Explaining a scientific problem to high-rank officials,
try doing this not in the way it is correct, but in the way it is understandable.
It will be a noble lie

Georgy FLEROV

Periodic table of elements and the Island of stability

Alexander Karpov

Flerov Laboratory of Nuclear Reactions, JINR, Dubna

science bringing nations together

Mendeleev Periodic table of chemical elements (1869)

2019 International year of the Periodic table of chemical elements

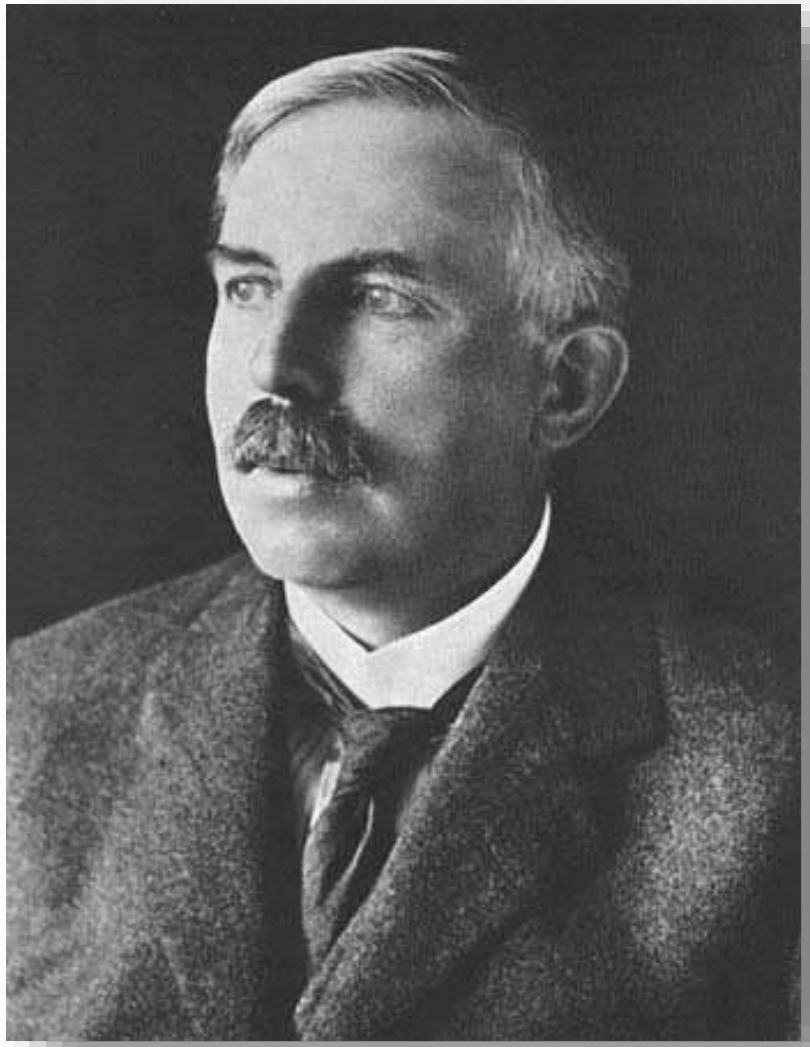
Periodic table today

Nuclear reactions

1919: First nuclear reactions

$^{4}He + ^{14}N \rightarrow p + ^{17}O$

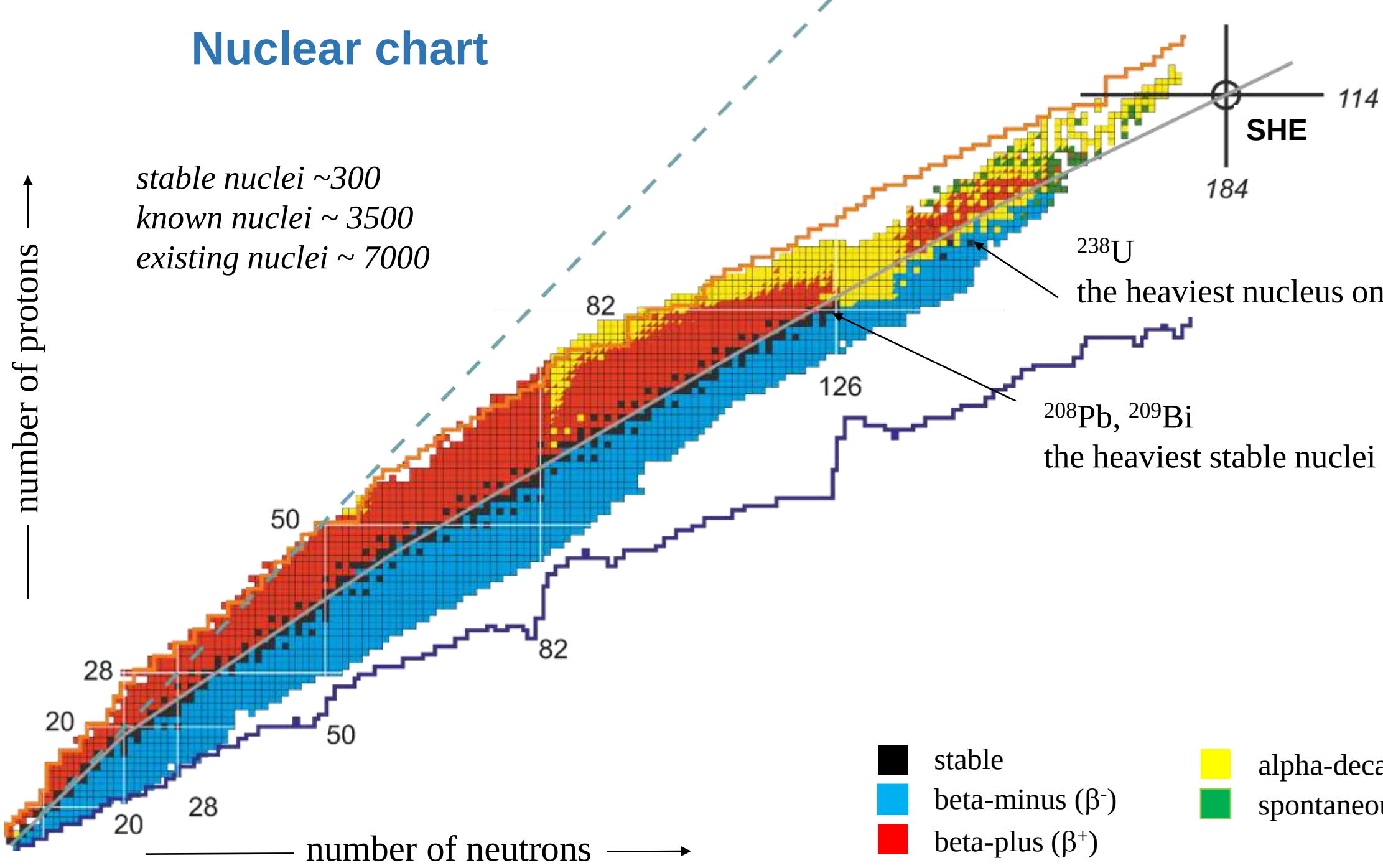
100 years ago mankind new how
to transform one nucleus (element) to another



Ernest Rutherford
(1871 – 1937)

Nuclear chart

stable nuclei ~300
known nuclei ~ 3500
existing nuclei ~ 7000



^{238}U
the heaviest nucleus on the Earth

^{208}Pb, ^{209}Bi
the heaviest stable nuclei

stable
beta-minus (β^-)
beta-plus (β^+)
alpha-decay (α)
spontaneous fission

Abundance of Elements in the Universe

The 11 Greatest Unanswered Questions of Physics
(National Research Council, NAS, USA, 2002):

1. What is dark matter?
2. What is dark energy?
3. How were the heavy elements from iron to uranium made?
4. Do neutrinos have mass?

