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Evidence of a new type of fission within a solid state nuclear detector (*)

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Résumé. — Lors de l'étude des réactions de l'U de 10 MeV/n sur des cibles d'U, Au et Pb à l'aide d'un détecteur visuel solide de traces, l'on a mis en évidence une configuration nouvelle qui pourrait correspondre à de la fission retardée.

Abstract. — An SSNTD study of reactions induced by 10 MeV/n U ions on U, Au and Pb targets led to the observation of a new type of fission event which can be explained as a delayed fission.

1. **Introduction.** — In the present paper we deal with a new phenomenon observed within solid state nuclear track detectors (SSNTD). Elastically or quasi-elastically uranium ions from very heavy targets (U, Pb, Au) were seen to decay into two heavy fragments. Three such events among 6 100 scattered ions were found.

The detector used, namely MAKROFOL, is a threshold detector. That is, only heavy ion tracks whose energy loss rates are larger than a critical value can be recorded [1]. Targets were irradiated by 10 MeV/n uranium at the G.S.I. in Darmstadt (West Germany).

After irradiation and development, different types of events were observed :

— Two-pronged events corresponding to elastic (or quasi-elastic) scattering of uranium on the target nuclei (U, Pb, Au) ;

— Three- and even four-, five-, and six-pronged events in correlation and corresponding to sequential fissions [2-4] of the scattered and/or recoil ions.

In addition, reactions of uranium on the carbon and/or oxygen nuclei of the detector were recorded. These interactions generally occurred between 1 and 40 μm depth within the detector bulk along the incident uranium path, which was perpendicular to the plane of the detector. These interactions, which lead to in-flight fission of uranium induced by carbon and/or oxygen have been previously investigated in our laboratory [5].

2. **Characteristics of the new events.** — A schematic diagram of the new events is presented in figure 1. In figure 2 is given a photograph of the tracks of these events projected on the plane of

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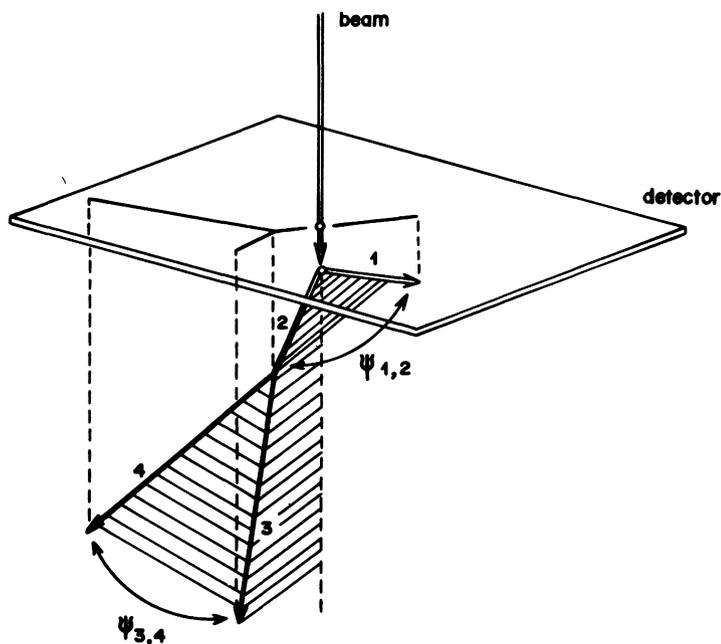


Fig. 1. — Schematic diagram of a typical new event.

the detector. Tracks are identified as follows : number « 1 » represents the recoil nucleus ; number « 2 » is the scattered ion before its decay and numbers « 3 » and « 4 » are the fragments issuing from the break-up. The characteristics of these correlated tracks are given in table I.

Table I. — *Characteristics of the 3 correlated tracks of new events.*

Projectile + target	Range in μm				Lifetime of the scattered nucleus (in s)	Space angle	
	R_1	R_2	R_3	R_4		$\psi_{1,2}$	$\psi_{3,4}$
U + U	15	12	94	88	0.3×10^{-12}	90°	38°
U + Pb	6	32	110	63	0.8×10^{-12}	90°	39°
U + Au	8	45	153	52	1.2×10^{-12}	85°	38°

In all cases, a geometrical calculation permitted us to verify that the tracks numbered 2, 3 and 4 are coplanar. The lifetime values are deduced from the measured ranges of the scattered nuclei.

3. **Discussion.** — Several tentative suggestions can be advanced to explain these observations :

— That these events be elastic collisions of uranium upon nuclei of the detector. However, this hypothesis is very improbable because MAKROFOL is a polycarbonate whose formula is $(\text{C}_{16}\text{H}_{14}\text{O}_3)_n$ and thus collisions would occur with light nuclei only. This threshold detector on the one hand would not record a proton recoil track and on the other hand records only oxygen and carbon recoil ranges of $\sim 12 \mu\text{m}$ in the standard chemical etching used. Moreover, the angle $\psi_{3,4}$ does not agree with an elastic collision.



Fig. 2. — Photograph of the three tracks of new events projected on the detector plane.

— That these events be nuclear reactions of the scattered uranium with a carbon or an oxygen nucleus of the detector, since the cross section is not completely negligible. Indeed, in the 36 cm^2 scanned area, we found 6 100 elastic scatterings of uranium for a flux of $1.6 \times 10^6/\text{cm}^2$ incident particles. The reaction cross section of $\text{U} + \text{C}$ (or $\text{U} + \text{O}$) is known as well as is the total number of C and O nuclei. From this information, the number of nuclear interactions of the scattered uranium with a nucleus of the detector is calculated to be 0.18. In fact, we experimentally found 3 events, or 16 times more. In addition, the decay of the scattered uranium nuclei occurred after path lengths of 12, 32 and $45 \text{ }\mu\text{m}$ inside the detector so that the residual energies of the three scattered nuclei were 8.5, 6.9 and 5.4 MeV/n , respectively. As for the latter two events, their energies are close to the potential barrier, so that the probability of forming a compound nucleus is very small.

Since the above hypotheses are not totally adequate, we propose that the events can be some type of isomeric fission whose lifetime is of the order of picoseconds as listed in table I.

If the branching ratios of these three events relative to that of the prompt fissions (3 + 4 + 5 pronged events) is calculated, a value of 3×10^{-3} is found. At first glance, this value seems too high in comparison with that usually given in the literature, which is of the order of 10^{-5} . Nevertheless, when reference is made to the data of P. Limkilde *et al.* [6] concerning two isomers of ^{238}Pu , it can be pointed out that the branching ratio increases noticeably as the isomer lifetime decreases. The maximum of this ratio is $\sim 2 \times 10^{-5}$ for the ^{238}Pu isomer whose lifetime is 0.5×10^{-9} s and $\sim 10^{-6}$ for that whose lifetime is 5×10^{-9} s. Provided that extrapolation of these results is valid, the branching ratio for an isomer whose lifetime is $\sim 10^{-12}$ s would be $\sim 10^{-3}$. This would agree with the values we found and thus is in favour of our proposition.

4. Conclusion. — Solid state nuclear track detectors would be particularly suited to the measurement of lifetimes of the order of picoseconds. The three events that have been described could be fission isomer ones, issuing from reactions of 10 MeV/n uranium on heavy targets in which the scattered uranium has become unstable in picking up nucleons from the target nuclei. Nevertheless, a deep inelastic nuclear reaction of uranium on a carbon or oxygen nucleus cannot be completely excluded.

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