NUCLEAR DISSIPATION VIA PERIPHERAL COLLISIONS WITH RELATIVISTIC RADIOACTIVE ACTINIDES BEAMS[1]

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Peripheral collisions with radioactive actinide beams at relativistic energies are proposed as a relevant approach for the study of dissipation in nuclear matter. The characteristics of the systems resulting from the primary fragmentation of such beams are particularly well suited for probing the controversial existence of a sizeable delay in fission. Thanks to the radioactive beam facility at GSI an unusually large set of data involving about 60 secondary unstable projectiles between At and U has been collected under identical conditions. The properties of the set-up enabled the coincident measurement of the atomic number of both fission fragments, permitting a judicious classification of the data. The width of the fission-fragment charge distribution is shown to establish a thermometer at the saddle point which is directly related to the transient delay caused by the friction force. From a comparison with realistic model calculations, the dissipation strength at small deformation and the transient time are inferred. The present strategy is promoted as a complementary approach that avoids some complex problems inherent to conventional techniques. Combined to the paramount size of the data set, it sheds light on contradictory conclusions that have been published in the past. There is at this point no definite consensus on our understanding of the damping process in fission.

1. Introduction

A purely microscopic description of the dynamical relaxation process of an

[1] * This work has be done within the CHARMS collaboration (http://www-w2k.gsi.de/charms).

excited nucleus remains a difficult task at present day. Most of the approaches are therefore based on transport theories [1] which distinguish between collective and intrinsic degrees of freedom, the later forming a heat bath in which evolve the former. Viscosity describes the transfer of energy between these two 'sub-spaces' and is commonly quantified by the so-called dissipation strength β. So far, neither theory nor experiment did converge about the true origin of the phenomenon. Whether the coupling between collective and intrinsic degrees of freedom arises from the collisions of the nucleons with the moving boundary of the system (one-body dissipation [2]) and/or from individual nucleon-nucleon collisions (two-body dissipation [3]) is still an open question. Besides the fundamental interest, a better knowledge about friction is also important for practical reasons, such as nuclide production at Radioactive Ion Beam (RIB) facilities, synthesis of super-heavy elements and population of super- or hyper-deformed rotational bands.

Similar to previous works, we use the collective motion experienced by a nucleus along its path to fission in order to track down nuclear viscosity. However, both the approach for inducing fission and the signature adopted here for tagging the phenomenon of interest differ from conventional methods. A brief reminder about how friction affects the evolution of an excited nucleus is given in section II. Special attention is drawn on the transient delay which governs the establishment of quasi-equilibrium. In section III the assets of i) initiating fission by a fragmentation reaction of radioactive spherical actinides, ii) tracking down relaxation effects by means of the width of the fission-fragment charge distribution and iii) measuring the charge of both fission fragments are highlighted. The general trend of the data is examined in section IV. With the help of realistic model calculations, the undeniable manifestation of transient effects at high excitation energy is pointed out in section V. The survey of the whole data set allows inferring a value for β and for the fission delay with much less uncertainty than previously. In the light of these results, a reviewed discussion about controversial publications is given in section VI. Our concluding remarks in section VII are intended to strongly support the complementary character of fragmentation- and fusion-induced fission experiments to go further forward.

2. Role of dynamics in fission

According to Bohr and Wheeler's early transition state model [4], the probability of an excited nucleus to split into two fragments is exclusively governed by the height of the fission barrier, the temperature and the level densities. Later on, the investigation of the temporal evolution of the system on its multi-dimensional potential energy surface (PES) by means of stochastic approaches [5] based on the Fokker-Planck or Langevin equation of motion brought to light the crucial importance of dynamics and especially of dissipation. Dividing the process into several stages as pictured on the left panel of Figure 1, the influence of viscosity is three-fold:

1. *Pre-saddle transients*: depending on the initial conditions, the system needs time to adjust to the available phase-space and establishes quasi-equilibrium [6]. That inhibits fission at the early stage of the decay process. It is customarily characterized by the transient delay τ_{trans}.
2. *Quasi-equilibrium regime*: due to the stochastic nature of friction, the constant flux across the barrier is reduced as compared to Bohr and Wheeler's prediction by the so-called Kramers factor K [7].
3. *Saddle-to-scission dynamics*: dissipation slows down the descent between the saddle and scission points giving rise to a saddle-to-scission delay τ_{ss} [8] .