…

2002-2019:

Discovery of gravitational waves →
first observation of gravitational waves
in a neutron star merge →
start of multimessage astronomy

future
understanding of astrophysical nucleosynthesis

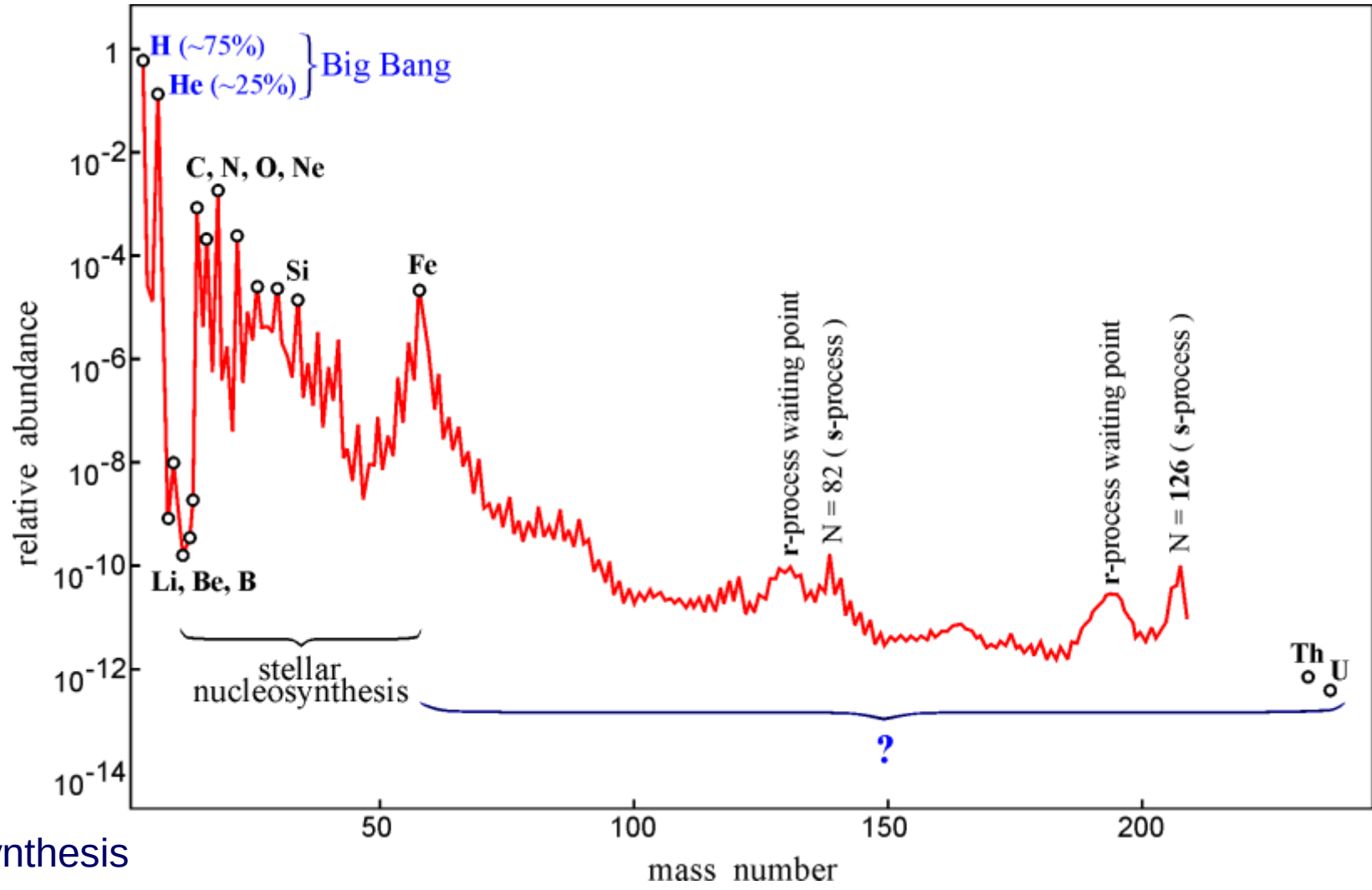


