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Synthesis and Study of Superheavy Elements

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Bottom lines:

In reactions $^{48}Ca + {}^{238}U, {}^{237}Np, {}^{242,244}Pu, {}^{243}Am, {}^{245,248}Cm, {}^{249}Bk$ and ^{249}Cf:

- **Isotopes $^{282-286}113, {}^{286-289}114, {}^{287-290}115, {}^{290-293}116, {}^{293,294}117$ and $^{294}118$ of 6 superheavy elements have been synthesized,**

- **Heavy isotopes of known elements $^{267}Rf, {}^{266-268,270}Db, {}^{266,271}Sg, {}^{270-272,274}Bh, {}^{270,275}Hs, {}^{274-276,278}Mt, {}^{279,281}Ds, {}^{278-282}Rg$ and $^{282-285}Cn$ have been synthesized,**

- **First chemical experiments with elements 112 and 114 have been conducted.**

Flerov Laboratory of Nuclear Reactions

BASIC DIRECTIONS of RESEARCH

1. Heavy and superheavy nuclei

- Synthesis and study of properties of superheavy elements
- Chemistry of new elements
- Fusion-fission and multi-nucleon transfer reactions
- Mass-spectrometry and nuclear spectroscopy of SH nuclei

2. Light exotic nuclei

- Properties and structure of light exotic nuclei
- Reactions with exotic nuclei

3. Radiation effects and physical bases of nanotechnology

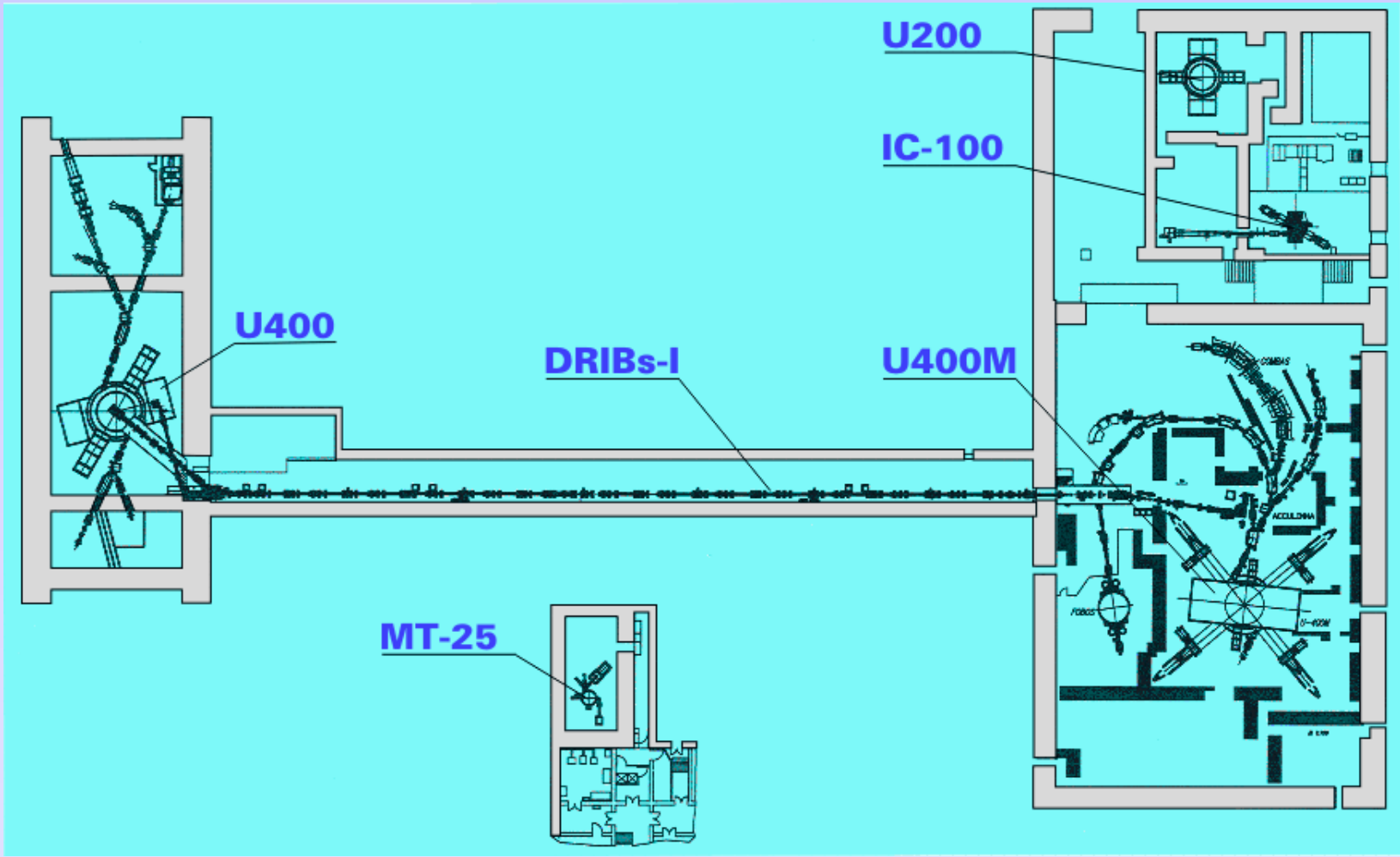
4. Accelerator technology

Staff : **350 people (including 100 younger than 35 years old)**

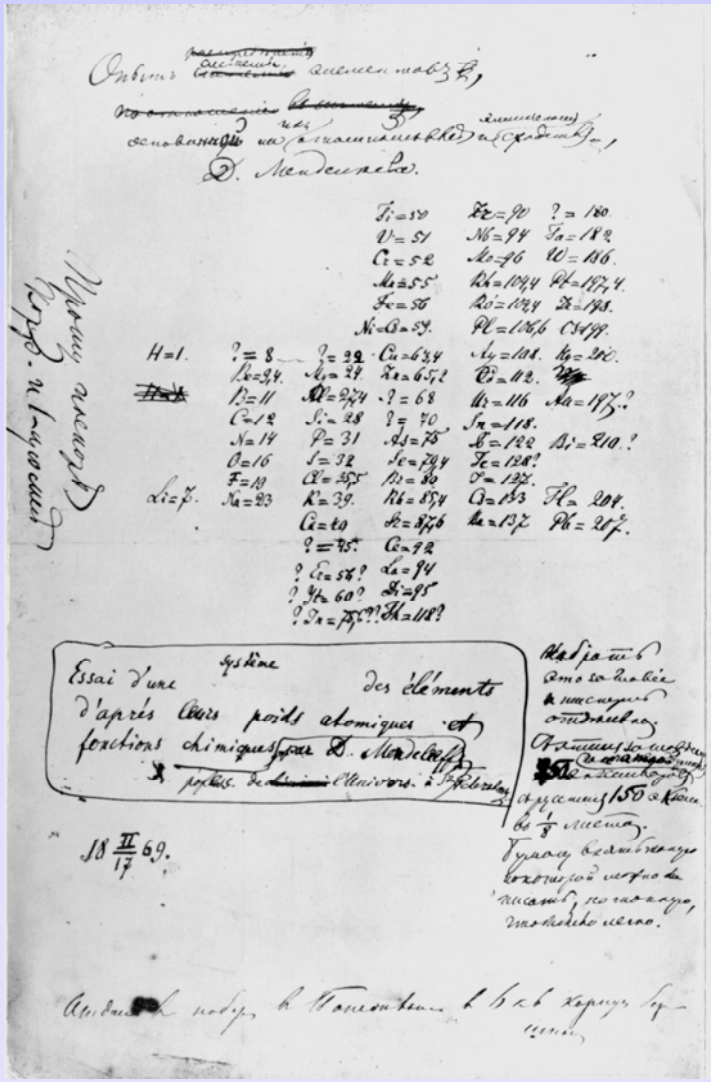
Budget: **~ 15.0 M$**

Out of budget staff: **140 people**

FLNR accelerators



Periodic table of the elements
Dmitri Mendeleev (1869)

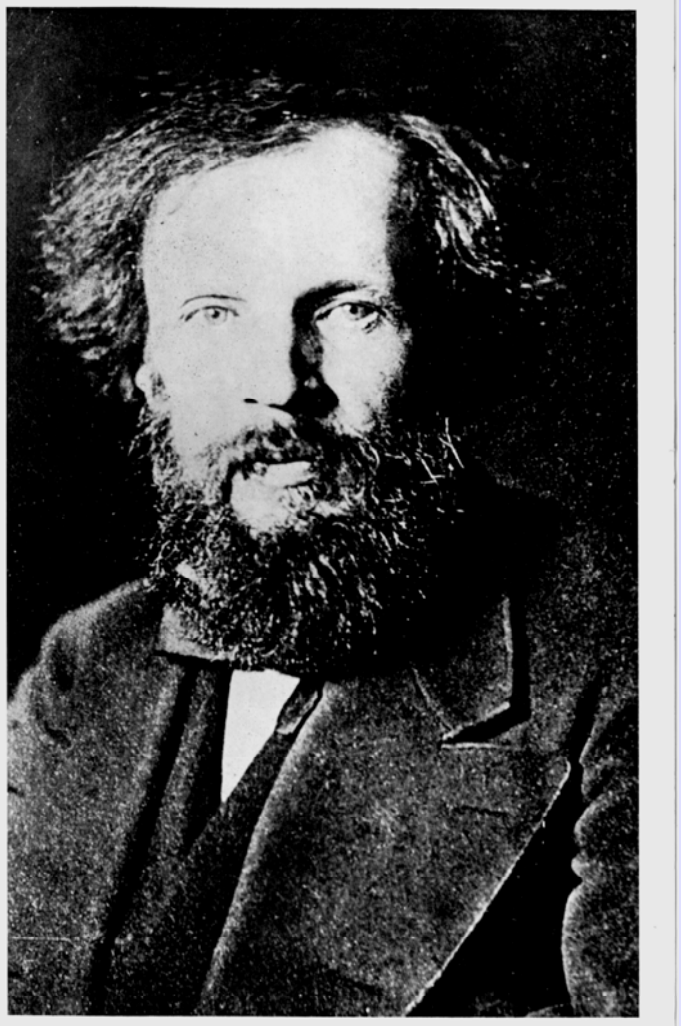


Опыт системы элементов, основанной на их атомном весе и химическом сходстве.
Д. Менделеева.

			Ti=50	Zr=90	?=180.	
			V=51	Nb=94	Ta=182.	
			Cr=52	Mo=96	W=186.	
			Mn=55	Rh=104,4	Pt=197,4.	
			Fe=56	Ru=104,4	Ir=198.	
			Ni=Co=59.	Pl=106,6	Os=199.	
H=1.		?=8	?=22	Cu=63,4	Ag=108.	Hg=200.
		Be=9,4	Mg=24	Zn=65,2	Cd=112.	
		B=11	Al=27,4	?=68	Ur=116	Au=197?.
		C=12	Si=28	?=70	Sn=118.	
		N=14	P=31	As=75	Sb=122	Bi=210?.
		O=16	S=32	Se=79,4	Te=128?	
		F=19	Cl=35,5	Br=80	J=127.	
Li=7.		Na=23	K=39.	Rb=85,4	Cs=133	Tl=204.
			Ca=40	Sr=87,6	Ba=137	Pb=207.
			?=45.	Ce=92		
			?Er=56?	La=94		
			?Yt=60?	Di=95		
			?In=75,6?	Th=118?		