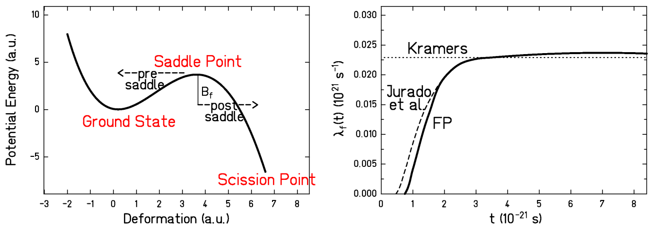

Figure 1. Left: Illustration of the milestones that pave fission on a one-dimensional potential energy path. Right: Typical evolution of the escape rate at the saddle point $\lambda_f(t) = \Gamma_f(t) / \hbar$ as function of time. The full line corresponds to the numerical Fokker-Planck solution [6], the dotted line represents Kramers' stationary Γ^K value [7] and the dashed curve corresponds to the analytical approximation developed by Jurado et al. [9, 10].

While the total fission time τ_f depends upon the three above items, only the first two points affect the fission decay-width Γ_f. Due to τ_{trans}, the latter varies with time as illustrated on the right panel of Figure 1. To infer the magnitude of nuclear dissipation from experiment, evaporation residue and fission cross sections [11] as well as light-particle [12, 13] and γ-ray pre-scission multiplicities [14] have shown particularly well suited. Provided the excitation energy is high enough, during the transient delay particle evaporation is favored with respect to fission. That increases the survival probability of the residue. In case fission finally still occurs, the slower the path, the larger the number of particles emitted prior to scission.

3. Fragmentation of spherical RIBs : an alternative approach

3.1. *Present status*

There are number of reasons for the controversial debates on the magnitude of dissipation:

- First, care shall be taken to the uncertain influence of the fusion mechanism usually used to induce fission. The initial shape and excitation energy of the system can noticeably differ from the spherical compound nucleus (*CN*) configuration assumed in most data analysis procedures [15]. Initial deformation affects the duration of the fission delay since the system does not necessarily start at the bottom of the *CN* pocket but already quite near to the saddle point [16]. A precise modelling of this effect does not exist yet. The same is true for the amount of available thermal energy. Furthermore, in heavy-ion collisions at intermediate energy, the angular momentum imparted to the composite is large and contributions from quasi-, fast- or transfer-induced fission become important [17].
- A second point concerns the sensitivity of the observables. Time scales are customarily derived using the number of emitted particles [18] or γ-rays [19] as clocks. Pre-scission multiplicities are affected by the whole path down to scission. They can be reproduced assuming dissipation is strong at the left of the barrier and weak on its right, or inversely. One stage compensates the other. Additional information from observables determined at the barrier is therefore relevant [11]. Unfortunately, due to uncertain parameters, a conclusive answer did not emerge yet.
- The behaviour of dissipation with deformation q, temperature T, fissility Z^2/A and angular momentum L, which all vary along the fission path, remains unknown. Multiplicity data have been equally well explained assuming either a T- or a q-dependent friction force [20].

3.2. *Alternative method*

Addressing the above issues requires:

- a reaction mechanism resulting in well defined initial conditions,
- experimental observables specifically sensitive to the pre- and post-saddle stages,
- a reasonable ‘control’ of critical parameters such as q, T, Z^2/A, L.

The present work is intended to trace back nuclear dissipation by isolating the early stage of the decay process i.e. transient effects. Hence, it shall enable probing the magnitude of β at the deformation characteristics of the initial system and additional influences from the saddle-to-scission descent should be negligible.

