International Conference “50 Years of Cold Fusion”
Yerevan, 20-23 November 2024

Solid-state nuclear track detectors in the study of rare spontaneous fission events

BASED ON HABILITATION THESIS OF SVETLANA TRETYAKOVA (1989)

Tatiana Tretyakova
SINP MSU, FLNP JINR

JOINT
INSTITUTE
FOR NUCLEAR
RESEARCH,
DUBNA

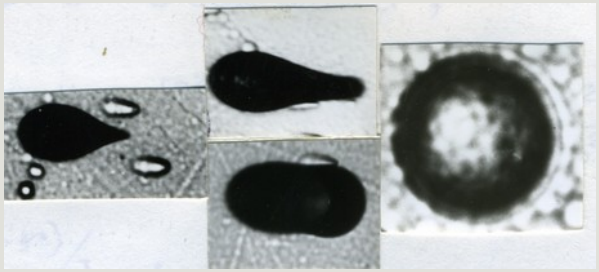
1976 Annual Report

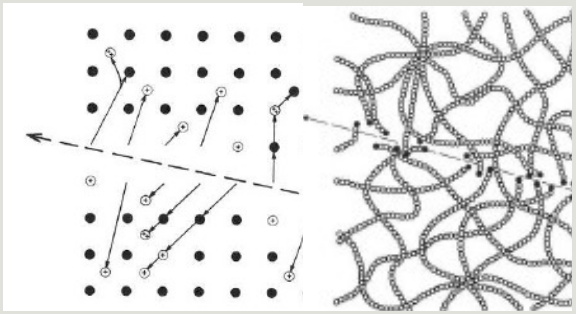
Laboratory of
Nuclear Reactions

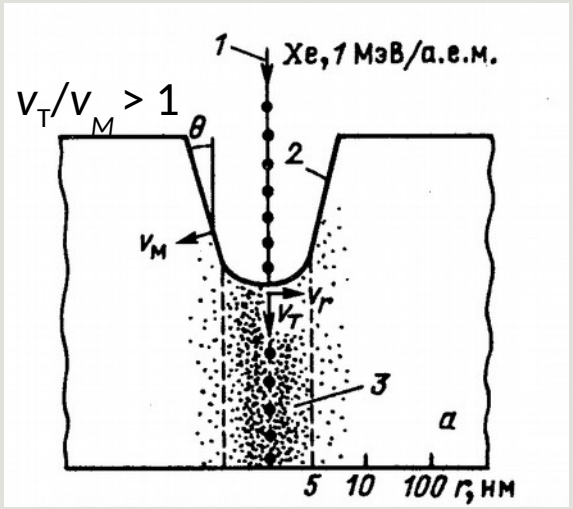
Plan

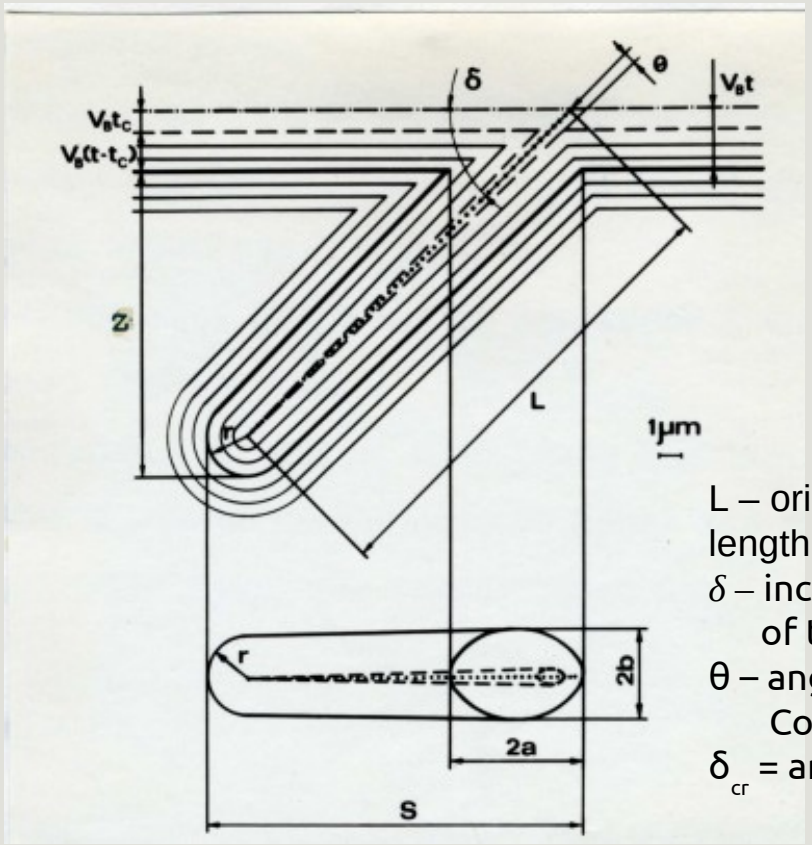
- Introduction
- Methods of heavy charged particle registration by SSNTD
- SHE synthesis registration
- Rare spontaneous fission events in nature
- Cluster radioactivity

Track formation









L – original track length

δ – incident angle of the particle

θ – angle of the track Cone

$\delta_{cr} = \arccos(V_M/V_T)$

Track revelation

Ion *Z*, *M*, *E*

Irradiation → Detector

R(E)
δ

dE/dx = f(Z,M,E)

Latent track

Etching → Etching selectivity

C, *T*, *t*

v = f(dE/dx)