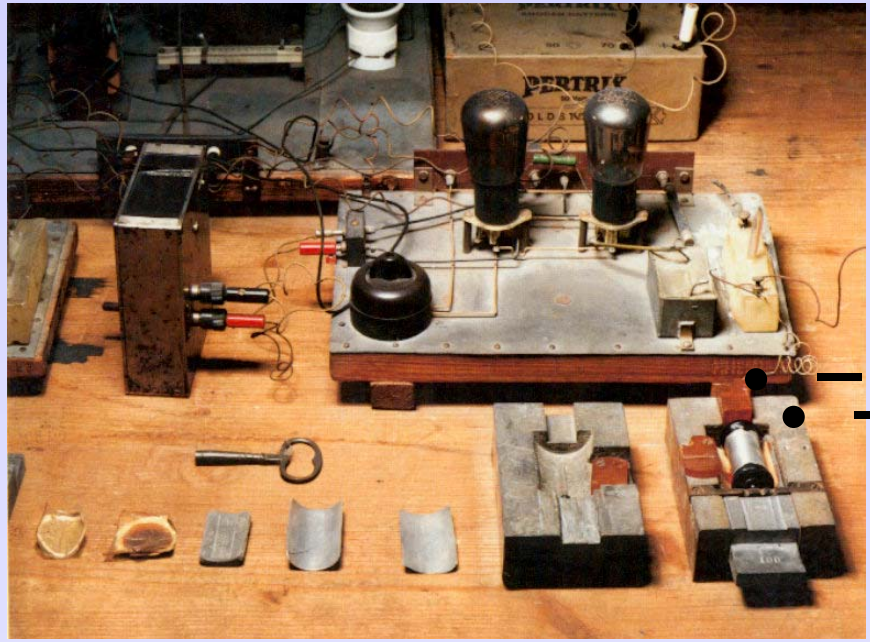
Essai d'une système des éléments d'après leurs poids atomiques et fonctions chimiques par D. Mendeleeff

18 II/17 69.



1934: search for transurane

$$^{238}_{92}U + n \rightarrow {}^{239}_{92}U^{*} \rightarrow {}^{239}_{93}Nn + e^{-} + \bar{\nu}$$

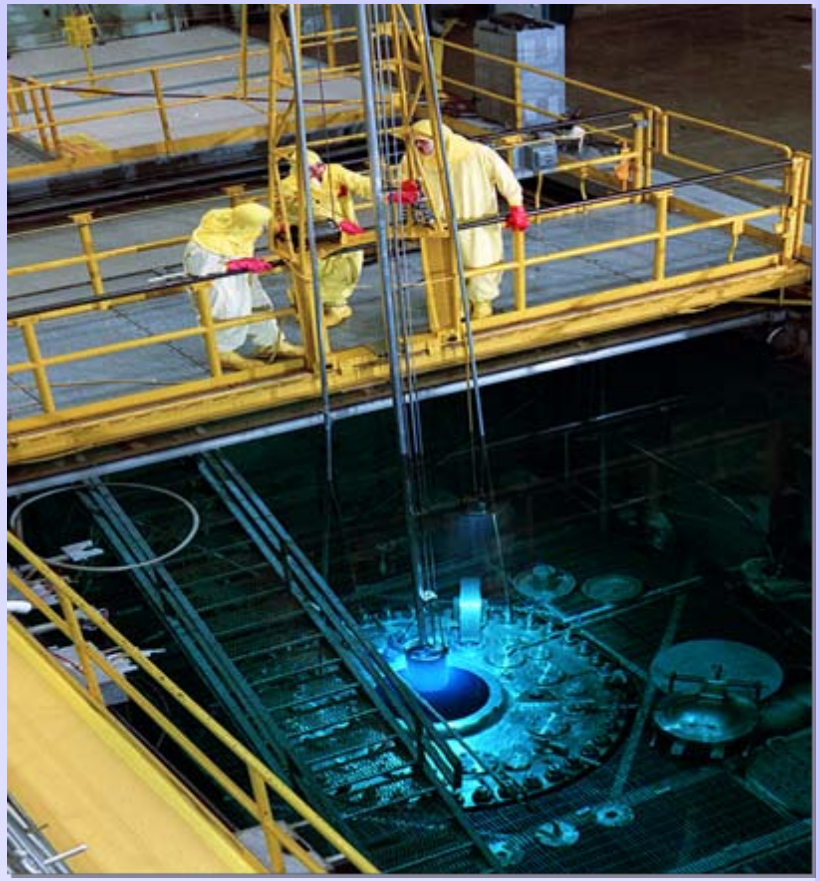


Otto Hahn und Lise Meitner

Irradiation of targets at HFIR reactor (Oak Ridge)

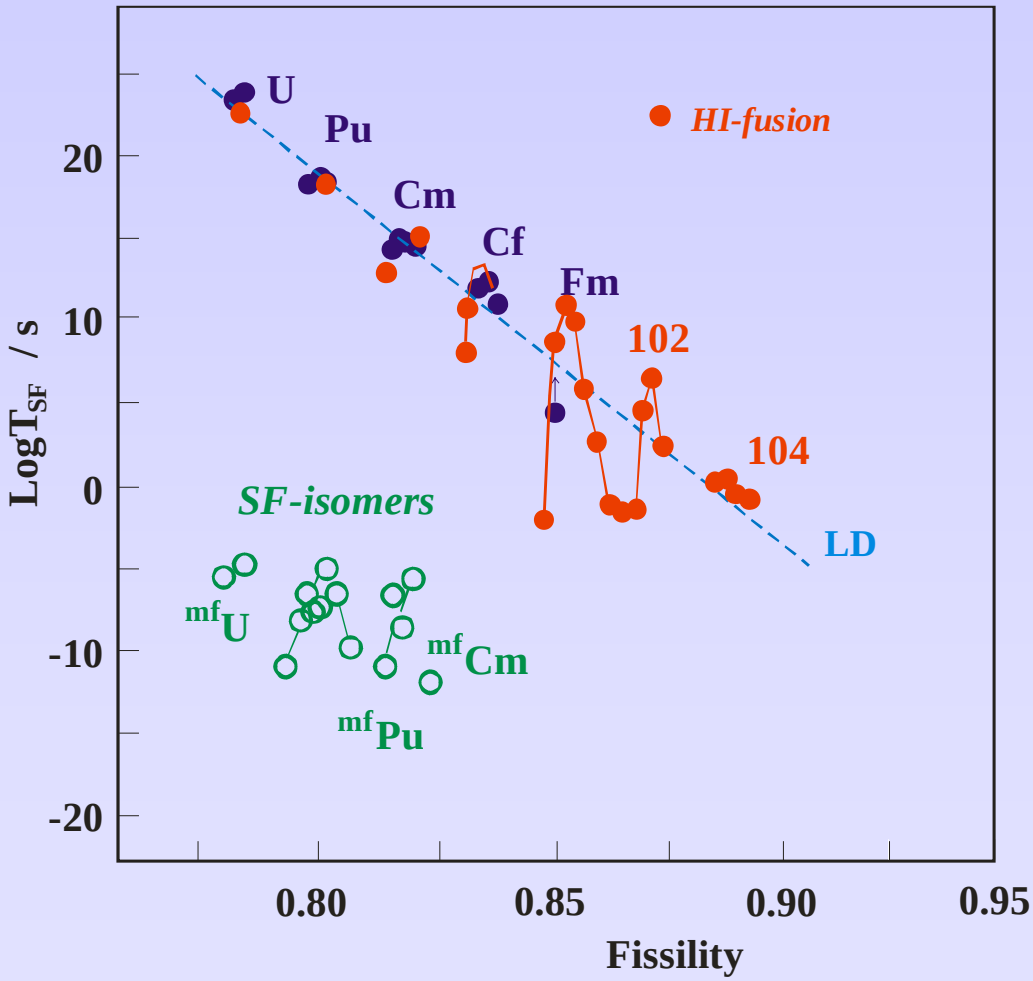
$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \xrightarrow[23.5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2.3565\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

$$^{239}_{94}\mathrm{Pu} \xrightarrow{(\mathrm{n},\gamma)} {}^{240}_{94}\mathrm{Pu} \xrightarrow{(\mathrm{n},\gamma)} {}^{241}_{94}\mathrm{Pu} \xrightarrow[14{,}35\ \mathrm{a}]{\beta^-} {}^{241}_{95}\mathrm{Am} \left(\xrightarrow[432{,}2\ \mathrm{a}]{\alpha} {}^{237}_{93}\mathrm{Np} \right)$$



- **Irradiation in the HFIR flux trap**
  - **Thermal-neutron flux of 2.5×10^{15} neutrons/cm^2·s**
  - **31 target positions (10–13 targets typically irradiated)**
  - **Produces ~35 mg ^{252}Cf per target (smaller quantities of Bk, Es, Fm, others)**

Spontaneous fission half-lives of actinides



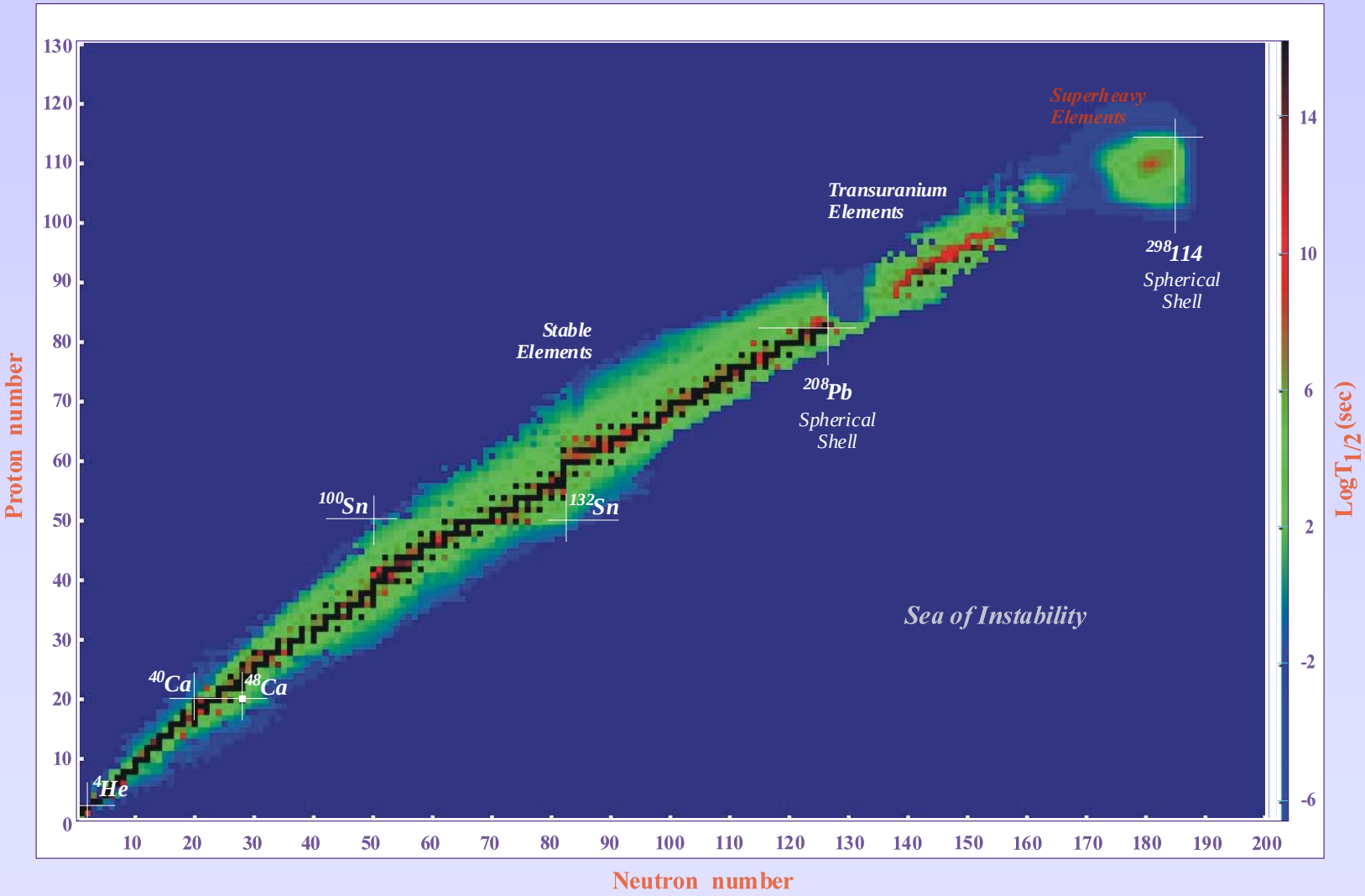
Prehistory

- **1966: A. Sobiczewski, F.A. Gareev, B.N. Kalinkin: next “magic numbers” are Z=114, N=184;**
- **1966: W.D. Myers, W.J. Swiatecki: next “magic numbers” are Z=126, N=184**
- **1966: V.M. Strutinsky; “shell correction” method**
- **1967: H.B. Meldner: next “magic numbers” are Z=114, N=184**