3.2.1. *Reaction mechanism: fragmentation of radioactive actinides*

Collisions between two heavy ions at relativistic energies present the advantages of leading to a quite well-defined remnant projectile (pre-fragment hereafter). The fast interaction or *abrasion* [21, 22] can be seen as a sharp cut-off of part of the projectile and target nuclei leaving a projectile-like pre-fragment which is nearly undistorted with respect to the projectile. Its excitation energy E_{prf} can be very high [23] and its angular momentum L remains small [24]. The same is true for spallation reactions [25] involving a light reaction partner (mostly protons or deuterons) except that larger L values are attained. Along the remainder of the present paper, unless specified, the term fragmentation refers to the abrasion and spallation mechanisms. As discussed above, the characteristics of a heavy fissile pre-fragment make it an ideal laboratory for probing the fission/evaporation competition during τ_{trans}. Furthermore, in the relativistic energy domain, contributions from other mechanisms that would induce fission are negligible. A few experiments involving protons [26, 27, 28], anti-protons [29] or heavy ions [30] have already been used to investigate dissipation. In some cases the conclusions are in strong disagreement. Fragmentation-induced fission involves either a heavy target in direct kinematics or a heavy projectile in inverse kinematics that yields a fissile pre-fragment. The stable actinides available for that purpose (e.g. ^{238}U, ^{232}Th) are well deformed in their ground state [31]. The resulting pre-fragment is likely to be distorted as well, causing problems related to initial deformation similar to those discussed above for fusion-fission reactions. Consequently, fissile spherical systems would be highly desirable which can be achieved by the use of *radioactive actinide* beams.

3.2.2. *Pertinent signatures*

The second issue concerns the sensitivity of the experimental information to the phenomenon of interest. We aim at tagging an eventual delay of fission. Since pre- and post-saddle particles can not be disentangled experimentally, one may try to establish a thermometer at the saddle point instead of a clock [32]. The larger τ_{trans}, the more numerous the particles emitted prior to the saddle point and the smaller the excitation energy of the system at the top of the barrier E^*_{sad}.

In the statistical limit, according to the transition-state model [33], the probability for a given decay channel is related to the number of transition states above the PES and to the temperature. Assuming that the distribution in charge $Z_{1,2}$ of the fission fragments is determined at the saddle point [34], the width of the $Z_{1,2}$ distribution is given by:

$$\sigma_Z = \left(\frac{Z_{fiss}}{A_{fiss}}\right)^2 \cdot \frac{T_{sad}}{d^2V/d\eta^2} \qquad (1)$$

with T_{sad} the temperature at the saddle point and $d^2V/d\eta^2$ the stiffness of the potential with respect to mass asymmetry. A_{fiss} (Z_{fiss}) is the mass (charge) of the fissioning nucleus. In accordance with (1) σ_Z establishes a thermometer at the fission barrier and, hence shall be particularly sensitive to transient effects.

The reliability of the σ_Z thermometer relies on two main assumptions which we discuss in the following. It is well known that the saddle point, the descent stage and the scission point play a special role in determining the fission-fragment distribution. Theory (see e.g. [35, 36]) and experiment (see e.g. [37, 38]) speak in favour of either the saddle or the scission point having a decisive influence and the debate is still vivid. From a wide compilation of data, Rusanov et al. [34] established a parameterisation of $d^2V/d\eta^2$ as function of fissility at both the saddle and the scission points, assuming there the validity of equation (1). Neither evaporation on the saddle-to-scission descent (neutron emission dominates), nor fluctuations along the trajectory affect the *Z*-width for our systems significantly [39] [a]. Hence, relation (1) together with the empirical $d^2V/d\eta^2$ formula [34] established *at the saddle point* provides a consistent measure of T_{sad}. The second hypothesis concerns statistical equilibrium. Theoretical dynamical studies [40, 39] have shown that the width σ_Z does not reach its statistical limit $\sigma_Z|_{\mathrm{stat}}$ below an excitation energy of about 400 MeV. Instead, the system keeps memory of previous states all along its evolution. Yet, the numerical *Z*-width as obtained by such calculations behaves very similar to $\sigma_Z|_{\mathrm{stat}}$ as a function of T_{sad}. In other words, the cooling of the system during τ_{trans} is reflected in σ_Z [30]. This constitutes a definite asset of the proposed σ_Z signature with respect to particle clocks which, in addition, depend on τ_{ss}.

