Studies on Fission Time Anomaly in fissile and very heavy nuclei

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Nuclear fission is one of the most important discoveries of the 20th century and in this context, the fission dynamics of highly excited fissile and superheavy nuclei has a special significance. The timescale of the nuclear fission process is one of the basic characteristics of the fission dynamics. However, the experimental measurements of fission time by the atomic and nuclear techniques give two very different timescales. On the one hand, very long fission times (on the order of 10^{-18} sec) for the highly excited uranium and transuranium nuclei have been measured by the atomic techniques (K x-ray-fission fragment coincidence and crystal blocking techniques) [1,2], whereas much shorter (~10^{-20} sec) fission times had been obtained using nuclear techniques [3,4]. It was argued [5] that the two fission timescales are due to the sensitivity of the nuclear and atomic techniques in short and long timescales respectively and the long fission times could provide information about the viscosity [5] of the nuclear medium and might be used as probes [1,2] for studying the production of long-lived superheavy nuclei. It was recently shown [6] that the observed long fission time (~10^{-18} s) for the majority of the fissioning events as obtained by the atomic techniques [1,2] cannot be reconciled with the short fission time (~10^{-20} s) obtained by the nuclear techniques [3,4] and calculations [7]. The fission time measurements by the atomic techniques are relatively new and only a few measurements are available. So, it is important to undertake the measurement of fission time of highly excited fissile nuclei by atomic techniques such as by the K x-ray technique. K x-ray-fission fragment coincidence technique clocks the fission time of the compound nucleus by the K vacancy lifetime and determines both the fission time and the percentage of long fission time component. However, so far only three published measurements [1,8,13] of fission time by K x-ray technique exist. Those experiments used heavy ion reactions and observed very broad (~20 keV) K x-ray peaks due to the electronic configuration mixing and contribution from nearby elements. So, they determined the fission time from the K x-ray multiplicity and probability of creation of K vacancy assuming a fission time distribution. However, fission time could be obtained from the intrinsic width of K x-ray line of the atom containing the fissioning nucleus using only quantum energy time uncertainty principle [14], $\tau_{fission} = \frac{\hbar}{\Gamma_{intrinsic}}$, where $\tau_{fission}$ is the fission time and $\Gamma_{intrinsic}$ is the intrinsic width of the K x-ray line of the atom containing the fissioning nucleus. In order to determine the intrinsic width of the relevant K x-ray line, one must use ^{4}He or ^{1}H induced reactions so that only one fissioning element would be produced and the effect of electronic configuration mixing would be negligible. Then, a narrow K x-ray line is expected to be observed, if long-lived fission component is dominant. Such measurements would open up new ways of looking at the fission process. To explore this dimension, ^{242}Pu ($E_X \approx 55$ MeV) was produced by bombarding a ^{238}U target (2.5 mg/cm^2 thick) with a ^{4}He beam at $E(^{4}He)_{Lab}$ =60 MeV from the Variable Energy Cyclotron Centre, Kolkata and a K x-ray-fission fragment coincidence experiment has been performed using a very close geometry. A large area solar cell detector was placed about ~2 cm away from the target subtending about 10% of 4π solid angle to detect the fission fragments. The center of the solar cell detector was making an angle of 120° with the beam direction. A four-segmented LEPS detector was placed ~10 cm away from the target at a polar angle of 90° subtending a solid angle of ~7 msr to measure low energy γ-rays and x-rays. In the random subtracted true coincidence spectrum, narrow plutonium $K_{\alpha 1}$ line was observed in coincidence with the fission fragments. The intrinsic width of the K x-ray line was determined from the measured FWHM of the line and known detector resolution. Using quantum energy-time uncertainty principle, we have obtained fission time $>1\times10^{-18}$ s [9] from the measured intrinsic width of K x-ray line. Using the estimated probability of K vacancy in plutonium, we obtain that most of the fission events should be slow (fission time $\sim10^{-18}$ s), in agreement with the earlier results obtained by the atomic techniques [8]. The long survival time obtained for this system appears to be inconsistent with the short fission delays obtained from the nuclear experiments and calculations [7,10].

To probe this inconsistency further, we have investigated [6] the fission timescale of highly excited Z=120 nucleus where a lot of measurements by atomic and nuclear techniques are available. We find that the long fission lifetime ($\sim10^{-18}$ s) measured by atomic techniques could not be reconciled with the short fission lifetime ($\sim10^{-20}$ s) measured by nuclear techniques. We see this as a general problem between nuclear and atomic techniques, because similar disagreements exist for many different fissioning and/or quasifissioning nuclei far away from the predicted island of the stable superheavy nuclei [6].

Considering the general nature of this large discrepancy (~two orders of magnitude) for a variety of nuclei, we have investigated this problem using a quantum decoherence model. In this model, the atom containing the fissioning nucleus is considered as a quantum detector observing the fission process [11,12]. It was shown that decoherence time of the fission process could be on the order of 10^{-18} sec and it could explain the apparent discrepancy between the fission times obtained by atomic and nuclear techniques.

In summary, the fission time of highly excited plutonium nuclei produced by $^{4}He+^{238}U$ reaction at $E(^{4}He)_{Lab}$=60 MeV was measured by K x-ray technique from the intrinsic width of K x-ray line. It was inferred from the K x-ray fluorescence yield that most of the fission events are slow [9]. A critical analysis [6] of available nuclear and atomic data showed their inherent incompatibility, contrary to the general perception that nuclear and atomic data could be reconciled by the standard sensitivity argument[5]. The apparent incompatibility between the nuclear and atomic data might indicate physics beyond fission dynamics and we have explored this dimension using a quantum decoherence model.

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