Critical analysis of dissipative effects in fission

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According to Grangé and Weidenmüller [1], dissipation effects in the fission process of a hot heavy-nucleus lead to a time-dependent fission-decay width Γ_f (t) that is first suppressed, then increases gradually and finally reaches a stationary value Γ_{stat}. see full line in figure 1.

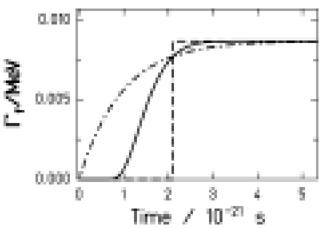

Figure 1: Γ_f(t) obtained from the solution of the Fokker-Planck eq. [2] (full line) in comparison with two approximations. The dashed-dotted line corresponds to the approximation (a) and the dashed line to the approximation (b)

However, the implementation of this function in a nuclear-reaction code is rather complicated, and thus most codes use one of the following approximations: (a) an exponential in-grow function of the form $\Gamma_f(t) = \Gamma_{stat}(1 - \exp(-2.3 \cdot t/\tau_f))$ and (b) a step function that switches from zero to the stationary value Γ_{stat} at the transient time τ_f, where the Fokker-Planck solution raises up to 90% of its stationary value. Both approximations are depicted in figure 1. Compared to the exact solution, the description (a) overestimates the fission width, while description (b) underestimates the fission width up to the transient time. We implemented both approximations in our Abrasion-Ablation Monte-Carlo code ABRABLA [3].

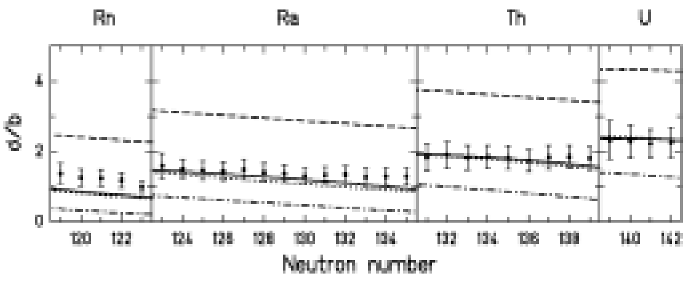

Figure 2: Experimental total nuclear-induced fission cross sections (black dots) as a function of the neutron number for different Rn, Ra, Th and U isotopes at 420 A MeV on a lead target. The data are compared with four calculations, see text

Model calculations are compared to measured total nuclear fission cross sections of different projectiles in figure 2. The full line represents a calculation with the description (b) and a value of the dissipation coefficient, $\beta = 2 \cdot 10^{21} s^{-1}$. This combination shows a very good agreement with the data. However, the combination $\beta = 2 \cdot 10^{21} s^{-1}$ and description (a) clearly overestimates the cross sections, dashed line in figure 2. Nevertheless, the reproduction of the total fission cross sections with description (a) is also possible if we increase the transient time by increasing β up to $9 \cdot 10^{21} s^{-1}$, this is represented in figure 2 by the dotted line. The dashed-dotted line shows that the combination Γ_f(t) according to (b) and $\beta = 9 \cdot 10^{21} s^{-1}$ underestimates the cross sections.

The experiment also allowed to determine the nuclear charges of the fission fragments. In figure 3 we compare the two combinations of β and Γ_f(t) that reproduce the total fission cross sections of figure 2 with experimental partial fission cross sections. We observe that only the step-function with $\beta = 2 \cdot 10^{21} s^{-1}$ fits the data, while description (b) leads to important deviations from the data.

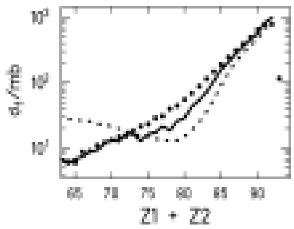

Figure 3: Fission cross sections for ^{238}U on CH_2 at 1 A GeV (full dots) as a function of the sum of the charges of the two fission fragments. The data are shown in comparison with two calculations. The full line is a calculation done with description (b) and $\beta = 2 \cdot 10^{21} s^{-1}$, and the dotted line is a calculation with description (a) and $\beta = 9 \cdot 10^{21} s^{-1}$

Our analysis is based on both a new experimental information from fission induced by relativistic nuclear collisions and the implementation of different in-grow functions in the same code. We conclude that the deduced dissipation coefficient β depends strongly on the function which is used to describe Γ_f(t). We have found that all our data are well reproduced with a step function for Γ_f(t) (option (b)) and $\beta = 2 \cdot 10^{21} s^{-1}$ and that the most widely used description of Γ_f(t), an exponential in-grow function, does not reproduce our data, because it fails to describe the essential feature of the solution of the Fokker-Planck equation, namely the practically complete suppression of fission during most part of the transient time. Our result sheds severe doubts on part of the previous work on nuclear dissipation.

References

1 P. Grangé et al., Phys. Rev. C 27 (1983) 2063

2 S. Chandrasekhar, Rev. Mod. Phys. 15 (1943) 1

3 A. Heinz et al., GSI Ann. Rep.(1999)30 and references within