3.2.3. *Characterisation of the fissioning system*

The last point emphasized above deals with the knowledge of critical parameters. In fragmentation-fission the measured data set contains a mixture of various fissile pre-fragments with masses ranging from values close to the projectile mass A_{proj} down to values far less than A_{proj}. The excitation energy of

[a] Charge polarization effects which are determined near scission are washed out in the present excitation energy range. Anyhow, even at low temperature, polarization leads to second order effects which redistribute $Z_{1,2}$ for a given mass split over 0.6 unit in average [W. Schwab et al., Eur. Phys. J A 2 (1998) 179].

the pre-fragment goes from a few MeV up to 600 MeV while its angular momentum is around $L \approx 10\ \hbar$ (in spallation L can be larger). Hence, the first task consists of sorting this out. Due to the low probability of pre- as well as post-scission light-charged particle (LCP) evaporation for our systems [41, 42], the sum Z_1+Z_2 of the charges of the two fragments is a good approximation for the charge Z_{fiss} of the fissioning nucleus and Z_{fiss} is close to the pre-fragment charge Z_{prf}. Furthermore, the size of the pre-fragment is directly related to the excitation energy E_{prf} induced into the system: the more violent the collision, the smaller Z_{prf} [43]. As a consequence, the measure of Z_1+Z_2 allows classifying the data according to the characteristics in charge (and, therefore, roughly in mass) and excitation energy of the decaying system. All the details about the experimental arrangement used to achieve this goal can be found in the contribution of A. Kelić to these Proceedings. Basically, the set-up consisted of two parts [44]:

- In a first stage, about 60 radioactive neutron-deficient actinides ranging from ^{205}At to ^{234}U produced by the fragmentation of a primary ^{238}U beam at 1 A GeV were identified and separated in-flight with the GSI fragment separator (FRS) .
- These relativistic secondary beams are excited via fragmentation in a secondary target located at the FRS exit. If fission occurs, thanks to the inverse kinematics of the reaction and the use of a double ionisation chamber, both fragments are detected in coincidence and their atomic number $Z_{1,2}$ determined with high accuracy ($\Delta Z_{1,2} \sim 0.4$).

Summarizing, we study the fragmentation of about 45 nearly spherical At, Rn, Fr, Ra, Ac, and Th radioactive beams which creates highly excited and almost undistorted fissile nuclei. The fission-fragment σ_Z is used to track down the early stage of the de-excitation process of compact systems and, hence, it allows extracting the β strength at *small* deformation. The coincident measurement of Z_1 and Z_2 permits classifying the data according to nuclear composition and excitation energy of the decaying system. A detailed discussion of the analysis can be found in [45].

