Fission Time Scales from Neutrons and Gamma Rays

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As reported previously [1], we have investigated simultaneously neutron and gamma ray emission for the same reactions to probe fission time scales. The analysis of four different reactions has been completed: 104 MeV ^{4}He + ^{188}Os & ^{209}Bi and 133 MeV ^{16}O + ^{176}Yb & ^{208}Pb. The first and the third reactions were chosen to form the same system at different angular momentum. The last system was selected to connect the current work with previous gamma ray studies [2].

Fission fragments were detected using a spectrometer consisting of a thin start parallel plate detector and two large solid angle PPAC's. Gamma rays were detected with two "pods" containing a total of 144 elements of the US National BaF_2 array. Neutrons were detected using eight elements of the DEMON array. The details of the experimental setup and the data analysis can be found in a previous report [1].

In order to extract fission time scales, the neutron and gamma ray data were analyzed using the code TIMCASC [3]. This code is a modified version of CASCADE [4] that follows the both the compound nucleus and the fission fragments. The program treats the compound nucleus GDR as a sum of two Lorentzian's, thus describing oblate, spherical and prolate systems. The gamma spectra were fit using TIMCASC linked to the code MINUIT. Initially, the fits were performed by varying several compound nucleus parameters: the deformation (β), the mean GDR energy (E_{cen}), the width of the GDR components, the strength of the perpendicular component of the GDR (S_{per}), a width parameter of the GDR (c), and the Kramer's viscocity coefficient (γ). The strength of the GDR was assumed to be 100% of the TRK sum rule in the

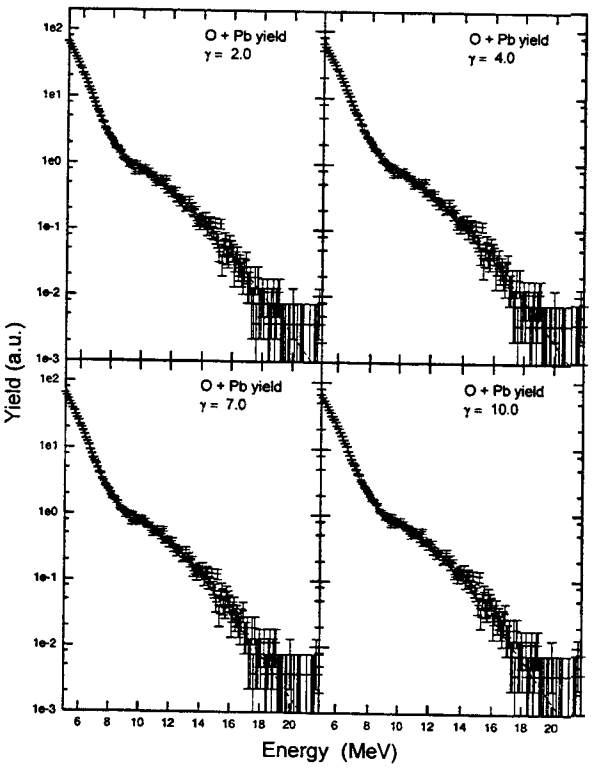

Figure 1. Best fits for the ^{16}O + ^{208}Pb system.

fits to the $^{16}O + ^{208}Pb$ data. For the less fissile systems, the total strength was allowed to vary by as much as 30% above the sum rule. The results of a fit to the $^{16}O + ^{208}Pb$ data are shown in Fig. 1. While the agreement is excellent, the fits obtained for the other systems were of lower quality. During the fitting process, it was found that the values of c and E_{cen} quickly converged to constant values. Thus these parameters were fixed at constant values to reduce the computation time, which was substantial.

A couple of options were available for extracting fission times from TIMCASC [3]. Since the code keeps track of both the fission cross section and the fission time at each step in the cascade, it is possible to define a fission time ($t_{f,i}$) for each point in the decay chain. If for example, a nucleus emits x neutrons before fission, the quantity $\tau_{xn,f}$ can be easily calculated from the various $t_{f,i}$'s. This is the so-called neutron fission clock time. Alternatively, the fission time can be determined from the cross section weighted average over the entire decay chain. This yields a mean fission time, $\tau_{f,tot}$. The results for both the neutron and the gamma data are given in Tabs. I&II. It is important to note that $\tau_{f,tot}$ is very sensitive to small errors in the fission cross sections for the long time tail in the fission time distribution. In comparing the present results with previous work, it is probably most appropriate to use the neutron clock values.

From an examination of the tables, one observes that the γ-values for the two different techniques are comparable, but the neutron results are generally higher for the same system. The lifetimes obtained with the different methods are similar. Comparing the $\tau_{xn,f}$ values, the ^{4}He-induced reactions generally exhibit shorter times than the ^{16}O-induced reactions. The shortest fission time is associated with the least fissile system, $^4He + ^{188}Os$. This is due to a low probability of multichance fission. The fission times obtained with the GDR method tend to be about a factor of two smaller than those obtained with the neutron method. It is not clear how much of this is due to the model dependence of the analysis. With the exception of the neutron results for the least fissile systems, $^{16}O + ^{176}Yb$ and the $^4He + ^{188}Os$, $\tau_{f,tot}$ is generally larger than $\tau_{xn,f}$. The $\tau_{f,tot}$ times for $^4He + ^{209}Bi$ are considerably larger than any of the other systems, indicating a long fission de-excitation chain. It would be of considerable interest to re-examine other data using this same method to see how much this approach affects the extracted times.

Table I. Results for the GDR fits.

Reaction	γ	$\tau_{f,tot}$ (zs)	$\tau_{f,xn}$ (zs)
$^{16}O + ^{208}Pb$	7	93 ± 27	67 ± 10
$^4He + ^{209}Bi$	20	250 ± 35	44 ± 9
$^{16}O + ^{176}Yb$	10	128 ± 35	66 ± 12

Table II. Results from the neutron fits.

Reaction	γ	$\tau_{f,tot}$ (zs)	$\tau_{f,xn}$ (zs)
$^{16}O + ^{208}Pb$	20	170 ± 30	105 ± 10
$^4He + ^{209}Bi$	10	293 ± 35	72 ± 7
$^4He + ^{209}Bi$	20	49 ± 10	112 ± 12
$^4He + ^{188}Os$	10	18 ± 5	31 ± 4

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