Accuracy of predictions:

- **Spontaneous fission half-life: $T_{1/2} * 10^{\pm 10}$!!**
- **α-decay: $T_{1/2} * 10^{\pm 10}$!!**

Chart of the Nuclides



Search for SHE in Nature

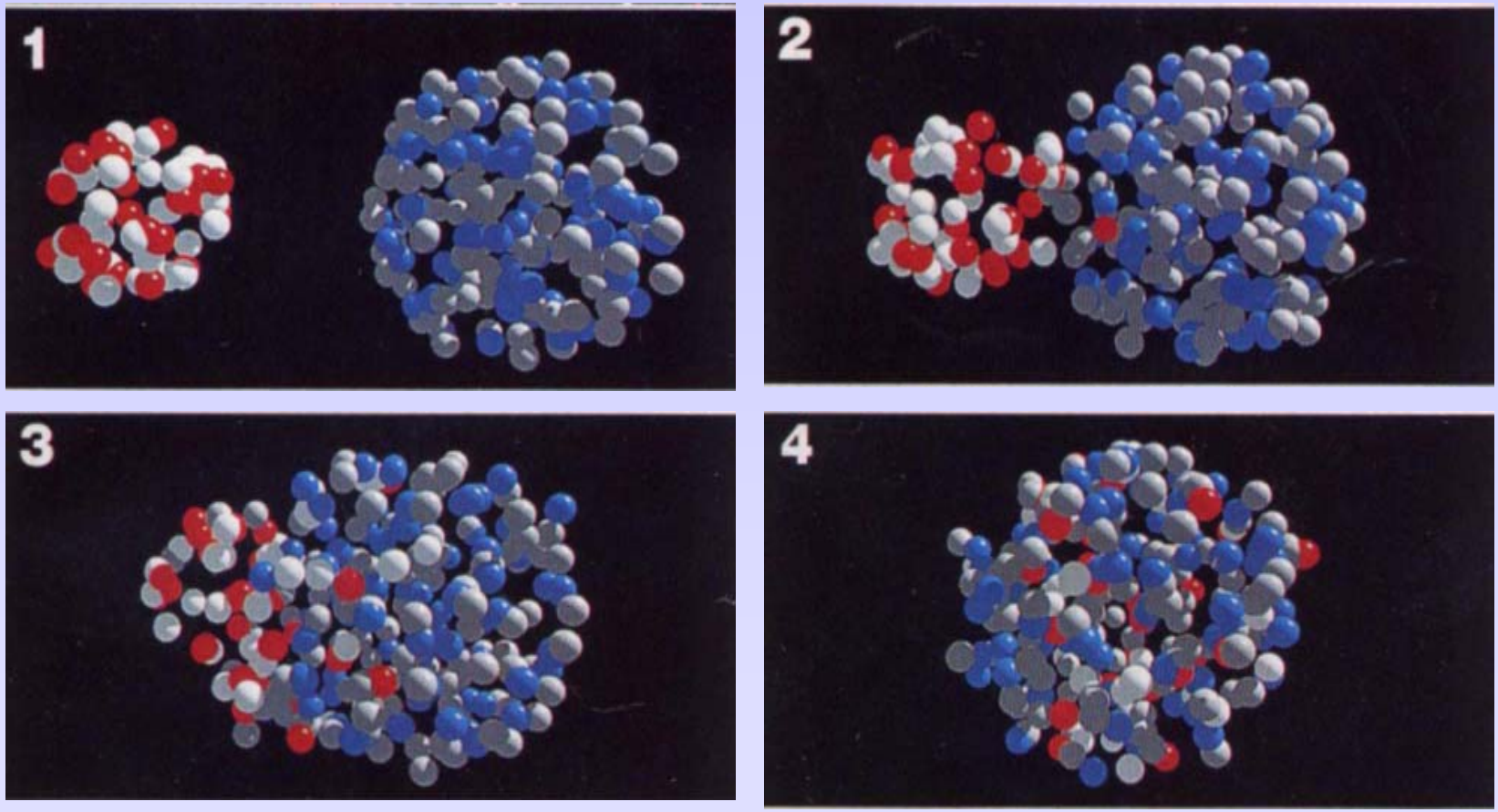
- **Search for SHE in terrestrial matter**
- **Search for SHE in meteorites**
- **Search for SHE in cosmic rays**
- **Investigation of isotopic anomalies**

20 years → void result,

but many new high sensitive detection methods were developed

Complete Fusion U+N→Es

instead of U+14n→7β→Es



Problems: crossection from 100 b → 1 pb, amount from 1000 kg → 1 mg

Synthesis of SHE at accelerators

- 1971; Orsay, France; $^{232}Th + {}^{82}Kr \rightarrow {}^{310}126 + 4n$; $\sigma_{4n} < 0.5$ mb !!!
- 1971-1975; Dubna, SU; deep inelastic or fission reactions of ^{76}Ge, $^{136}Xe + {}^{238}U$
- 1975; Dubna, SU; ^{48}Ca + actinides

Cross-section limits for ^{48}Ca-induced reactions

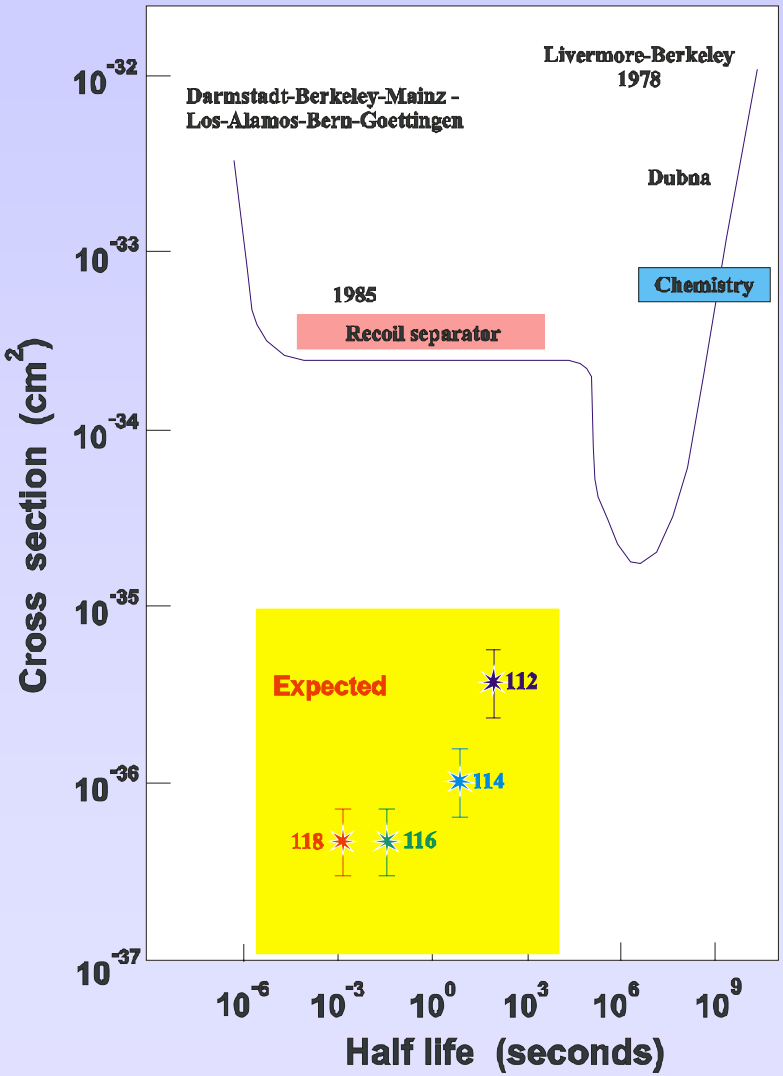
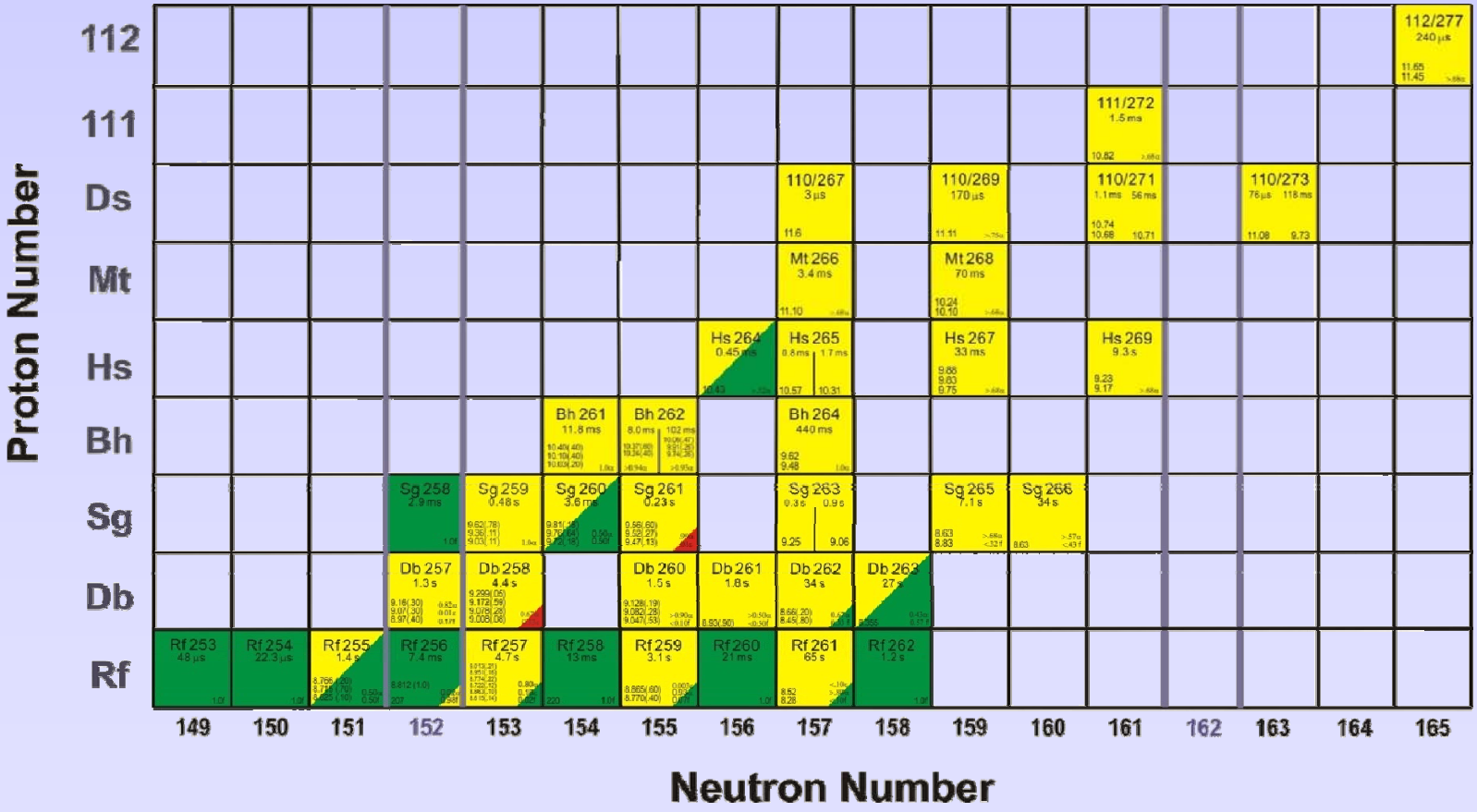
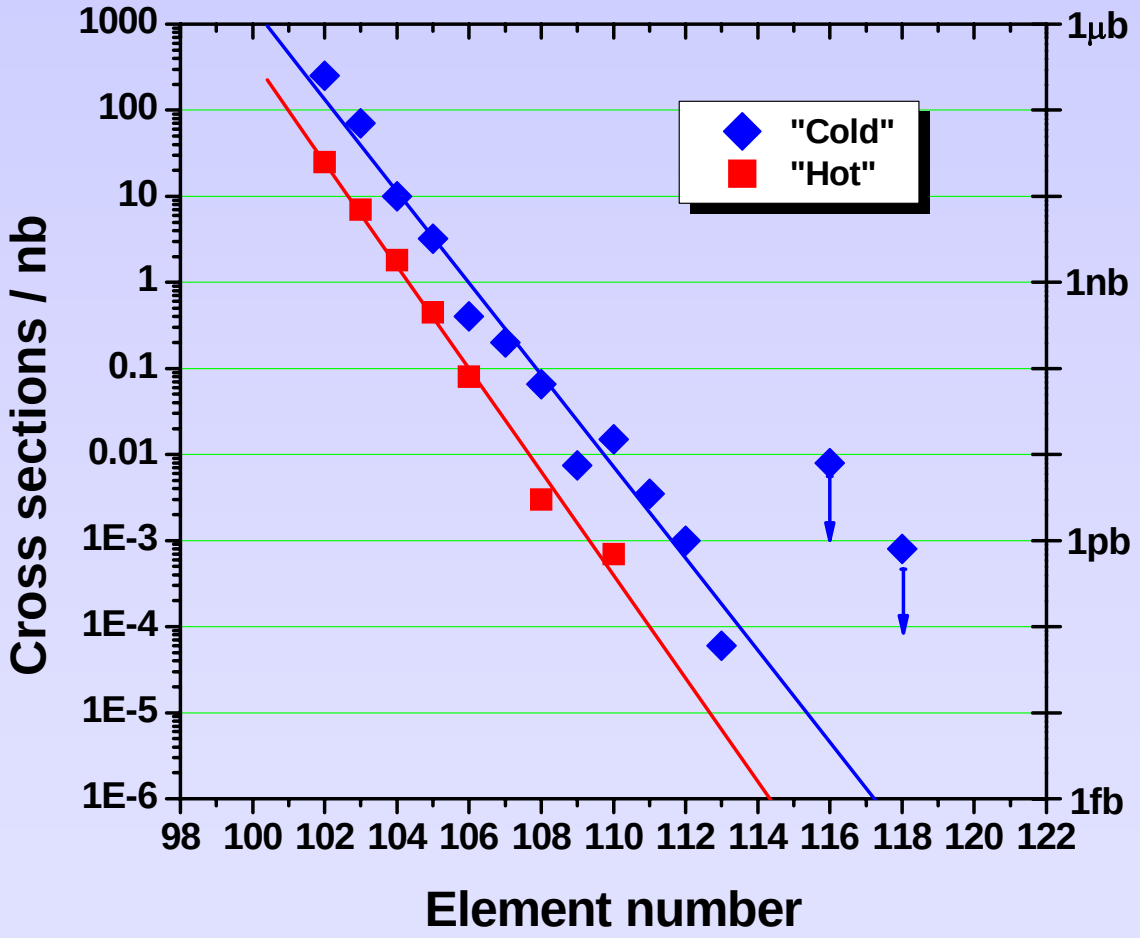


