Indication of long fission lifetime of ^{242}Pu at E_X≈55 MeV

A. Ray[1], A. K. Sikdar[1], B. Dey[1], D. Pandit[1],S. Bhattacharya[1], A. De[2], S. Paul[2], Srijit Bhattacharya[3] ,A. Bisoi[4]

[1]*Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata – 700064, INDIA*
[2]*Raniganj Girls' College, Raniganj, West Bengal, INDIA*
[3]*Department of Physics, Barasat Govt. College, Barasat, N 24 Pgs, Kolkata 700124, India*
[4]*Saha Institute of Nuclear Physics, 1/AF, Bidhan Nagar, Kolkata - 700064, INDIA*

Introduction

Although both the fission and quasfission processes have been known for a long time [1], recently a controversy has developed [2] regarding the time scales of these nuclear processes. The nuclear theories of these processes [1] predict quasifission and fission time scales of the order of 10^{-21} sec to 10^{-20} sec for the highly excited transuranium or uranium-like nuclei, assuming exponential decay in time. Experimentally, fission/quasifission timescales of highly excited transuranium nuclei have been determined on the one hand from the model dependent mass-angle distribution plots [3] and neutron multiplicity measurements [4] and on the other hand from the crystal blocking [5,6] and X-ray-fission fragment coincidence techniques that are much less model dependent non-nuclear techniques. It was found that the crystal blocking and atomic X-ray techniques generally obtained quasifission/fission lifetimes (~10^{-18} sec) much longer than the ones (~10^{-20} sec) inferred by using nuclear techniques. However X-ray-fission fragment experiments have so far obtained only very broad bumps in the region of characteristic K-X-ray because of various experimental reasons and no experiment has seen sharp characteristic K-X-ray of the compound atom in coincidence with the fission fragments.

Experiment

In order to probe the problem further, we performed a K-X-ray-fission fragment coincidence experiment by bombarding a natural uranium-oxide film (<1mg/cm^2) electrodeposited on a thin aluminium foil (~1 micron thick) with a beam of 60 MeV ^{4}He beam (~ 2 pnA current) from the Room Temperature Cyclotron of Variable Energy Cyclotron Centre, Kolkata, India. A large area solar cell detector was placed at a distance of ~ 2 cm from the target and was used as a fission fragment detector. A segmented LEPS detector comprising four crystals was placed at a distance of ~10 cm from the target. A coincidence circuit using a TAC was setup between the LEPS detector and the solar cell (fission fragment) detector. In this reaction, since there is no possibility of incomplete fusion, a compound plutonium atom should be produced in the fusion process and a sharp K-X ray line of plutonium should be seen, if indeed fission of plutonium (E_X ~55 MeV) is slow.

Results

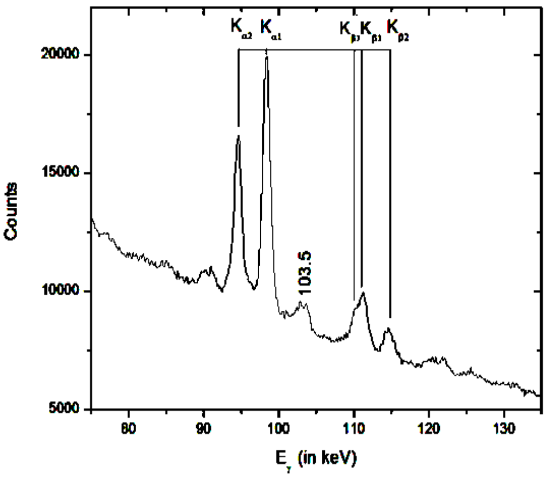

Fig. 1 Singles X-ray spectrum from ^{4}He+^{238}U reaction at E(^{4}He)=60 MeV.