Chart of nuclei (upper part). Vision in 1950th

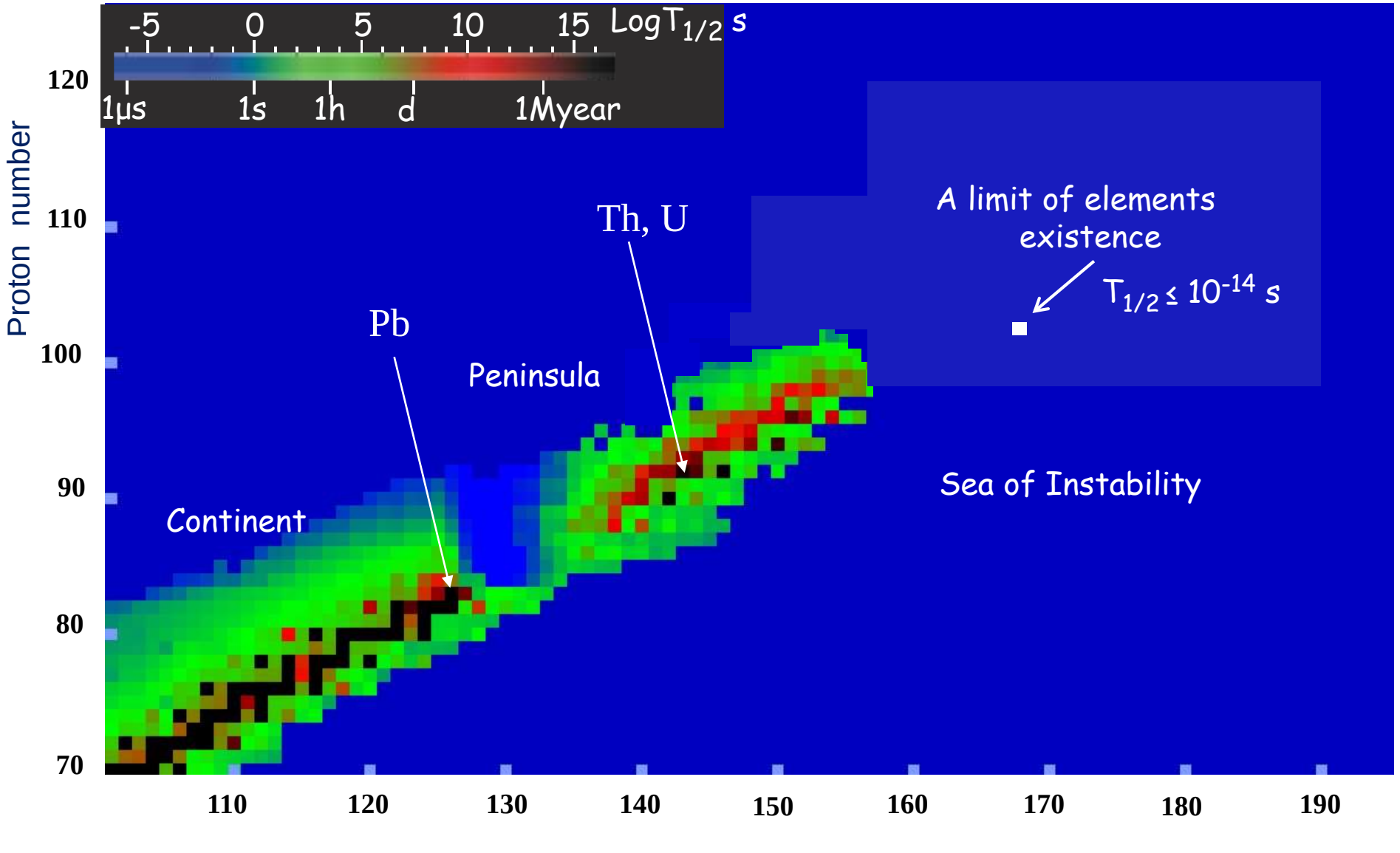
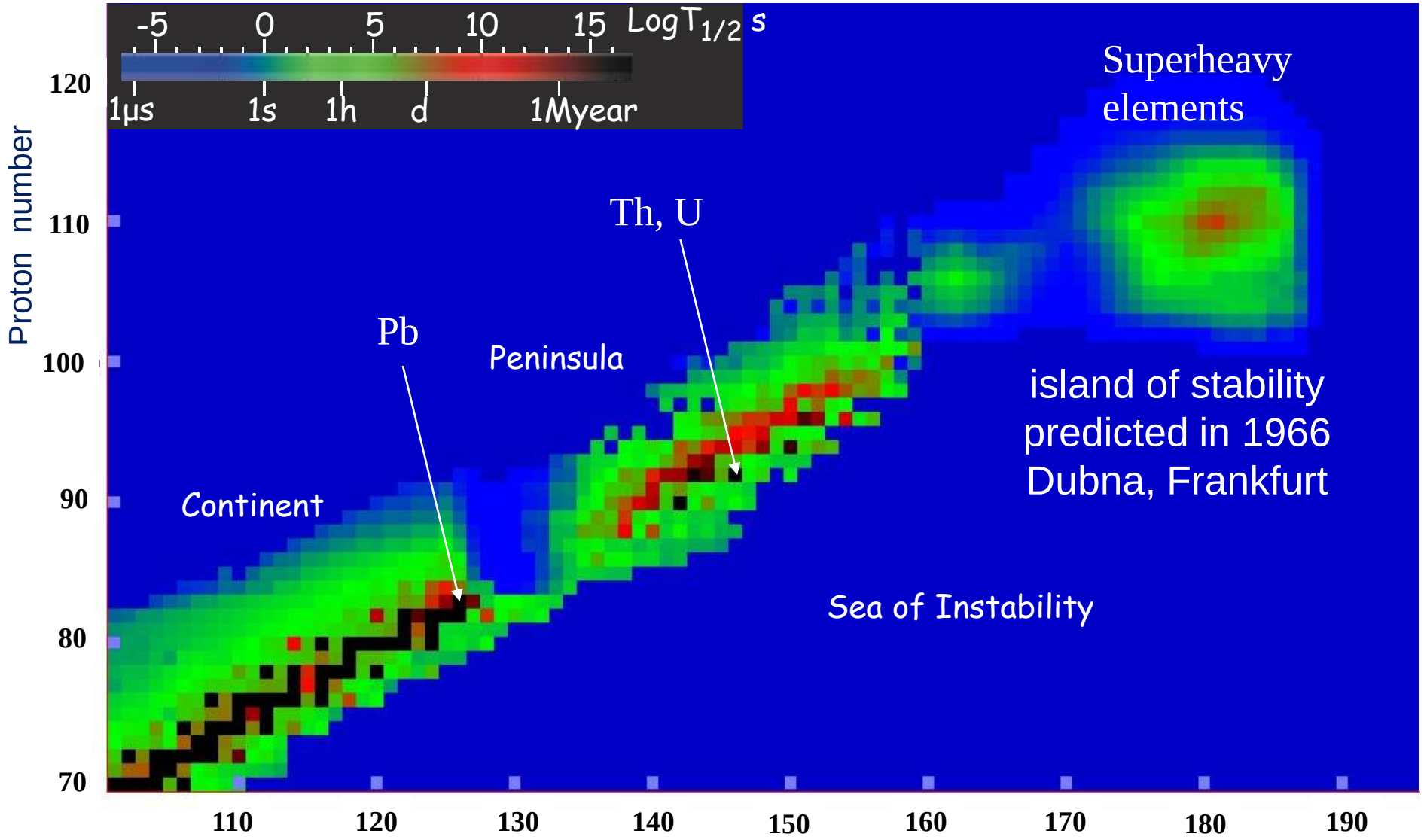