4. Experimental results

A sample of fission-fragment charge distributions obtained for various RIBs and selections on Z_1+Z_2 are shown on the left panel of Figure 2. The pre-fragment formed after fragmentation of the secondary projectile plays the role of the initial compound nucleus. Due to the correlation between Z_1+Z_2 and (Z_{prf}, E_{prf}), each panel of Figure 2 can thus be considered as equivalent to *one* fusion-fission experiment. It is worth noting that a given Z_{prf} is related to different excitation energies E_{prf} depending on the beam: since E_{prf} scales with the number of abraded nucleons, it depends on the difference between Z_{prf} and the projectile charge Z_{proj}. As an example, Z_{prf} = 84 corresponds to $E_{prf} \approx 400$ MeV for an initial ^{224}Th beam while it is connected to $E_{prf} \approx 200$ MeV for a ^{217}Fr projectile. Presently we have analysed the data from 45 beams over the range $Z_1+Z_2 \in [70, Z_{proj}-2]$ [b]. That gives an idea about the unusual size of the data set. The width σ_Z extracted from the $Z_{1,2}$ distributions are displayed on the right panel of Figure 2 as a function of Z_1+Z_2 for a sample of RIBs. As expected from (1), σ_Z increases with decreasing Z_1+Z_2 i.e. increasing excitation energy. Nonetheless, the slope of this rise, as will shown below, is directly governed by the dynamics of the fission process.

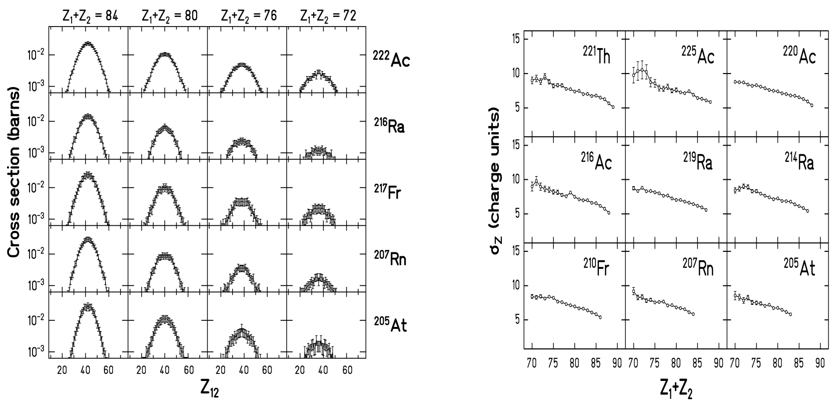

Figure 2. Left: Fission-fragment $Z_{1,2}$ distribution as measured for some RIBs and gated on Z_1+Z_2 as indicated. Right: Width σ_Z as a function of Z_1+Z_2 for a sample of RIBs.

5. Interpretation – Dissipation strength and transient delay

5.1. *Model calculations*

To infer quantitative estimates about the magnitude of the dissipation strength and the fission delay calls for model calculations. We presently use the extended version of the Monte Carlo nuclear reaction code ABRABLA [22, [46]] developed at GSI. It consists of three main stages describing the entire reaction mechanism i.e. from the primary collision at relativistic energies until the de-excitation cascade of the products. In a first step, the characteristics of the pre-

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[b] The analysis is restricted to $Z_1+Z_2 \leq (Z_{proj}-1)$ in order to exclude contribution from low-energy fission concentrated around Z_{proj}. As explained in the text, high excitation energy is a pre-requisite to evidence transient effects. Besides, it allows applying macroscopic considerations. The study of the low-energy fission component of the data set is presented in A. Heinz et al., Nucl. Phys. A 713 (2003) 3 and references therein.

fragment are determined in the framework of the participant-spectator picture within the hyper-geometrical abrasion model. In such collisions E_{prf} can reach values which lie above the threshold at which multifragmentation-like phenomena set in. In that case, a second stage accounts for the simultaneous emission of nucleons and clusters caused by thermal instabilities that cools the system down to a temperature of 5 MeV [47]. Finally, the ablation stage treats the de-excitation of the remaining excited nucleus via the competition between evaporation and fission according to the statistical model. Properly accounting for transient effects in $_f(t)$ requires in principle solving the equation of motion at each evaporation step along the cascade. For computing time reasons, it is impractical to couple dynamical calculations and nuclear de-excitation codes. Instead, reliable approximations of the numerical $_f(t)$ solution shall be used. An analytical expression of the time-dependence of $_f(t)$ [9] that is based on the exact Fokker-Planck solution, has been recently introduced in ABRABLA. As seen on the right panel of Figure 1, it is highly realistic avoiding the deficiencies of previously proposed formulae (for details, see [10]).