$v = v_T/v_M$

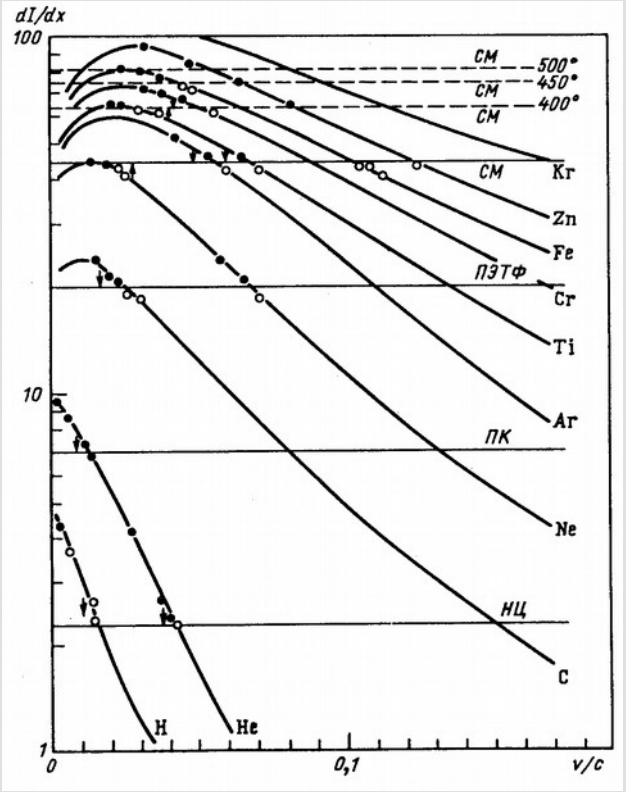
Observation

$v_T/v_M > 1$

→ Visible track

f(v, h, δ, R_0)

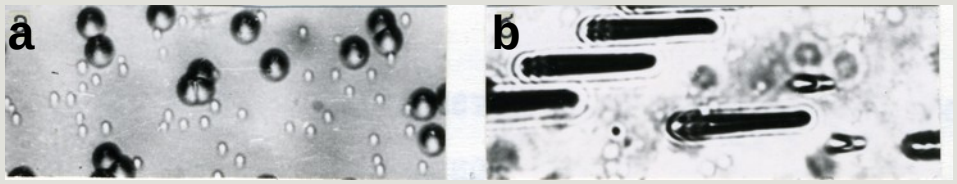
S. Tretyakova PEPAN 23 (1992)

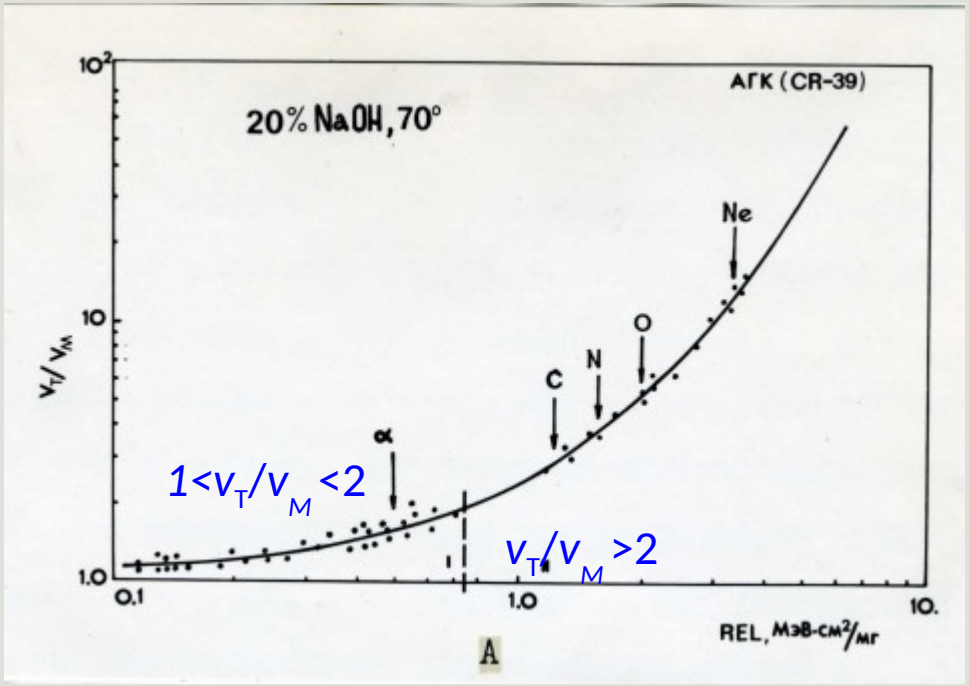


Detection efficiency

SSNTD	Sensitivity threshhold E, ion	heat resistance T°C	fissile concentration, g/g	Chemical etching	Eff. %	δ . grad
Muscovite mica	2 MeV, ^{20}Ne	700	10^{-7} – 10^{-8}	40%HF, 22°C, 2 h	90 ± 3	6
Phosphate glass	20 MeV, ^{20}Ne	500	10^{-7} – 10^{-9}	40%HF, 20°C, 1 h 30’	90 ± 3	6
PET	12 MeV, ^{12}C	250	10^{-10}	20%NaOH, 60°C, 1 h	95 ± 3	4
PC	300 keV, ^{4}He	250	10^{-10}	20%NaOH, 70°C, 1 h	95 ± 3	4
CN	550 keV, ^{1}H	200	10^{-9}	10%NaOH, 40°C, 1 h	90 ± 3	6
CR-39 (PADC)	100 MeV, ^{4}He	300	10^{-10}	20%NaOH, 70°C, 1 h	90 ± 3	6

Registration





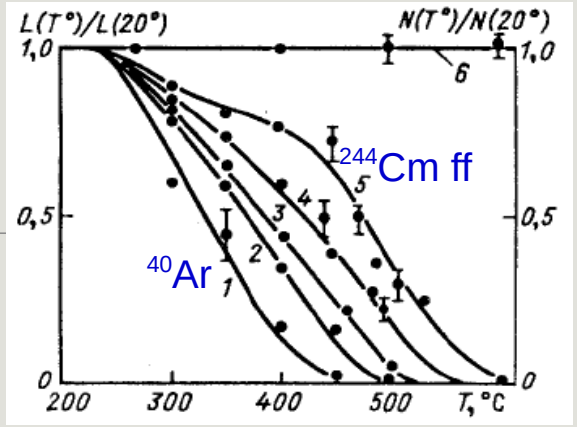
a) Zn and S (small) (glass, 60^0)
b) Zn and S (small) (glass, 45^0)
5.6 MeV/u
c) Xe and O (small) (PET, 45^0)
1 MeV/u

v_T/v_M ~2 (S and O)