Chart of transactinide nuclides 1996



Cross-sections of “Hot” (actinide targets) and “Cold” (Pb or Bi targets) fusion reactions



→100 1/h

→1 /10d

→1 /20y

“Warm” (^{48}Ca + actinide targets) complete fusion reactions

Efforts focused on the synthesis of SHE

New ECR-ion source
(GANIL, JINR)

ACCELERATORS

^{48}Ca

Enrichment up to 68-70%
(Lesnoy)

ISOTOPE ENRICHMENT

beam intensity - $4 - 8 \cdot 10^{12}$/s

beam time - 4000 h/y

TARGET TECHNOLOGY

Isotopes:
U[233, 238], Pu[242, 244], Am[243], Cm[245, 248], Cf[249] + ^{48}Ca → Z = 112 - 118

technology of the target preparation – 0.3 mg/cm^2

Separation and detection of superheavy nuclei

Gas-filled separator & detectors
(Dubna, Livermore)

isotope enrichment 98-99%
S-2 separator
(Sarov)

isotope production
high flux reactors
(Oak Ridge, Dimitrovgrad)

REACTOR REGIME

Prices per 1 mg

$^{197}Au \approx 0.03$ US$

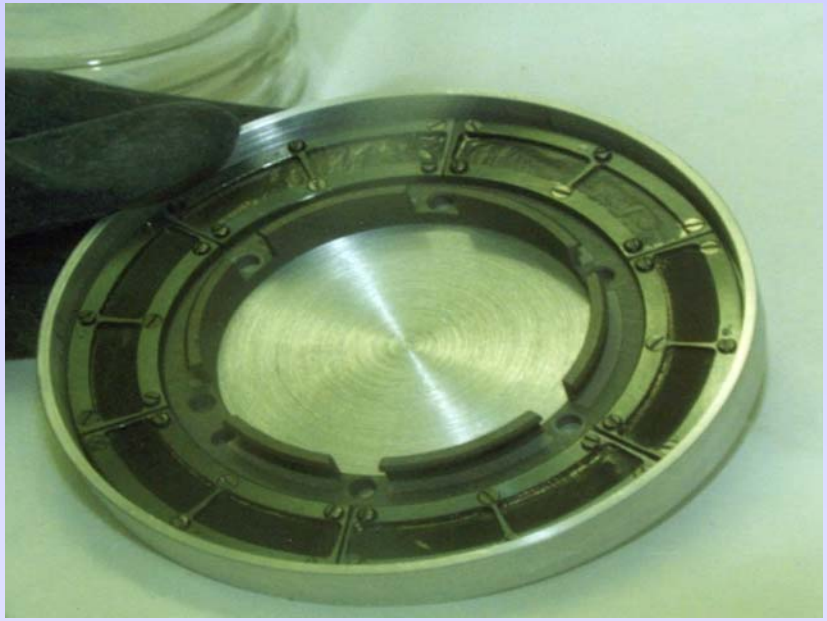
$^{239}Pu \approx 4$ US$

$^{48}Ca \approx 80$ US$

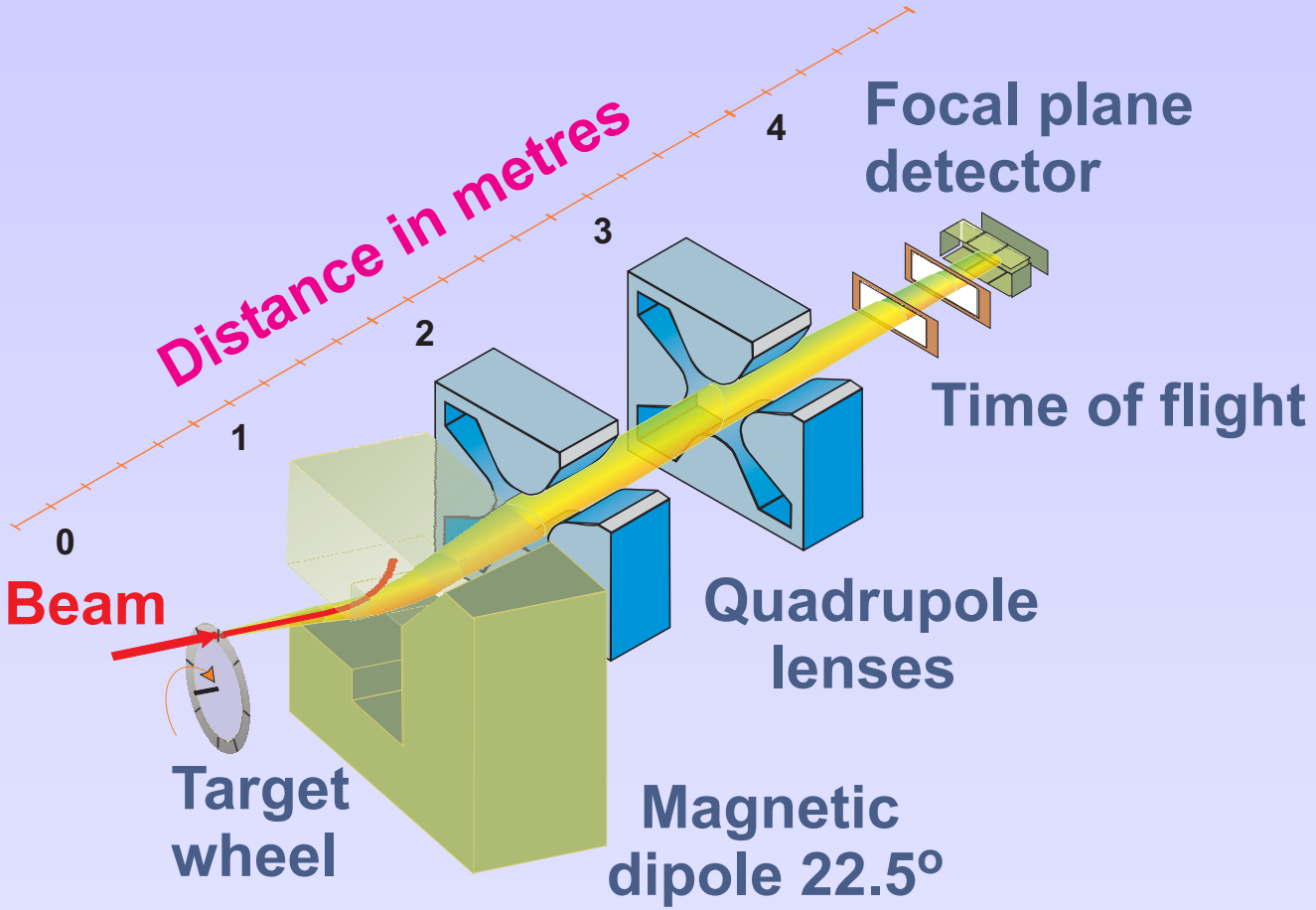
$^{249}Cf \approx 60{,}000$ US$

FLNR U400 cyclotron

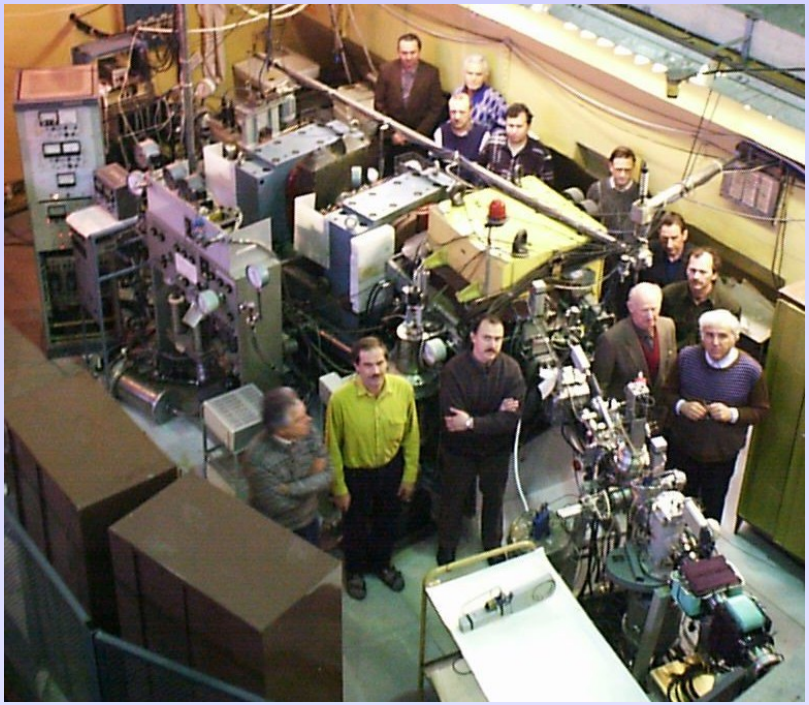
^{249}Cf - target

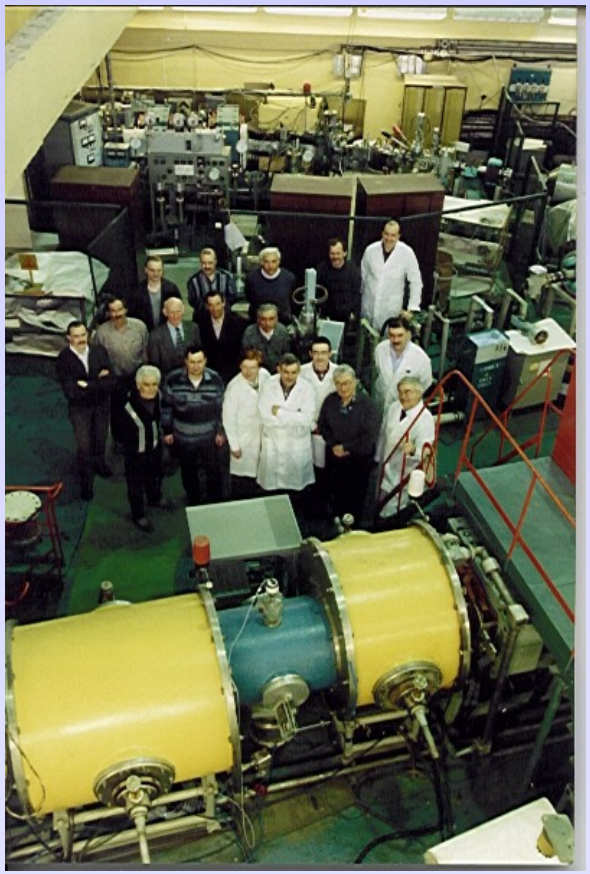


Dubna Gas Filled Recoil Separator



Research groups at DGFRS and VASSILISSA



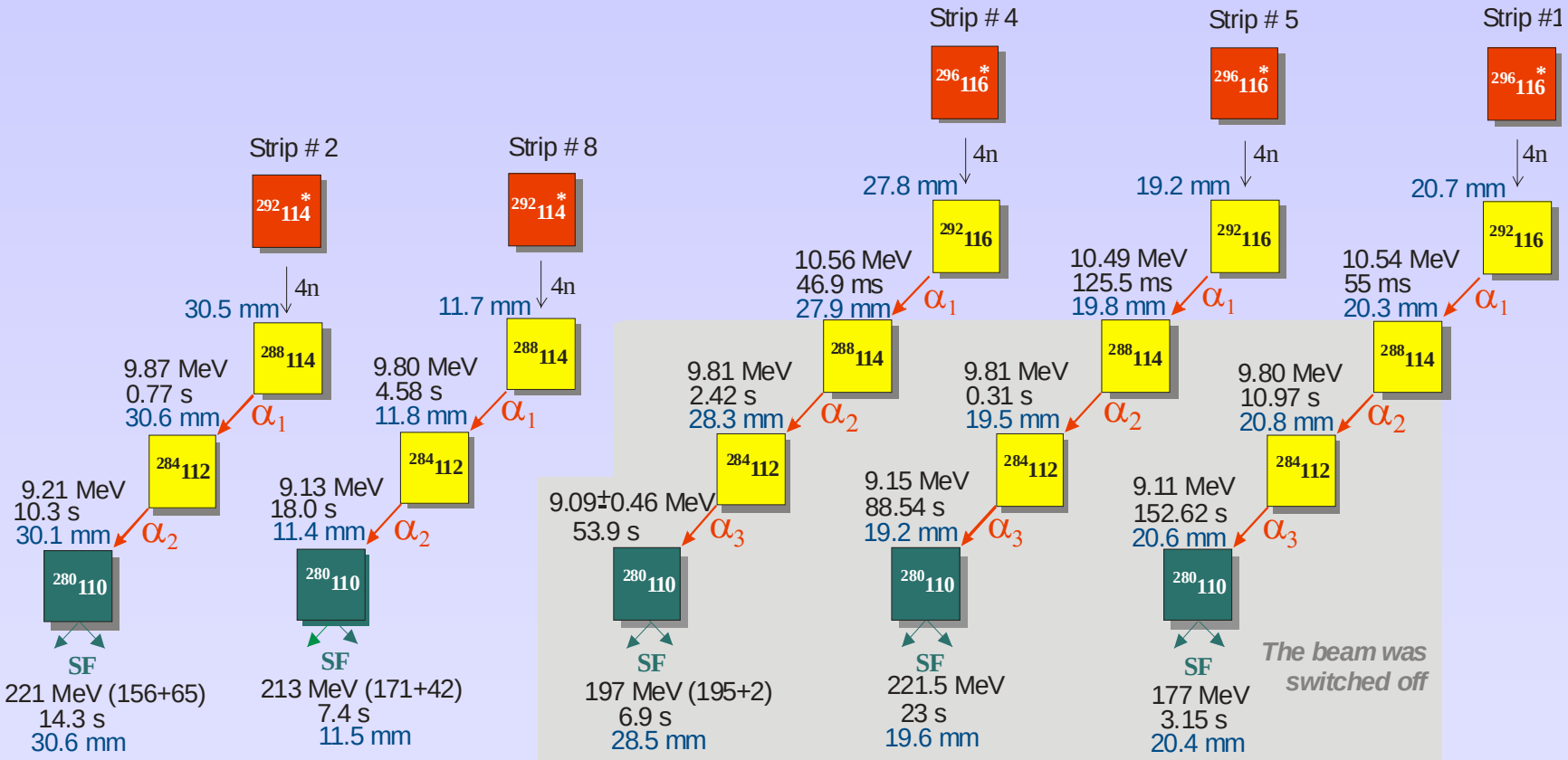


$^{244}Pu + {}^{48}Ca \rightarrow {}^{292}114^*$

Total beam dose: $1.5 \cdot 10^{19}$

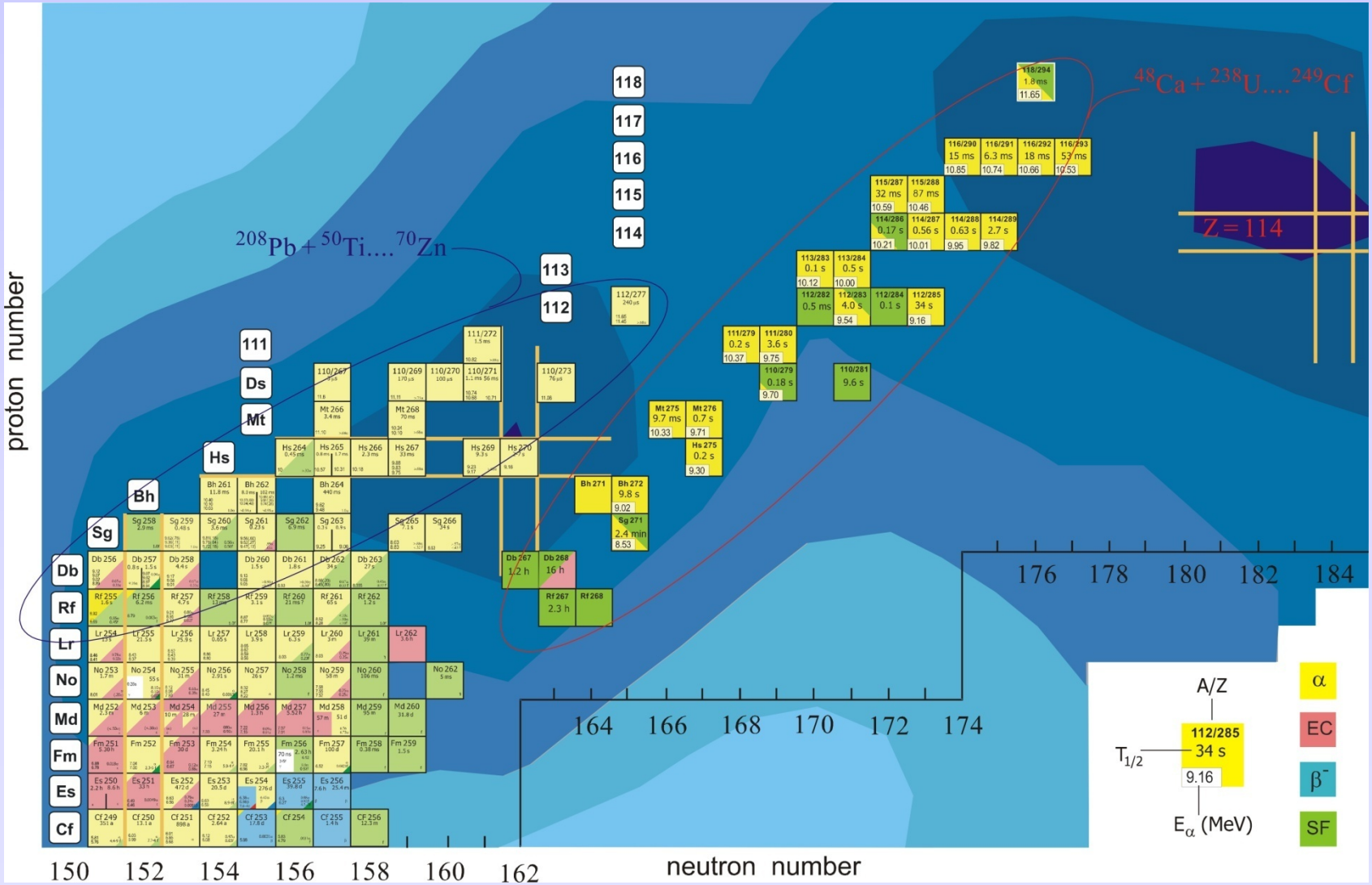
$^{248}Cm + {}^{48}Ca \rightarrow {}^{296}116^*$