In Fig. 1, we show the singles spectrum from the LEPS detectors after adding all the four crystals with proper gain matching. Uranium $K_{\alpha1}$, $K_{\alpha2}$,

$K_{\beta1}$, $K_{\beta2}$, $K_{\beta3}$ X-ray peaks are seen. Plutonium K-X- ray line (103.75 keV) produced due to the electromagnetic transitions and corresponding electron conversion of compound atoms whose nuclei do not undergo fission (because of small orbital angular momentum) is seen in the spectrum along with the $(4^+ \rightarrow 2^+)$ transition nuclear γ-ray (102.8 keV) line from ^{242}Pu. We gated on the TAC spectrum and obtained X-ray spectra in coincidence with the fission fragments. We also generated random X-ray spectra by gating on the background of TAC spectrum. In Fig. 2, we show the coincidence X-ray spectrum from one crystal gated on the TAC peak as well as the corresponding random X-ray spectrum by

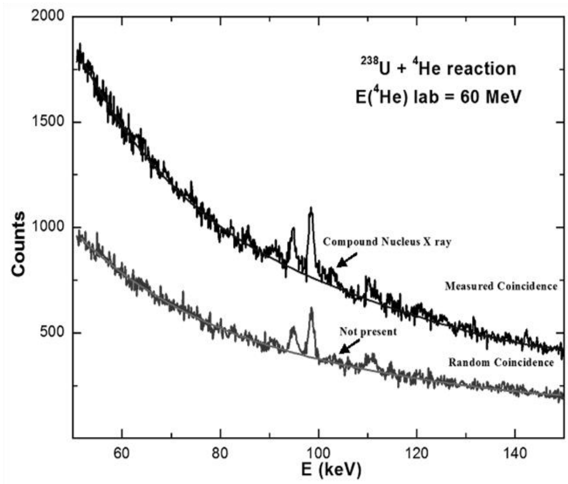

Fig. 2 TAC gated X-ray spectrum from ^{4}He+^{238}U reaction at E(^{4}He) lab=60 MeV.

gating on TAC background of equal number of channels. We find that the areas of the uranium K-X-ray lines present in the random X-ray background at 98.4 keV and 94.65 keV are 1737.0 ± 174.7 and 1250.0 ± 136.8 counts respectively. The areas of those peaks in TAC gated X-ray spectrum are 2193.3 ± 243.3 and 1327.1 ± 252.3 respectively. So, within our error bars they are almost equal. However, there is a sharp X-ray line around plutonium K-X ray region with no corresponding significant background line (as indicated by arrows in Fig. 2). The area of K-X-ray peak (~103.5 keV) gated on TAC peak is = 328.8± 145.8 and the area of any possible K-X-ray peak at the same energy gated by equal number of channels of TAC background is consistent with zero. This indicates that X-ray line (~103.5 keV) is in true coincidence with the fission fragments. The FWHM of the X-ray line is ~1 keV similar to the resolution of X-ray detector at that energy. The observation of this sharp K X-ray line indicates long fission lifetime (~10^{-18} sec) of ^{242}Pu (E_X ~55 MeV), because the lifetime of K-vacancy of plutonium atom is of the order of 10^{-18} sec. We found by gating on different regions of the fission spectrum that the coincident plutonium K-X-ray line is coming from the entire fission spectrum and not from any particular region. The intensity of the observed coincident K-X-ray line shows that almost all the emitted fission fragments are coming from slow fission with lifetime (~10^{-18} sec).

References

[1] *Treatise on Heavy-Ion Science*, vol 2, ed. D. A. Bromley, Plenum Publishing, N.Y., 1984.

[2] J. U. Andersen et al., Phys. Rev C **78** (2008) 064609.

[3] R. du Rietz et al., Phys. Rev. Lett.**106** (2011) 05271.

[4] D. J. Hind et al., Phys. Rev C**45** (1992) 1229.

[5] M. O. Fregeau et al., Phys. Rev. Lett.**108** (2012) 122701.

[6] P. Paul and M. Theonessen, Ann. Rev. Nucl. Part. Sci.**44** (1994) 65.