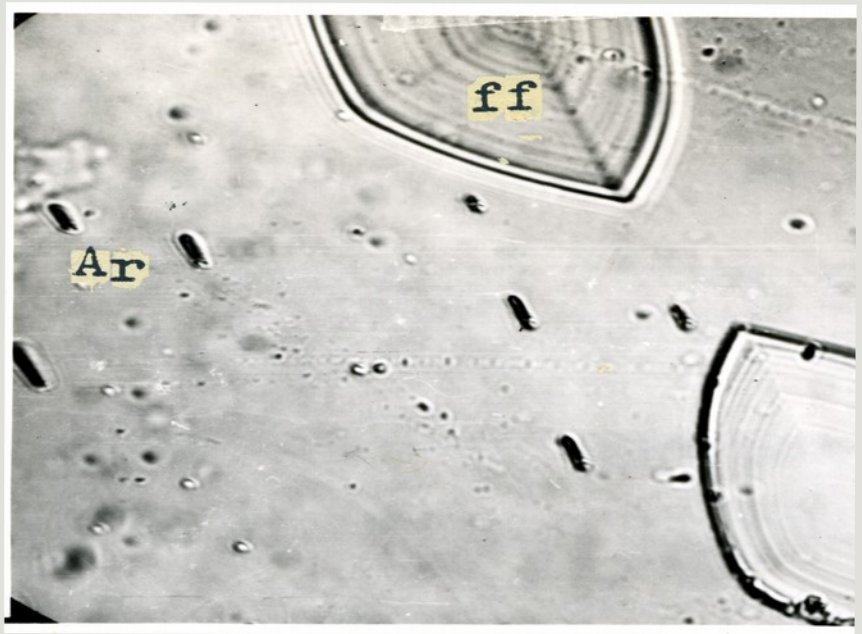
v_T/v_M >10 (Zn and Xe)

Registration

The sensitivity threshold can be adjusted using chemical processing, heating, UV, γ- or α-irradiation

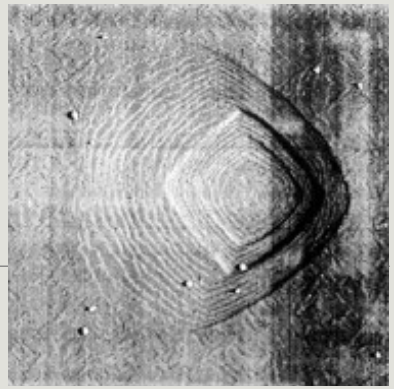


	Temp. limit for storing ff tracks		Dose limit, kGr
Muscovite mica	650 – 700 °C		$5 \cdot 10^4$
Phosphate glass	300 – 500 °C		$5 \cdot 10^4$
PET	160 °C		$5 \cdot 10^3$
PC	160 °C		$5 \cdot 10^2$
CN	120 °C		10
CR-39	180 °C		5



U fission fragment tracks (annealing at 600°C, etching 40% HF at 22°C, 72 h) and scattered Ar ion tracks(without annealing)

Identification



- Threshold discrimination

- Above-threshold identification:

A. High ionizing particles (track length R(E), track diameter D(E), sequential etching method)

B. Weak ionizing Particles (layer-by-layer detection, sequential etching method)

Identification accuracy:

charge $\Delta Z = \pm 0.2$ and mass number $\Delta A = \pm 1$

energy (depends on E) $\Delta E = \pm 1\%$ ($L \geq 100$ μm)

for weak ionizing particles $\Delta E = \pm 10\%$

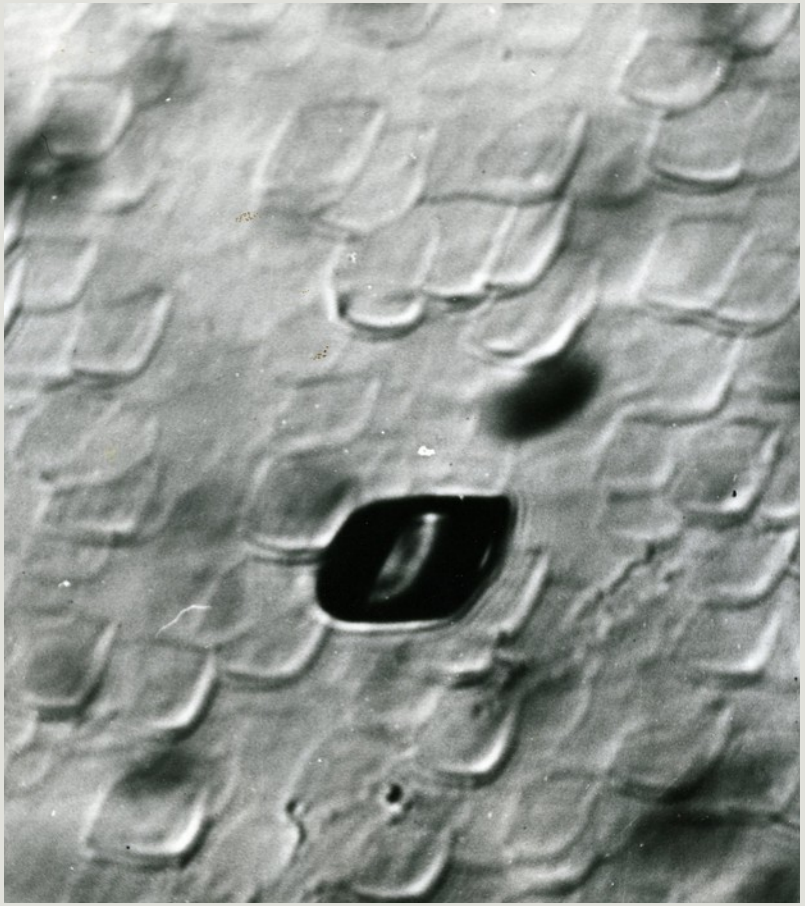
By choosing the detector and processing conditions, the identification accuracy can be improved by 2-3 times.