Total beam dose: $2.3 \cdot 10^{19}$



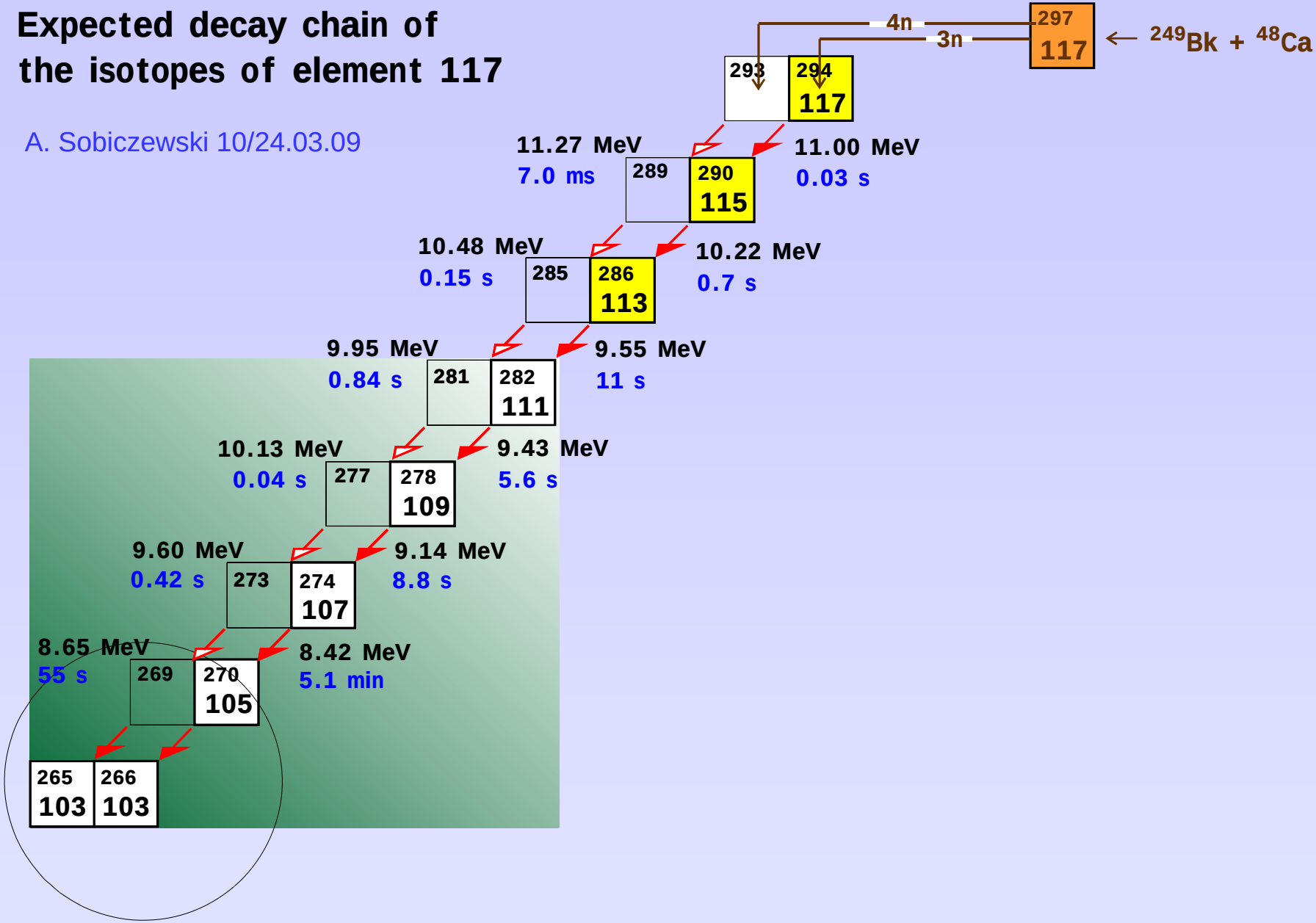
June 25, 1999 05:39 *Oct. 28, 1999 22:24* *July 19, 2000 01:21* *May 02, 2001 06:21* *May 08, 2001 16:54*

Chart of the nuclides 2006



Expected decay chain of the isotopes of element 117

A. Sobiczewski 10/24.03.09



22 mg of ^{249}Bk have been produced with neutrons of HIFR ORNL

$Bk(NO_3)_3$Product

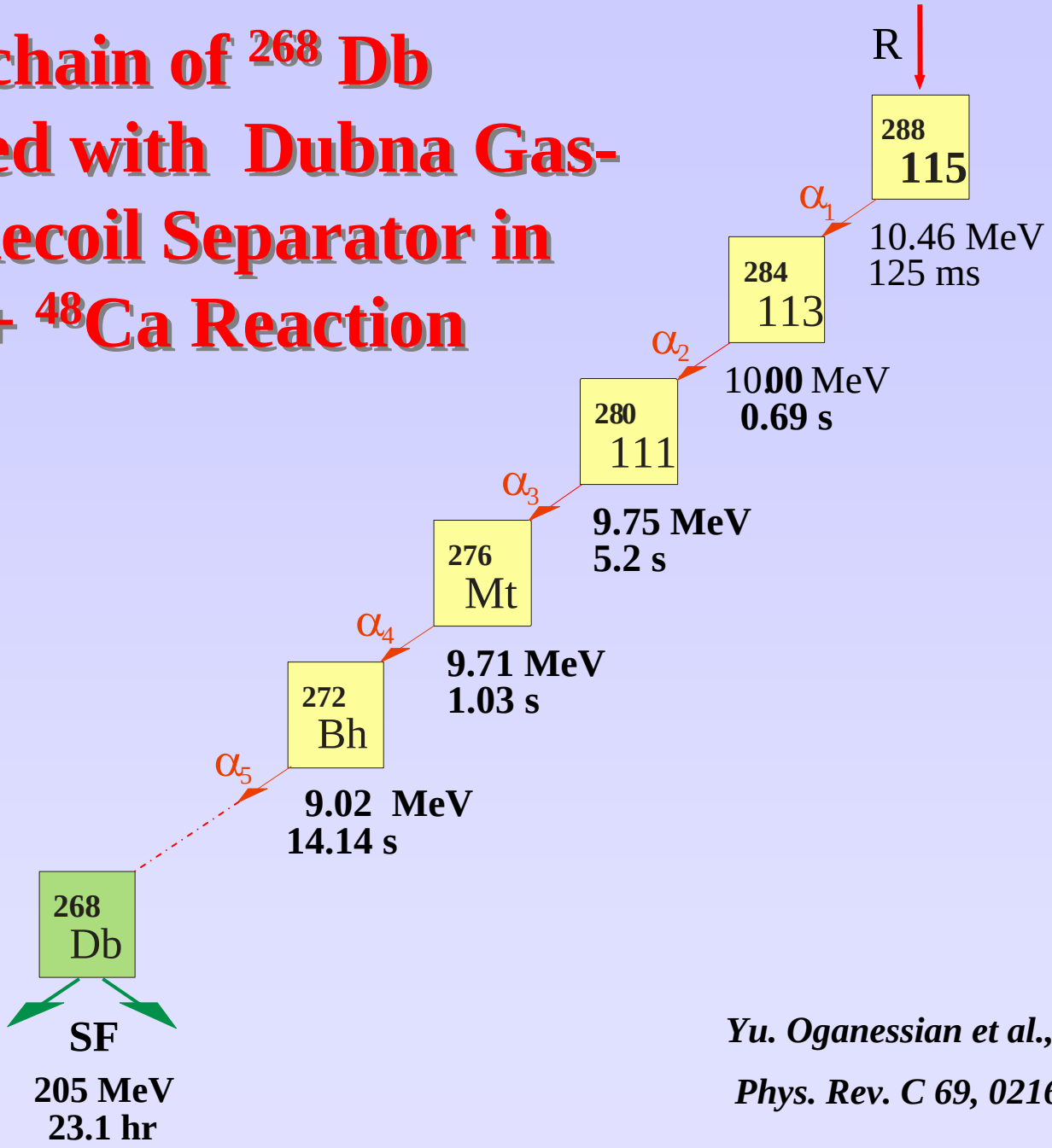
22 mg ^{249}Bk transport

Since July 2009:

Run #	E*	∫ - flux	N_{events}
1	39 MeV	2.4×10^{19}	**Will be published soon**
2	35 MeV	2.0×10^{19}	

Experiment is still going on…

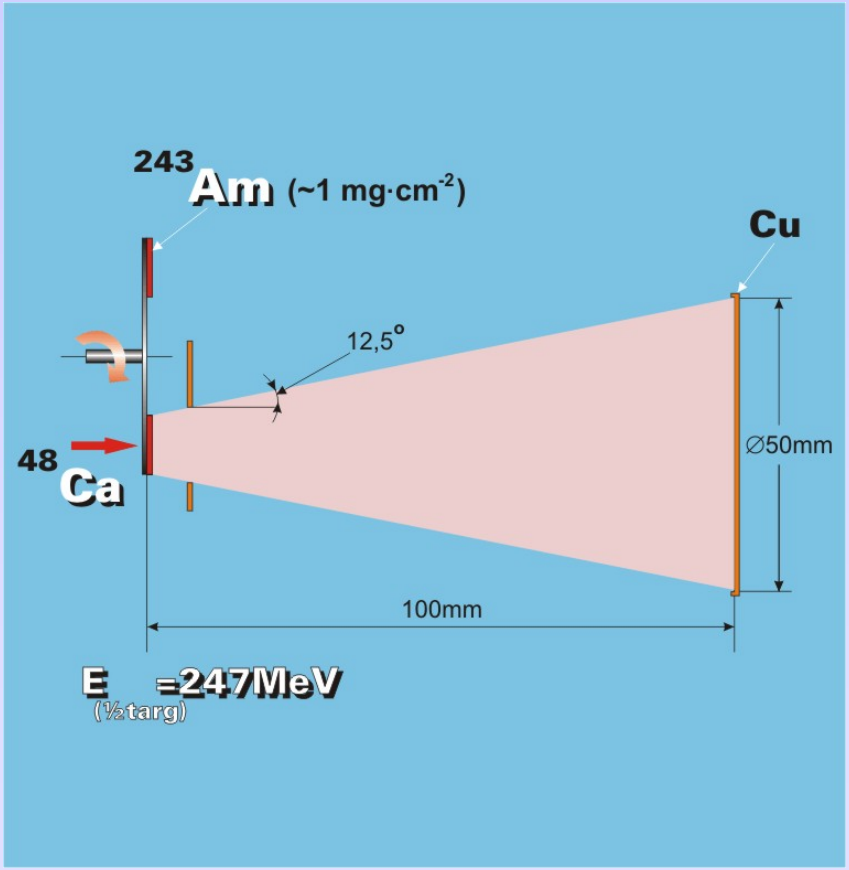
Decay chain of ^{268}Db observed with Dubna Gas-filled Recoil Separator in ^{243}Am + ^{48}Ca Reaction



Yu. Oganessian et al.,

Phys. Rev. C 69, 021601(R) 2004

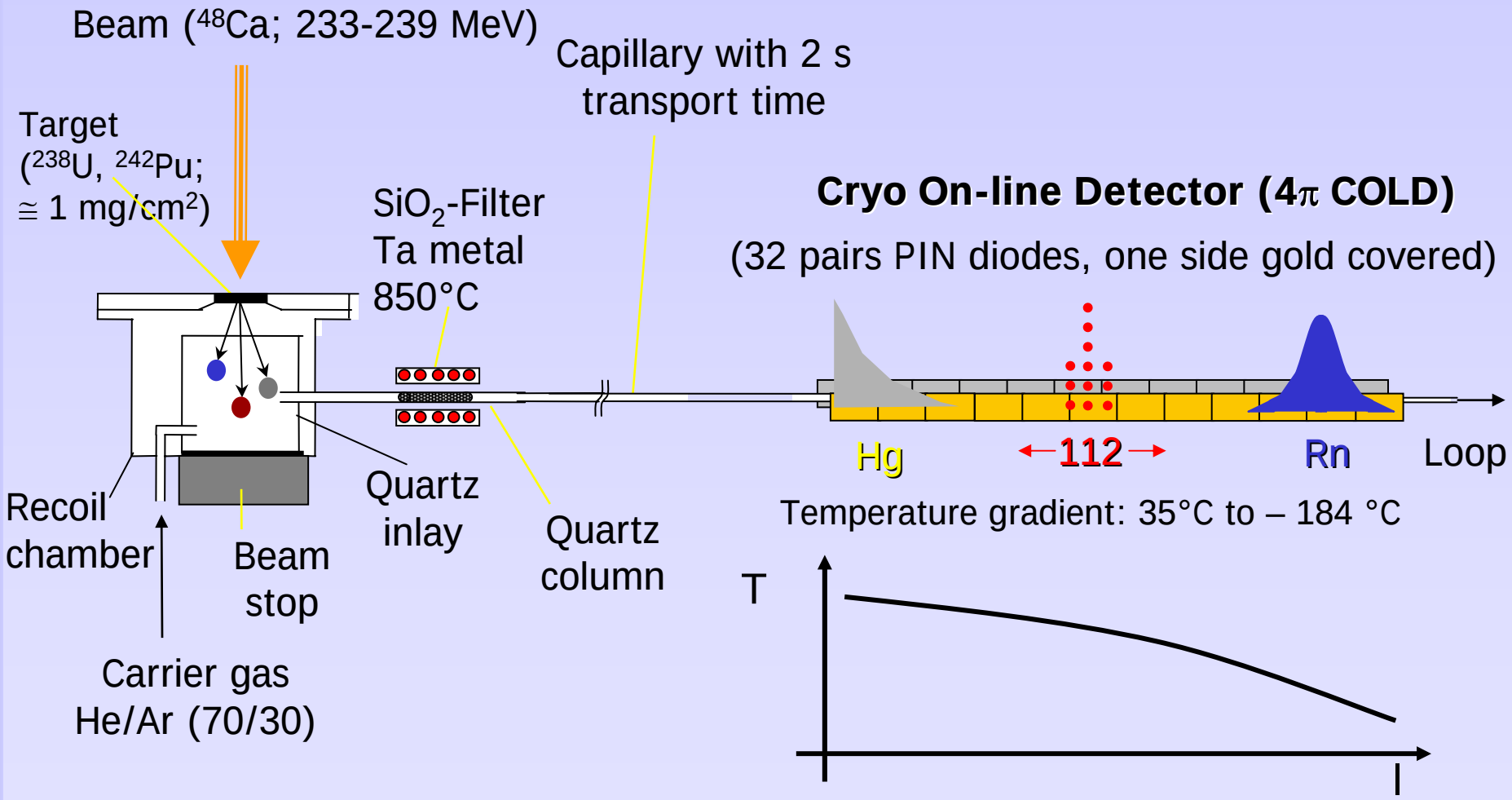
Irradiation of ^{243}Am-target with ^{48}Ca-ions



