.m.} = 332$ MeV increasing at most by a factor of (10–50) [16] compared to the fusion cross section near the Coulomb barrier energy of $E_{c.m.} = 270$ MeV. Hence using the results of Hofmann *et al.* [20], the fusion cross section for compound nucleus ($Z = 120$) formation at $E_{c.m.} = 332.8$ MeV should be less than (1–5) pb making it essentially impossible to see a compound atom x-ray yield in a fission fragment x-ray coincidence experiment. So an interpretation in terms of seeing asymmetric fission fragments from a superheavy $Z = 120$ nucleus and corresponding coincident x rays would imply a many orders of magnitude (compared to the picobarn level) higher compound nucleus fusion cross section, contradicting the results of Hofmann *et al.* [20]. On the other hand, both the theoretical calculations [18] of a low fission barrier and the measurement of very short ($\sim 10^{-21}$-s) fission time by Toke *et al.* [2] and Hinde *et al.* [10] are consistent with the nonobservation [20] of $Z = 120$ evaporation residues in the $^{64}Ni + ^{238}U$ reaction.

The claim [8,9] of the observation of a superheavy $Z = 120$ element (with a high fission barrier) is based on the observation of a long fission lifetime ($\sim 10^{-18}$ s) for a highly excited $Z = 120$ nucleus and a shorter fission lifetime ($< 10^{-18}$ s) for the similarly excited neutron deficient $Z = 114$, $A = 280$ nucleus. However the observation of long fission times using the atomic techniques is a rather common observation [4–9] seen for a large number of quasifission and fission processes unrelated to the formation of superheavy nuclei. For example, Andersen *et al.* [7] using the crystal blocking technique observed that all the detected fragments (100%) came from slow processes having long fission times ($\sim 10^{-18}$ s) for a large number of reactions [such as $^{74}Ge + W$ at $E(^{74}Ge)_{lab} = 390$ MeV, $^{58}Ni + W$ at $E(^{58}Ni)_{lab} = 330$–375 MeV, $^{48}Ti + W$ at $E(^{48}Ti)_{lab} = 240$–255 MeV] expected to be dominated by the quasifission process and producing highly excited transuranium composites ($Z = 102$–106) far away from the predicted landscape of the superheavy nuclei. On the other hand, using the mass-angle correlation technique, du Rietz *et al.* [15] obtained 2D mass-angle correlation plots for very similar systems ($^{64}Ni + W$, $^{48}Ti + W$) at similar center-of-mass energies and deduced their exponential quasifission and fission lifetimes on the order of $\sim 10^{-21}$–10^{-20} s. Molitoris *et al.* [4] using an x-ray technique observed a long fission time ($\sim 10^{-18}$ s) for the majority of the observed fission fragments emitted by the highly excited ($E_X = 40$–105-MeV) uraniumlike nuclei having low fission barriers [18]. Using the crystal blocking technique, Goldenbaum *et al.* [5] obtained a fission time of highly excited ($E_X \approx 200$ MeV) ^{238}U on the order of 10^{-18} s. Wilschut and Kravchuk [6] measured the fission time of highly excited ($E_X = 145$-MeV) neptunium nuclei on the order of 10^{-18} s using an x-ray technique. Several authors [7,11,12] attempted to explain such a long fission time by introducing a large viscosity parameter of the nuclear medium that produced a very broad fission time distribution extending to 10^{-15} s and shifted the mean value of the fission time distribution to $\sim 10^{-18}$ s. However, if the nuclear medium indeed offers such a high viscous friction, this effect should be present in all quasifissioning or fissioning processes and hence, all the quasifissioning or fissioning systems should have long splitting times ($\sim 10^{-18}$ s). Hence, one cannot conclude that the observed long fission time [8,9] of the $Z = 120$ nucleus measured by the atomic techniques implies a high fission barrier of the nucleus.

In this paper, we are not offering any explanation as to why there is such a large apparent discrepancy between the fission times obtained by the nuclear and atomic techniques. We are not saying that the fission lifetime measured by either the atomic or the nuclear technique is incorrect. Each technique stands on its own. We are only pointing out that the observed large percentage of the long-lived fission component as measured by the atomic techniques and the corresponding very short fission time measured by the nuclear techniques (at the lower end of the nuclear clock's range) cannot be explained by the sensitivity argument of the different techniques in the different time domains. The explanation of the long fission time in terms of the large viscosity parameter of the nuclear medium should be applicable to all heavy systems including the $Z = 120$ nucleus. Hence, it is clearly not possible to claim the observation of a $Z = 120$ superheavy nucleus with a high fission barrier on the basis of an observed long fission time by the atomic techniques.

To summarize, the long fission lifetime measured by the atomic techniques cannot be reconciled with the short fission lifetime measured by the nuclear techniques using the sensitivity argument. The x-ray data of Fregeau *et al.* [9] could be made consistent with the results of Hinde *et al.* [10] only in the context of an extreme bimodal fission time distribution comprising a 53% long-lived component ($\tau \geqslant 10^{-16}$ s) and a 47% short-lived component ($\tau \leqslant 10^{-21}$ s), provided the neutron emission from the accelerating fragments could be ignored. Such an extreme bimodal distribution looks implausible. Even in the context of this extreme bimodal distribution, the result of Fregeau *et al.* [9] is inconsistent with the mass-angle distribution data of Toke *et al.* [2]. The nonobservation of the $Z = 120$ evaporation residue in the ^{238}U + ^{64}Ni reaction contradicts the conclusions of Refs. [8,9] regarding the high fission barrier of $Z = 120$. The fission time measurements [2,10] using the nuclear techniques agree with each other and are consistent with the theoretical calculations [18] as well as with the nonobservation of the $Z = 120$ evaporation residue [20]. The atomic results [8,9] and the conclusion that the fusion-fission reaction mechanism dominates the reaction ^{238}U + ^{64}Ni at 6.6 MeV/nucleon and leads to the formation of the superheavy nucleus $Z = 120$ with a high fission barrier are inconsistent with the nuclear results [2,10,20] and calculations [18]. The incompatibility among the measured fission times by the nuclear and atomic techniques might indicate new physics [21] beyond the scope of fission physics.

We acknowledge useful discussions with R. Vandenbosch (CENPA, University of Washington, Seattle, USA).

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