Applications

- SHE synthesis registration

- Rare spontaneous fission
- events in nature

- Cluster radioactivity



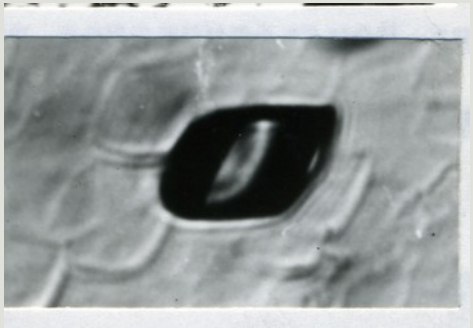
SHE synthesis

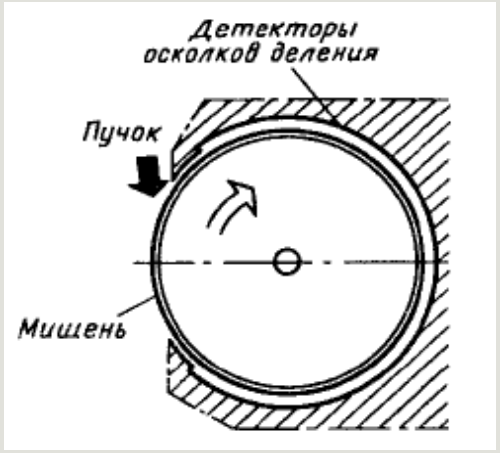
$^{208}Pb + {}^{54}Cr \rightarrow {}^{259}106 + 3n$

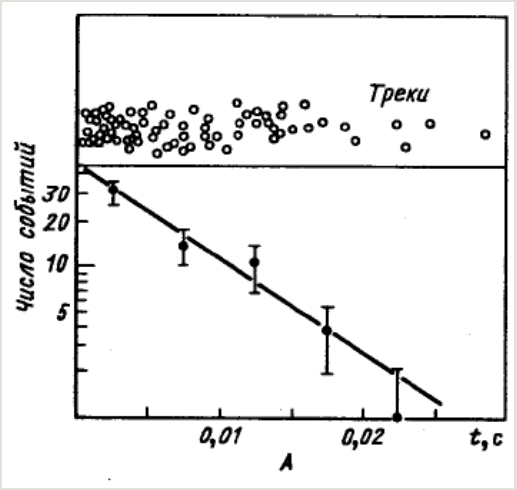
Cross sections ≤ 10^{-10} b (up to 1 pb)
$T_{1/2} \leq 10^{-3}$ s (up to 0,4 ms)

Flux ~10^{18} cm^{-2}
Neutron flux ~10^{11}–10^{13} cm^{-2}
Background: flux >10^{6} cm^{-2}
T ~ 80°C

208Pb+54Cr annealing 460°C, 6h



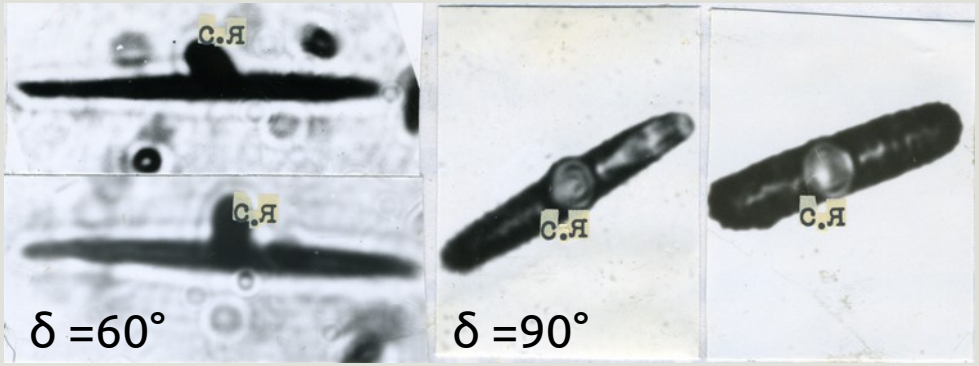




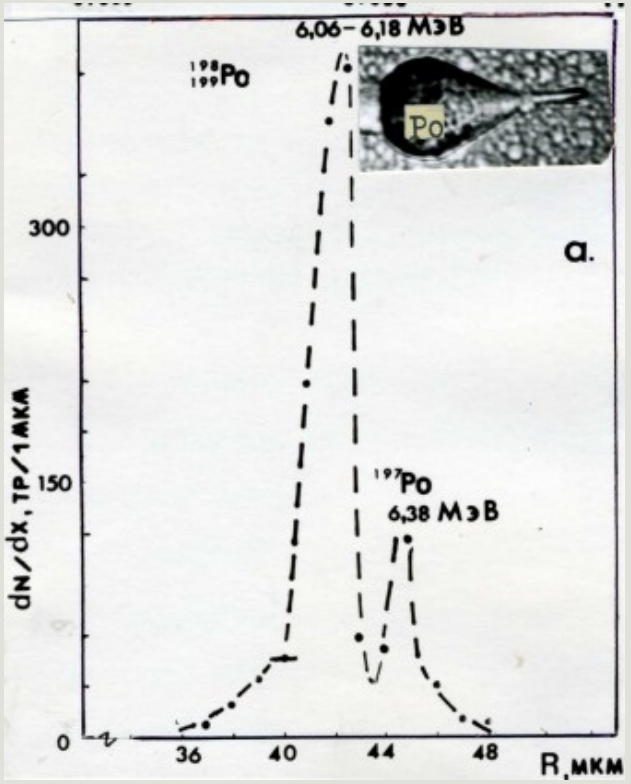
Cold Fusion

U + Mg
Th + Mg, Ar, Ca, Ti
Bi + Cl, **Ti, V, Cr, Mn, Fe, Co, Ni**
Pb + Ar, Ca, Ti, V, Cr, Mn, Fe
Tl + Sc, Cr, Fe