5.2. *Conclusive manifestation of transient effects*

In order to assess the sensitivity of the proposed approach to relaxation effects, a sample of σ_Z data is compared in Figure 3 with two different types of calculation:

- Kramers' simulations where the fission decay-width is given by the stationary Γ_f^K [7] value (i.e. no transient delay) and
- time-dependent calculations where the Γ_f(t) expression of [9, 10] is used (i.e. transient delay included).

In both cases, the dissipation strength β is set to $4.5 \cdot 10^{21} s^{-1}$ for reasons explained in the following section. We emphasize that the conclusion remains unchanged whatever the precise value of β. The slope of the σ_Z curve is seen to depend strongly on the type of calculation. Using Γ_f^K implies a much too steep rise of σ_Z with decreasing Z_1+Z_2. This is easily understood by the absence of 'extra' cooling during τ_{trans}. Conversely, when transient effects are included, particle evaporation is favoured at the beginning of the de-excitation process; it lowers the temperature of the decaying system and, hence, limits the rise of σ_Z with increasing initial excitation energy. Note that Γ_f^K reproduces reasonably well the data for the largest Z_1+Z_2's. Since close to Z_{proj} the latter Z_1+Z_2 values are correlated to the lowest excitation energies. This observation corroborates the aforementioned suggestion: transient effects effectively manifest themselves at high excitation energies where evaporation competes with fission inhibition. The difference between the two calculations shown in Figure 3 can only be ascribed to τ_{trans}. That definitely shows that *transient effects are observable* in contrast to claims that this is impossible [48].

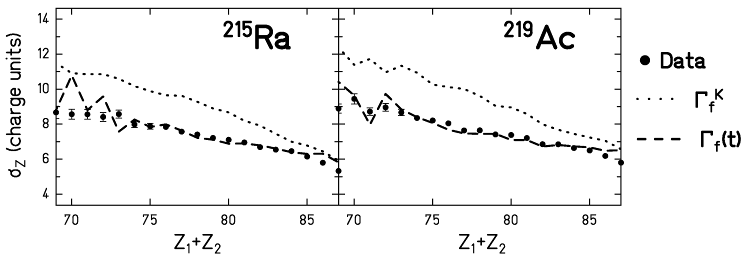

Figure 3. Width σ_Z as a function of Z_1+Z_2 for two typical RIBs. The data (dots) are compared with Kramers Γ_f^K 's (dotted lines) and $\Gamma_f(t)$- (dashed lines) type calculations, see text. The staggering in the calculations is due to statistical fluctuations.

In most of the published fusion data, the *CN* excitation energy hardly exceeds 150-200 MeV. As discussed earlier, transient effects become only important above a given excitation energy. This threshold energy is presumably dependent on the reaction mechanism and the used experimental signature; it is by no means well-established. Together with the uncertainty of some model parameters, the fact that fusion data are located rather close to the threshold energy certainly contributes increasing problems in their analysis. We estimate that the sensitivity of the present approach is restricted to E^*_{sad} > 150 MeV [32].

5.3. *Dissipation strength – Transient time*

The experimental *Z*-widths for the 45 nearly spherical RIBs have been meticulously compared with Γ_f(t)-type calculations computed with different β values going from 1 up to $7{\cdot}10^{21}$s^{-1}, as shown in Figure 4 for one secondary beam (upper left most panel). The data are described fairly well with β = (4.5± 0.5)$\cdot 10^{21}$ s^{-1} independent on Z_1+Z_2 i.e. independent on excitation energy and fissility of the fissioning nucleus. This conclusion holds for the 45 nearly spherical beams we analysed [45], as seen on the other panels of the figure. From these calculations the mean transient time is extracted : a value of τ_{trans} = (3.4±0.7)$\cdot 10^{-21}$ s has been inferred over the whole range of systems. The stated independence on *T* and Z^2/A should nevertheless be taken with caution due to the still crude available data filtering. Nevertheless, the latter allows excluding a strong influence of temperature and fissility on β and τ_{trans}. We emphasize again that we are presently concerned with nearly undistorted highly excited nuclei at small angular momentum and we handle an experimental observable directly connected to the fission saddle. Hence, the extracted β and τ_{trans} values are assigned, respectively, to the magnitude of dissipation at *small deformation* and the fission delay inherent to systems *initially* characterized by a *compact* configuration. Note the impressive result achieved with ABRABLA over a wide range of fissioning nuclei. That suggests the relevance of the physical arguments which the code is based on (see also discussion below).