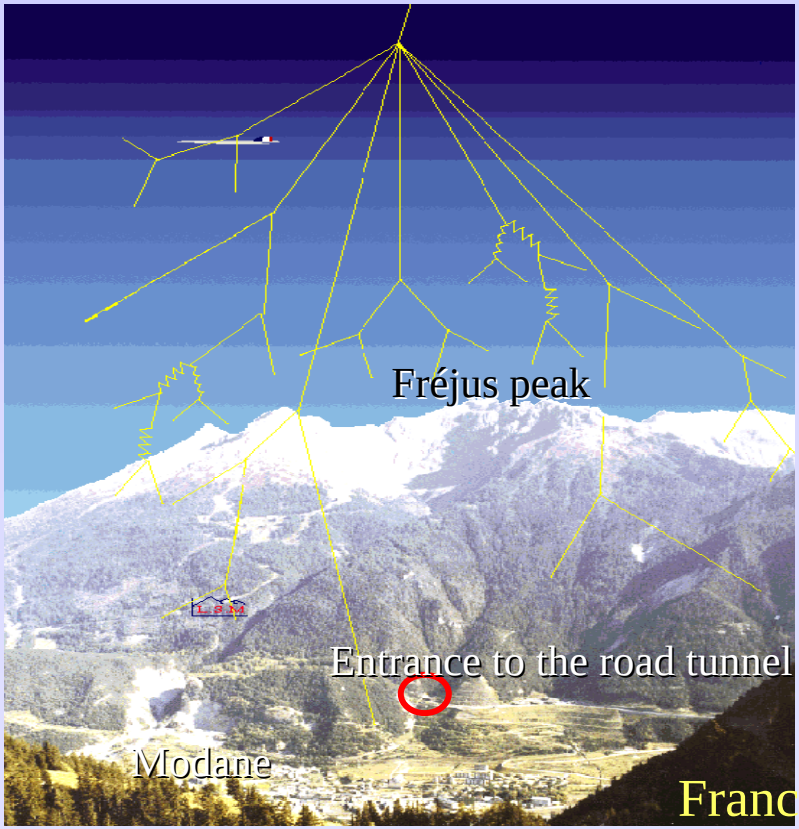
GAS PHASE CHEMISTRY WITH ELEMENTS 112 AND 114

- **Are elements 112 and 114 volatile metals?**
- **How do relativistic effects influence the chemistry of E112 and of E114?**

Chemistry of the elements 112 & 114

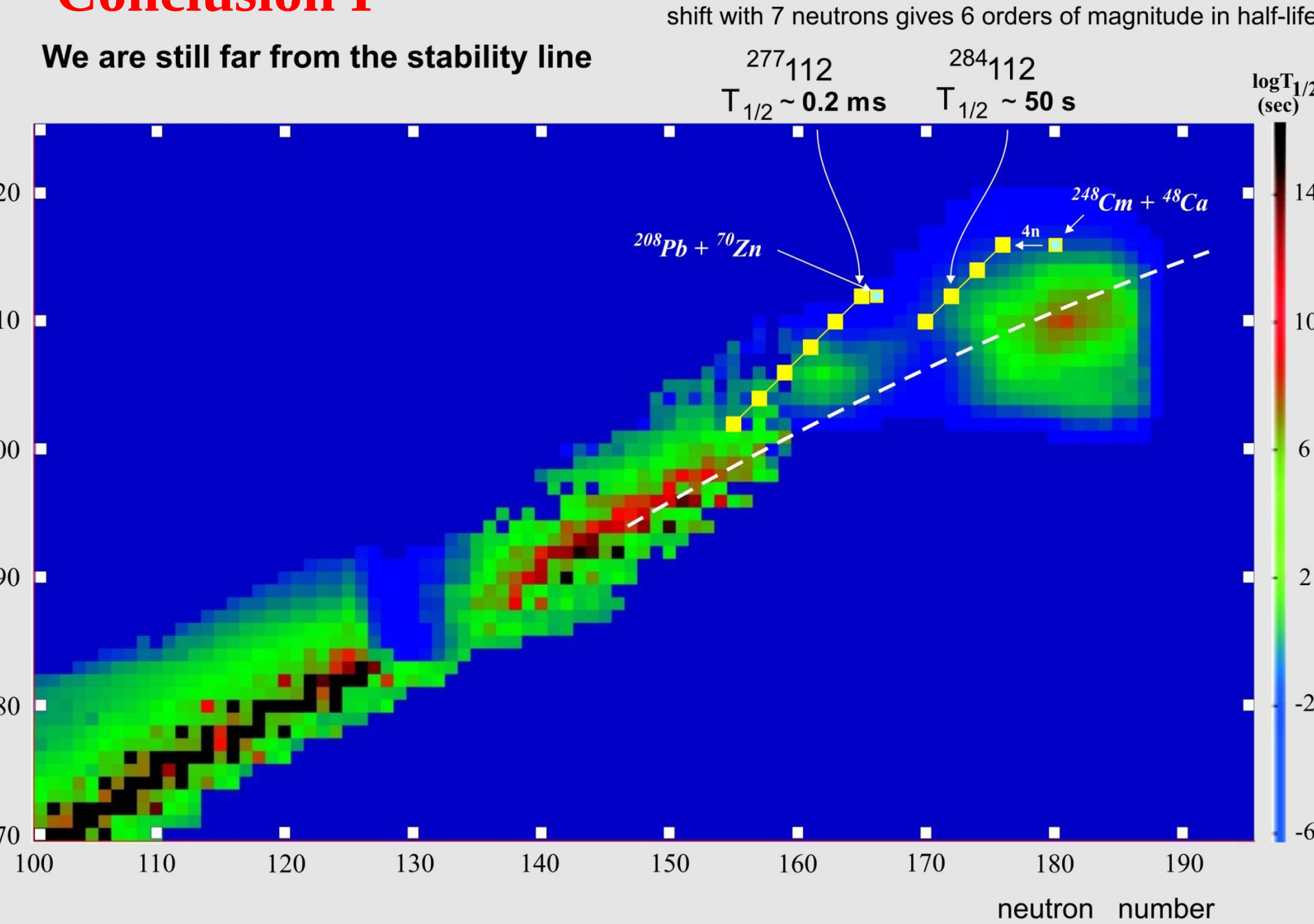


Detector installed in Modana (France)

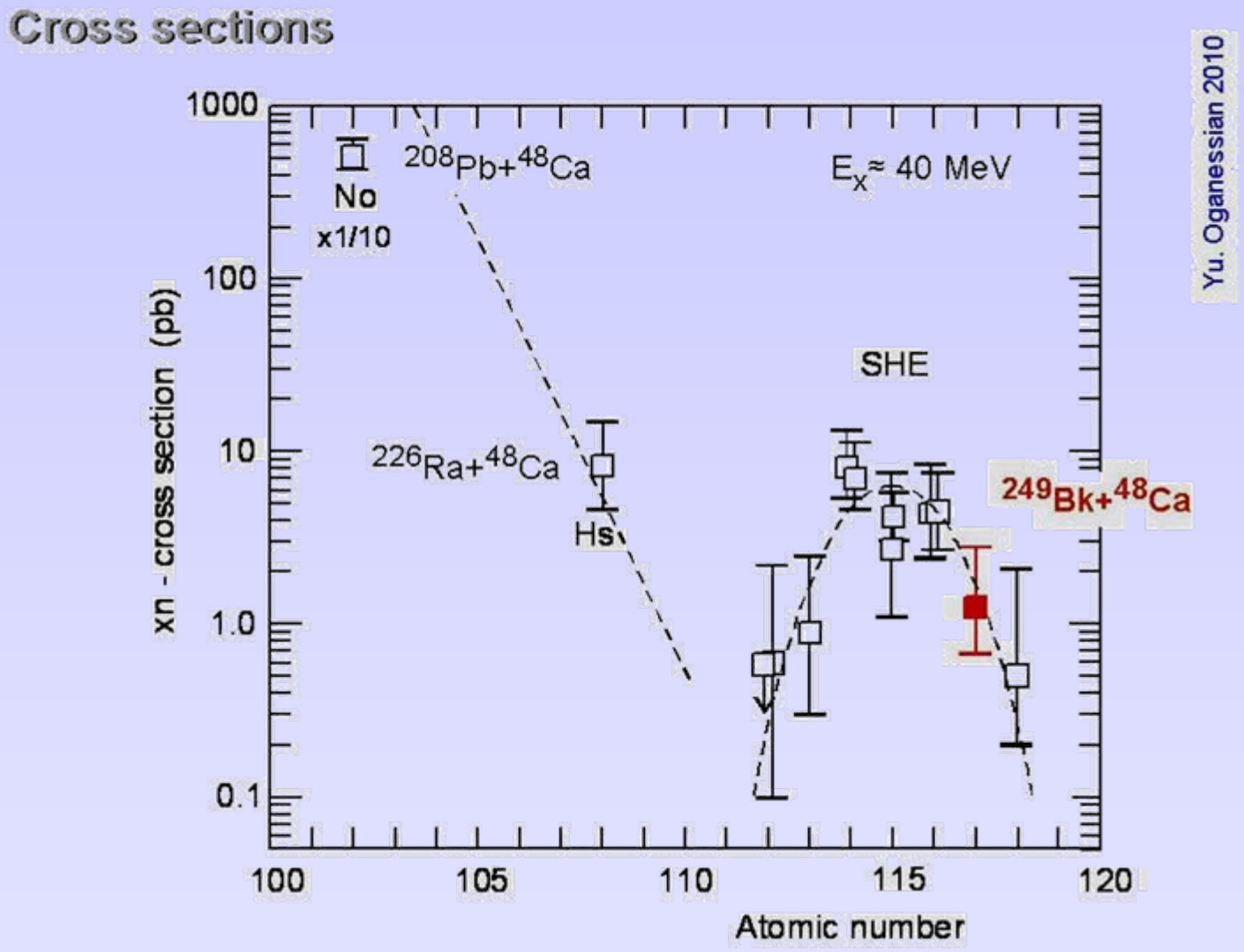


Conclusion I

We are still far from the stability line



Conclusion II



Conclusion III

- **Heaviest target: $^{249}Cf \rightarrow Z_{max} = 118$;**
- **Projectiles: ^{54}Cr, ^{50}Ti, ^{58}Fe, ^{64}Ni;**
- **symmetric reactions: $^{136}Xe + ^{150}Nd$;**
- **RIB: ^{132}Sn.**

$^{238}U + {}^{64}Ni$ GSI 2008

$^{244}Pu + {}^{58}Fe$ FLNR 2007

$^{248}Cm + {}^{54}Cr$ GSI 2010

$^{252}Cf + {}^{50}Ti$???????