$100 \leq Z \leq 112$



$^{209}Pb + {}^{40}Ar$ (5,5 MeV/u) → Fm (*sf*)

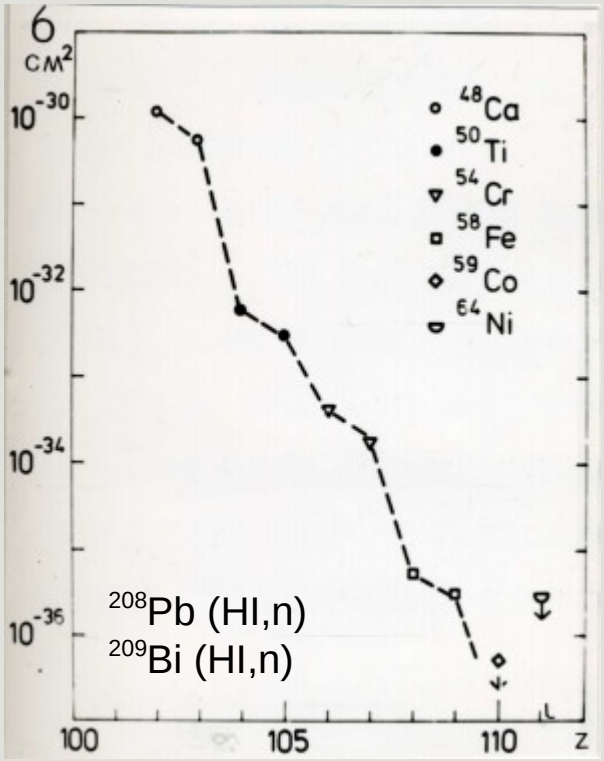


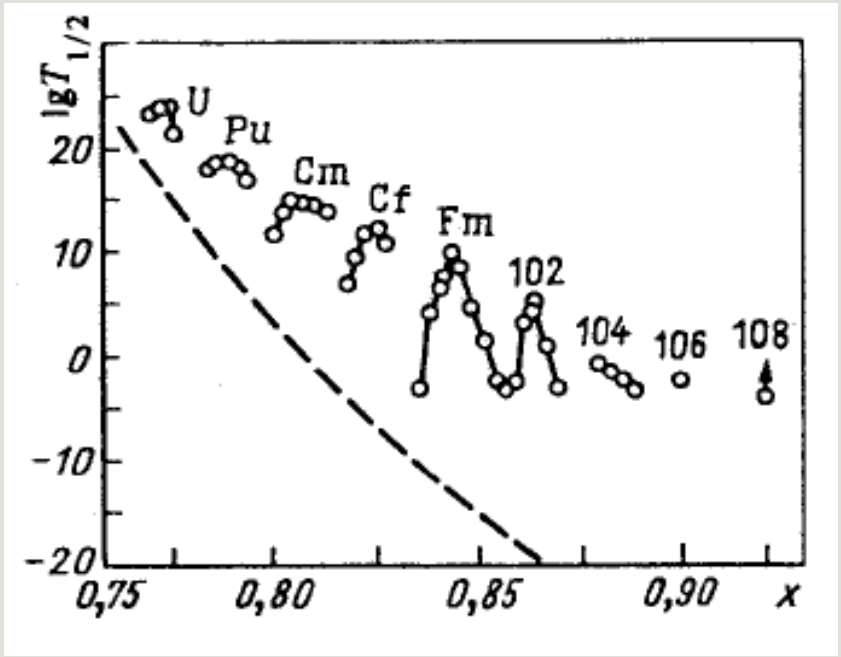
$^{nat}Dy + {}^{40}Ar$ (5,5 MeV/u) → Po (α)