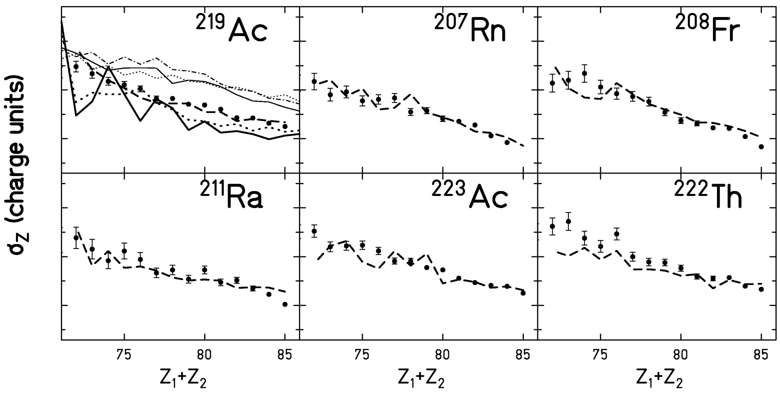

Figure 4. Width σ_Z as a function of Z_1+Z_2 for some RIBs. The data (dots) are compared with $\Gamma_f(t)$-type calculations computed with β = 4.5·10^{21}s^{-1} (thick dashed lines). On the upper left, additional calculations obtained for β = 1 (thin dotted), 2 (thin dashed-dotted), 3 (thin full), 6 (thick dotted), 7 (thick dashed-dotted) ·10^{21}s^{-1} are also shown.

6. Discussion

In the light of our findings, we are coming back to the discussion of previously published, sometimes contradicting, results. As an example we consider the conclusions drawn recently from proton-induced spallation reactions. More specifically, we consider experiments performed in direct [28] and inverse kinematics [27] at Jülich and GSI, respectively. From fission excitation functions, Tishchenko et al. [28] concluded that transient effects are inexistent up to the highest energies whereas, evaporation residue measurements reported by Benlliure et al. [27] yielded a non-zero transient delay. The calculations of Tishchenko et al. have been performed with a ratio for the level densities at saddle to that at equilibrium deformation a_f/a_n of unity, while Ignatyuk's prescription [49] is employed in the analysis of Benlliure et al.. The fact that different parameter sets achieve similar agreement with the data is actually not surprising since intricate effects can compensate each other along the de-excitation chain. That is even more critical when the calculation relies on the tuning of some uncertain quantities. And, indeed, as corroborated by Figure 5, the data of Benlliure et al. can be equally well described combining either τ_{trans} =

0s with a_f/a_n = 1 or $\tau_{trans} \neq$ 0s with $a_f/a_n \neq$ 1 [27]. Although there are strong arguments in favour of Ignatyuk's level-density prescription [50, 51], the problem remains unresolved.