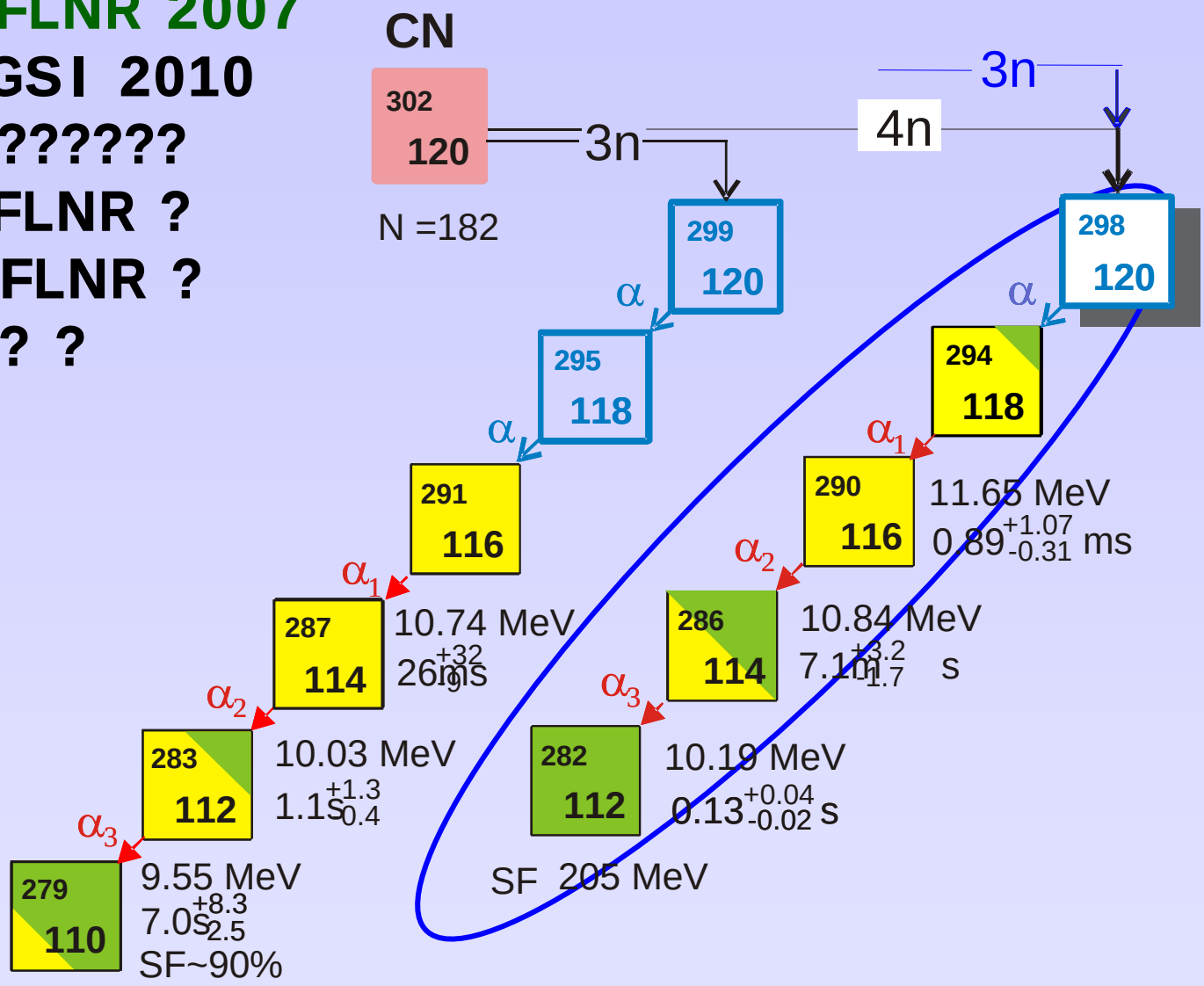
$^{251}Cf + {}^{50}Ti$ FLNR ?

$^{251}Cf + {}^{48}Ca$ FLNR ?

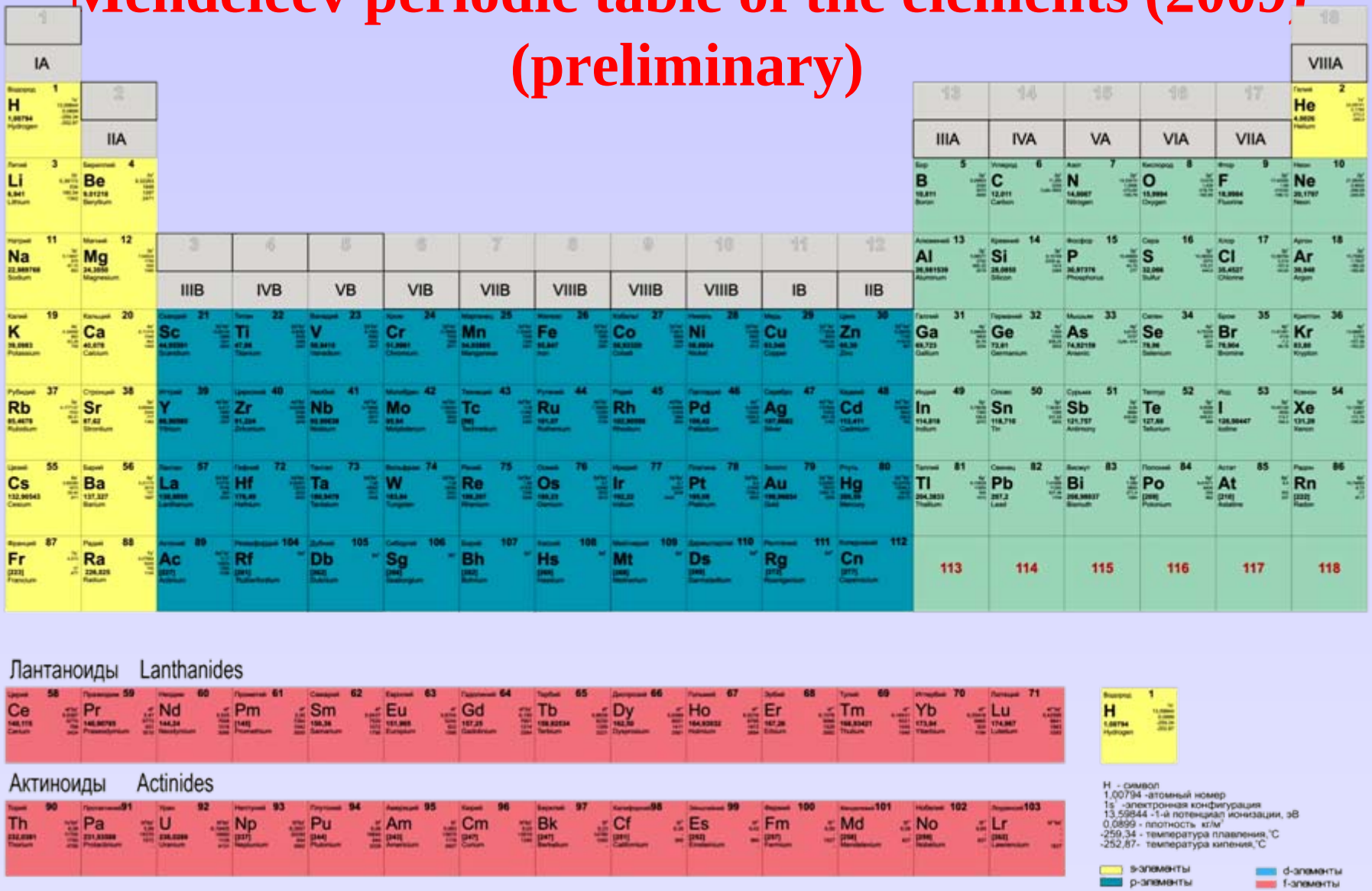
$^{254}Es + {}^{48}Ca$? ?

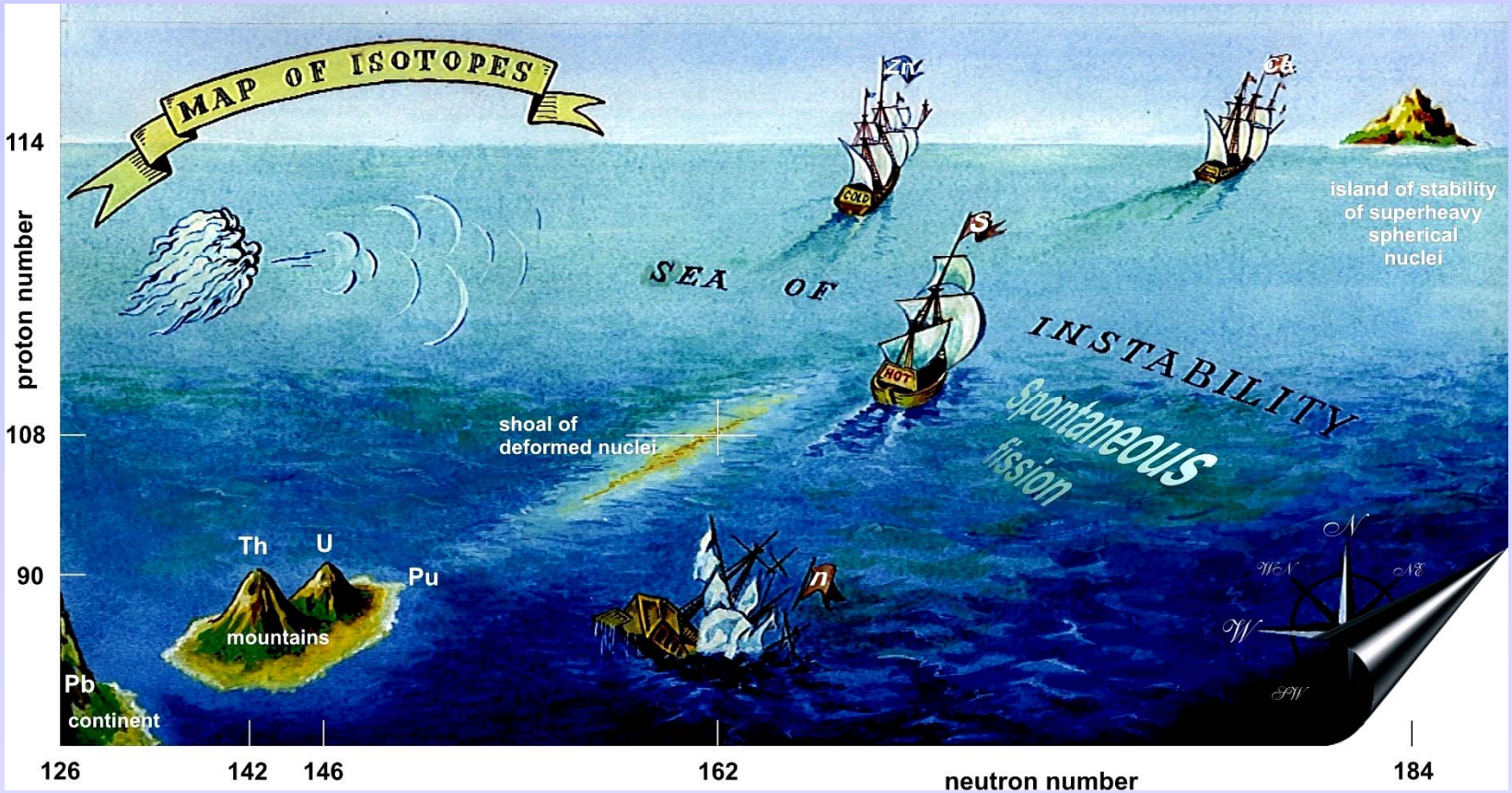
^{251}Cf

(α/898y)



Conclusion IV
Mendeleev periodic table of the elements (2009) (preliminary)





Thank you for your attention!

Many thanks to the organizers!!