Cold Fusion

104 ≤ Z ≤ 110

Cross sections ~ 1 pb; $T_{1/2} \leq 10^{-4}$ s





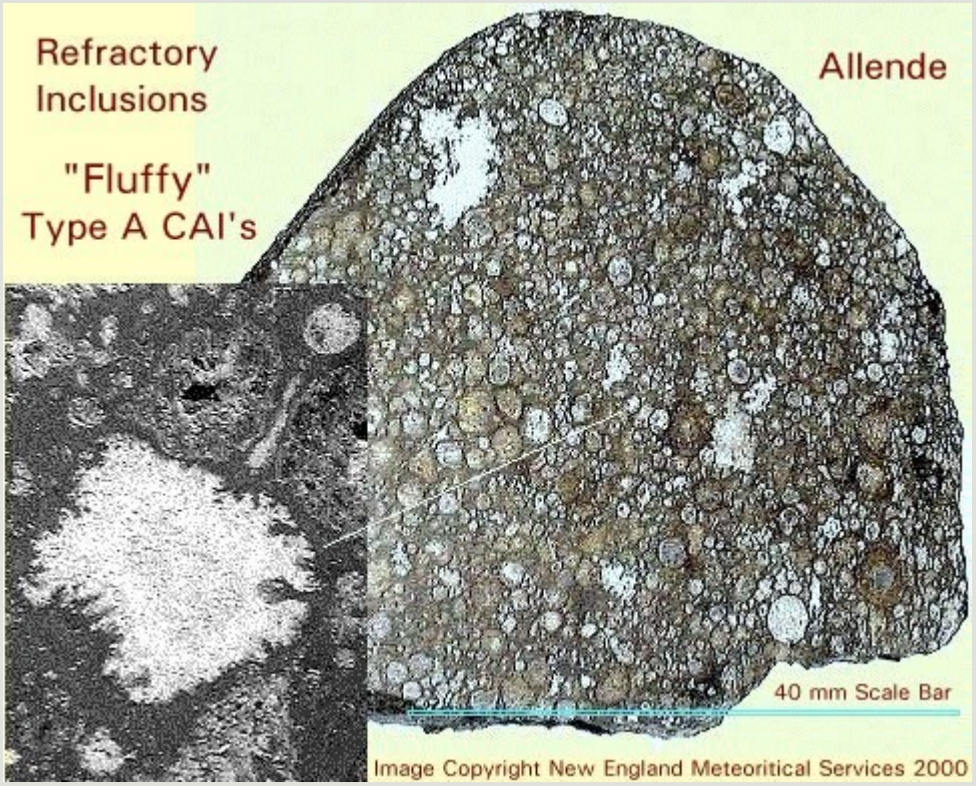
$x = Z^2/A$

Rare spontaneous fission events in nature

Search for elements
Z~114, N~184
in natural samples

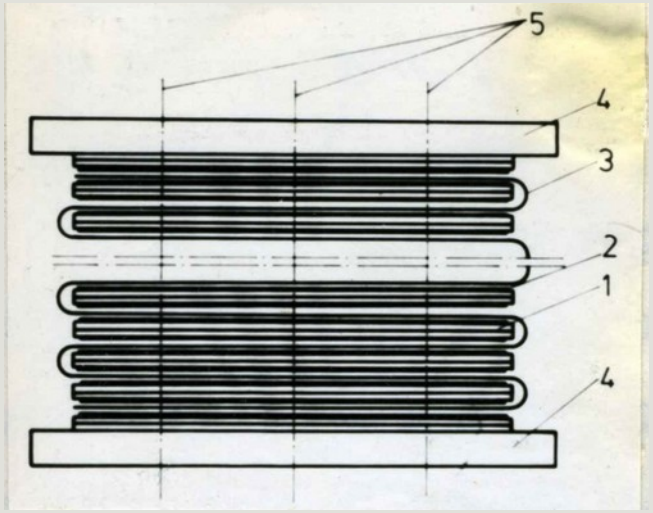
Allende (8.02.1969 Mexico) carbonaceous chondrite (class CV) (the most ancient of known forms of matter in the Solar system).
2 tons collected.

Estimation of the required sensitivity ~3·10(−14) g/g :
Mass of meteorite substance ~1 kg
Exposition ~1 year



Allende

Sample: 850 g (layer 1-2 mg/cm2) (2)
Detector: Polycarbonate
(mean range estimation ~ 24 µm)
Polycarbonate 185 µm: 433 layers (1)
Total area 2000 cm2
Polycarbonate 12 µm (~ 7 m length) (3)



Exposure: 10 months
Shielding: concrete 2 m

Etching:
12 µm 10% KOH (60°C)
185 µm: 20% NaOH (70°C) [D_{tr} 10 µm]

Spark Detection (eff ~ 40%)
Background
– film defect breakdown
5 – 10 pcs per 650 cm2
– uranium 2·10(—8) g/g
(1 decay in 10 months)
– technogenic impurities
(1 decay per year)

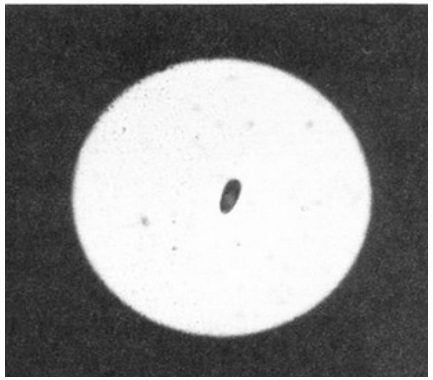
6 events in 10 months
0.02 decay per day per kg
(concentration 10(–14) g/g)

Spontaneous fission of ^{232}Th

Cran Sasso Underground Laboratory

(Dubna - Milano collaboration grant N 93-02-03-719)

Bonetti et al. PRC 51 (1995) 2530

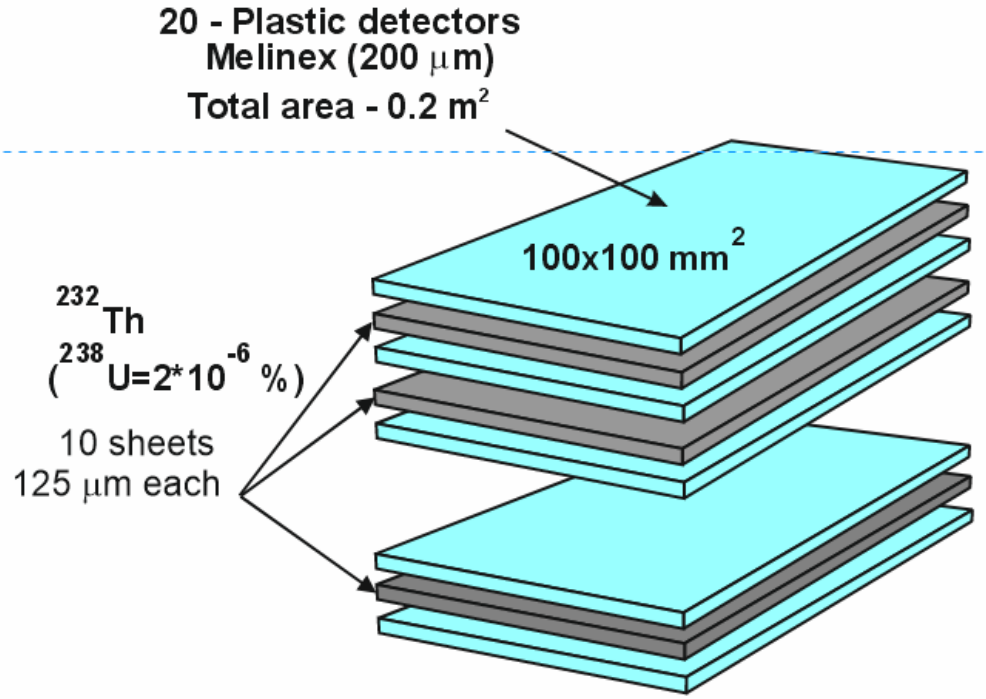


Exposition : 665 days

On the front side: 21 tracks

On the back side: 2 tracks

$$T_{SF}(^{232}Th) = (1.22 \pm 0.43)10^{21}\ a$$



$$T_{SF}(^{232}Th) = (1.2 \pm 0.4) \cdot 10^{21}\ y$$

(Holden, Hoffman. IUPAC Tech Rep 2000)