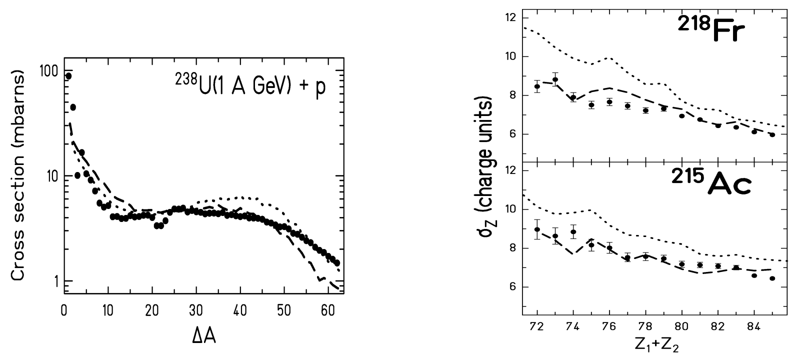

Figure 5. Left: Evaporation residue cross section for the spallation reaction ^{238}U(1 A GeV)+*p* as a function of mass loss with respect to projectile mass. The data (dots) extracted from [27] are compared with calculations performed for ($\tau_{trans} \neq$ 0s, $a_f/a_n \neq$ 1) (dashed lines) and (τ_{trans} = 0s, a_f/a_n = 1) (dotted lines), see the text. Right: Width σ_Z as a function of Z_1+Z_2 for two typical RIBs. Meaning of symbols as for the left panel.

Motivated by the presumably stronger connection of the *Z*-width signature to the excitation energy at the saddle point, as compared to the cross sections of [27, 28], the experimental σ_Z is compared with calculations performed with the above mentioned different combinations of τ_{trans} and a_f/a_n. It is seen in Figure 6 that the σ_Z data can *not* be explained omitting transient effects. In other words, the parameter set (τ_{trans} = 0s, a_f/a_n = 1) can *not* mock up the result obtained with ($\tau_{trans} \neq$ 0s, $a_f/a_n \neq$ 1). The *Z*-width observable allows definitely ruling out the reliability of such a parameter set for describing fission at high excitation energy, and the manifestation of transient effects is again undeniably brought to light.

7. Conclusion

The manifestation of dissipation in nuclear matter is investigated using an approach based on *fission induced by projectile fragmentation of radioactive actinide beams at relativistic energies*. The RIBs have been prepared at the FRS at GSI. Taking advantage of the nearly undistorted configuration of the fissioning systems left after fragmentation of spherical actinides, it is proposed to track down the early stage of the decay process governed by transient effects that delay fission. The width σ_Z of the fission-fragment charge distribution is shown to stand for a pertinent thermometer at the saddle point enabling to isolate the pre-saddle stage. That is not feasible with the particle clock tool

commonly used in dissipation studies. When comparing the data to calculations computed with a realistic reaction model, the motion is found to be over-damped at small deformation and high excitation energy with a dissipation strength $\beta = 4.5 \cdot 10^{21} s^{-1}$ and a transient time of a few 10^{-21}s. The unusual size of the data set enabled drawing conclusions on β and τ_{trans} with much less uncertainty than previously.
The asset of the present approach lies primarily in the absence of complex effects which hampered the interpretation of fusion-fission experiments in the past. We focus on the proper inclusion of dissipation in de-excitation codes as well as on the critical influence of the characteristics of the initial system, namely in deformation. Thanks to the particularly strong sensitivity of the σ_Z observable to transient effects, the danger of misinterpreting data depending on uncertain parameters and/or sizeable initial deformation is brought to light. The present findings encourage revisiting previous analysis; some contradicting results published so far might require corrections.

Compared to fusion, fragmentation induced fission might seem experimentally rather difficult in the sense that an elaborate set-up is mandatory for identifying the various fission candidates. On the other hand, the initial conditions are better defined and the fission-fragment identification is easier due to the kinematics. We aim to promote peripheral collisions involving relativistic heavy-ions as an alternative complementary approach for dissipation studies in fission. Conducting such experiments in parallel to conventional approaches shall help to clarify and pin down the dependence of dissipation in nuclear matter on various parameters such as fissility, temperature, angular momentum and deformation. These studies will greatly profit from future RIB facilities like FAIR at GSI and SPIRAL2 at Ganil.

Acknowledgments

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