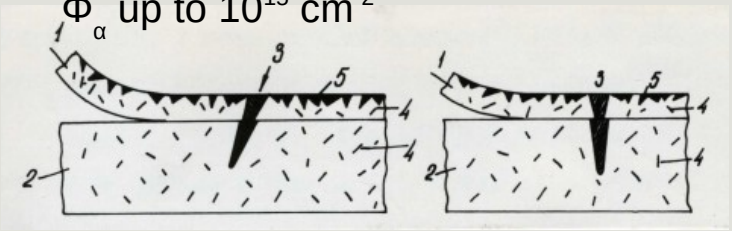
with permission of Yu.Ts. Oganessian

Cluster radioactivity

$^{223}Ra \rightarrow {}^{209}Pb + {}^{14}C$: $\lambda_{cl}/\lambda_{\alpha} \sim 10^{-10}$

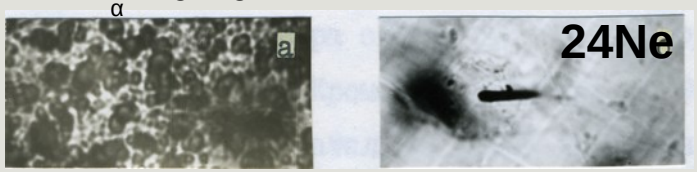
SSNTD:
Registration threshhold Z ≥ 6
Energy ~ 2MeV/u
Large area (up to 10^3 cm^2)
Step-by-step etching

Two-layer detector:
Φ_{α} up to 10^{15} cm^{-2}

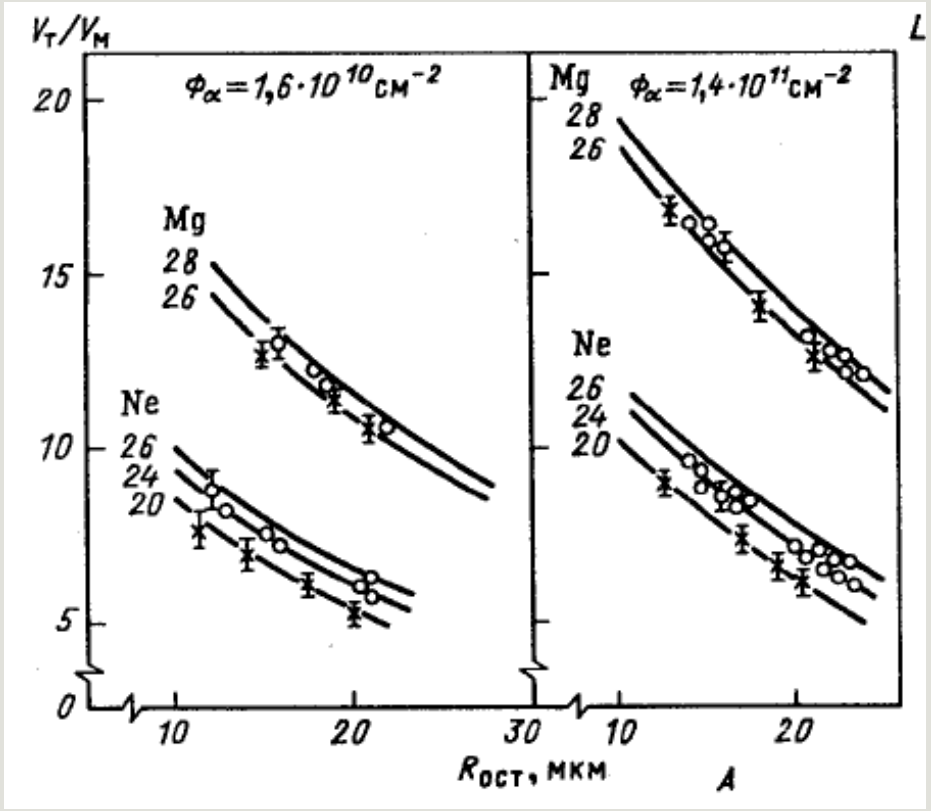


$\Phi_{\alpha}=10^{13}$ cm^{-2}

$^{231}Pa \rightarrow$

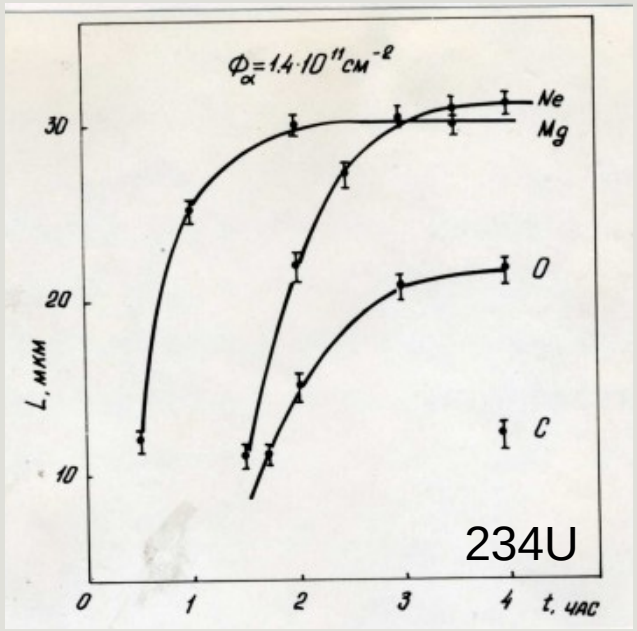


Zamyatnin et al PEPAN 21 (1990)



Cluster identification: calibration ○, exp: ^{234}U (x)

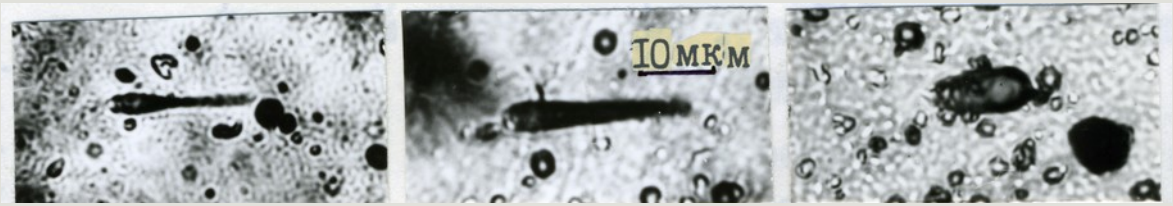
Cluster radioactivity



Zamyatnin et al PEPAN 21 (1990)

DUBNA:

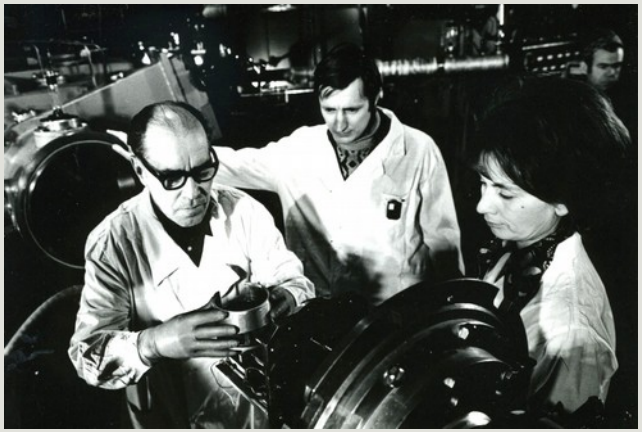
Nucl.	*Cluster*	$T_{1/2}$
^{231}Pa	^{24}Ne	$(8{,}6\pm1{,}6)\cdot10^{15}$ a
^{233}U	Ne	
^{234}U	^{24}Ne,	$(5{,}7\pm0{,}6)\cdot10^{17}$ a
	^{28}Mg	$(1{,}6\pm0{,}2)\cdot10^{18}$ a
^{235}U	Ne, Mg	
^{236}U	Ne, Mg	
^{236}Pu	^{28}Mg	$\sim1.5\cdot10^{14}$ a
^{237}Np	^{30}Mg	$> 5\cdot10^{19}$ a
^{241}Am	^{34}Si	$> 9\cdot10^{16}$ a

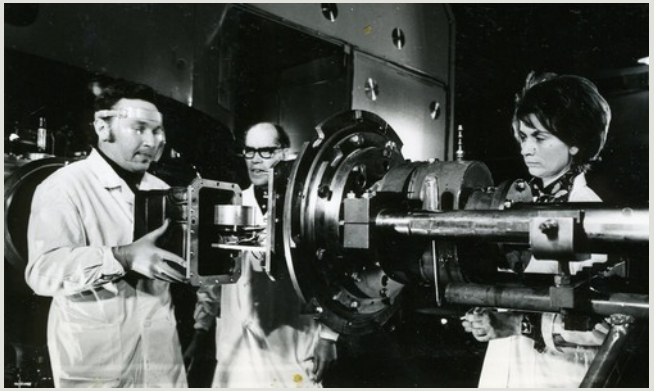


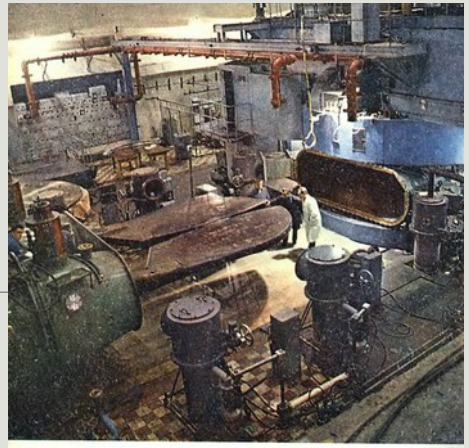
Ne **Mg** **ff**

2020: > **20 parent nuclei**
87 < Z <96; Z = 56
11 types of clusters
Z=6, 8, 9, 10, 12,14

Photos





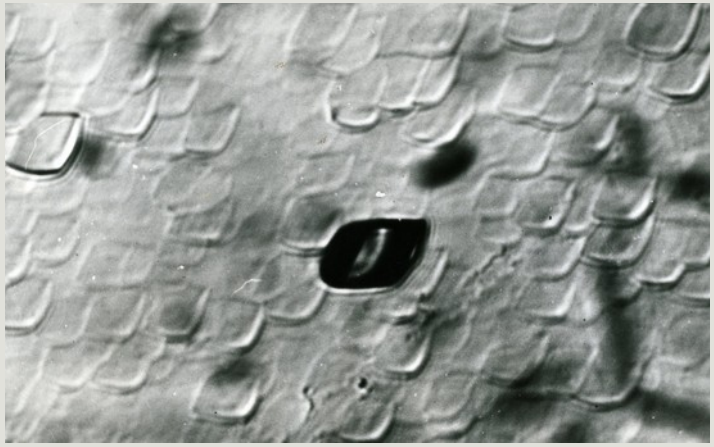


НАУКА И ЖИЗНЬ

2 1975

● Коломенский тепловозостроительный завод готовится к серийному выпуску самого мощного в СССР односекционного тепловоза ТЭП70. ● Современная животноводческая

ИЗДАТЕЛЬСТВО «ПРАВДА», МОСКВА



Thank you for your attention