Chart of nuclei (upper part)



Experimenters rushed to find this Island

1970-1985

Los Alamos (USA)

Berkeley (USA)

Dubna (JINR)

Oak Ridge (USA)

Mainz (Germany)

Darmstadt (Germany)

Orsay (France)

Würenlingen (Switzerland)

Tokyo (Japan) some later

The task of every laboratory was:

To find the method of producing

Search in nature:

earth/lunar objects, cosmic rays,

Artificial synthesis:

high-flux reactor,
nuclear explosion,
powerful accelerator

To develop setups:

separator/detector,
spectrometers,
chemical methods, etc.

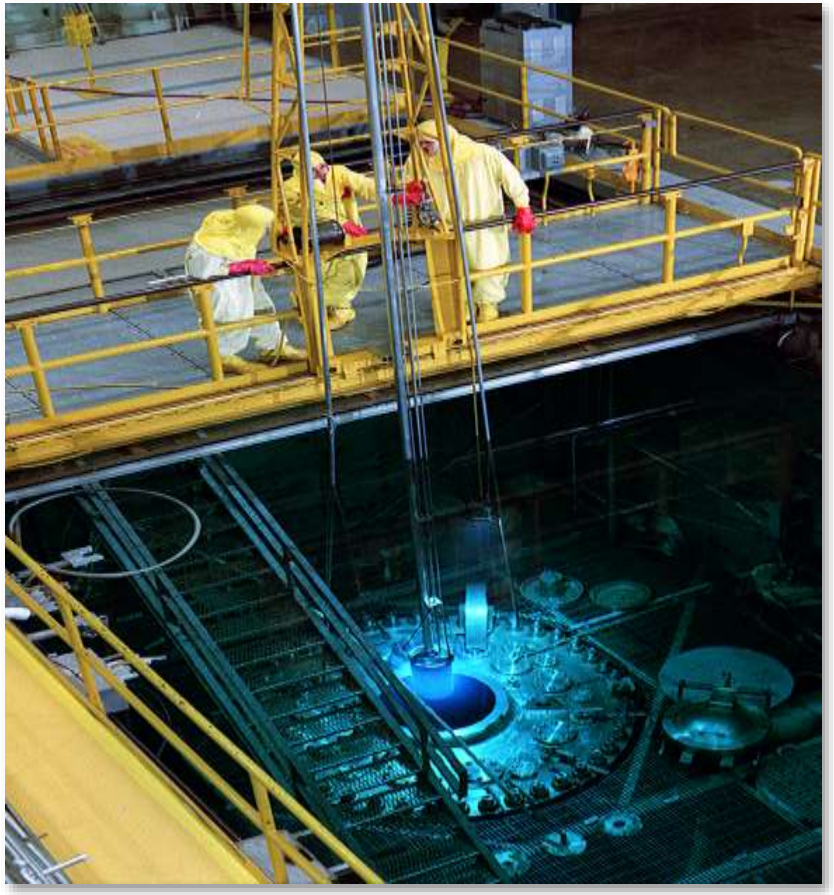
Unfortunately in all attempts superheavy elements were not found

The problem of artificial synthesis of SHE is related with reaction of synthesis

Dubna, beginning of 90th: many times tried ^{48}Ca+Act. reactions are the last hope to produce superheavies

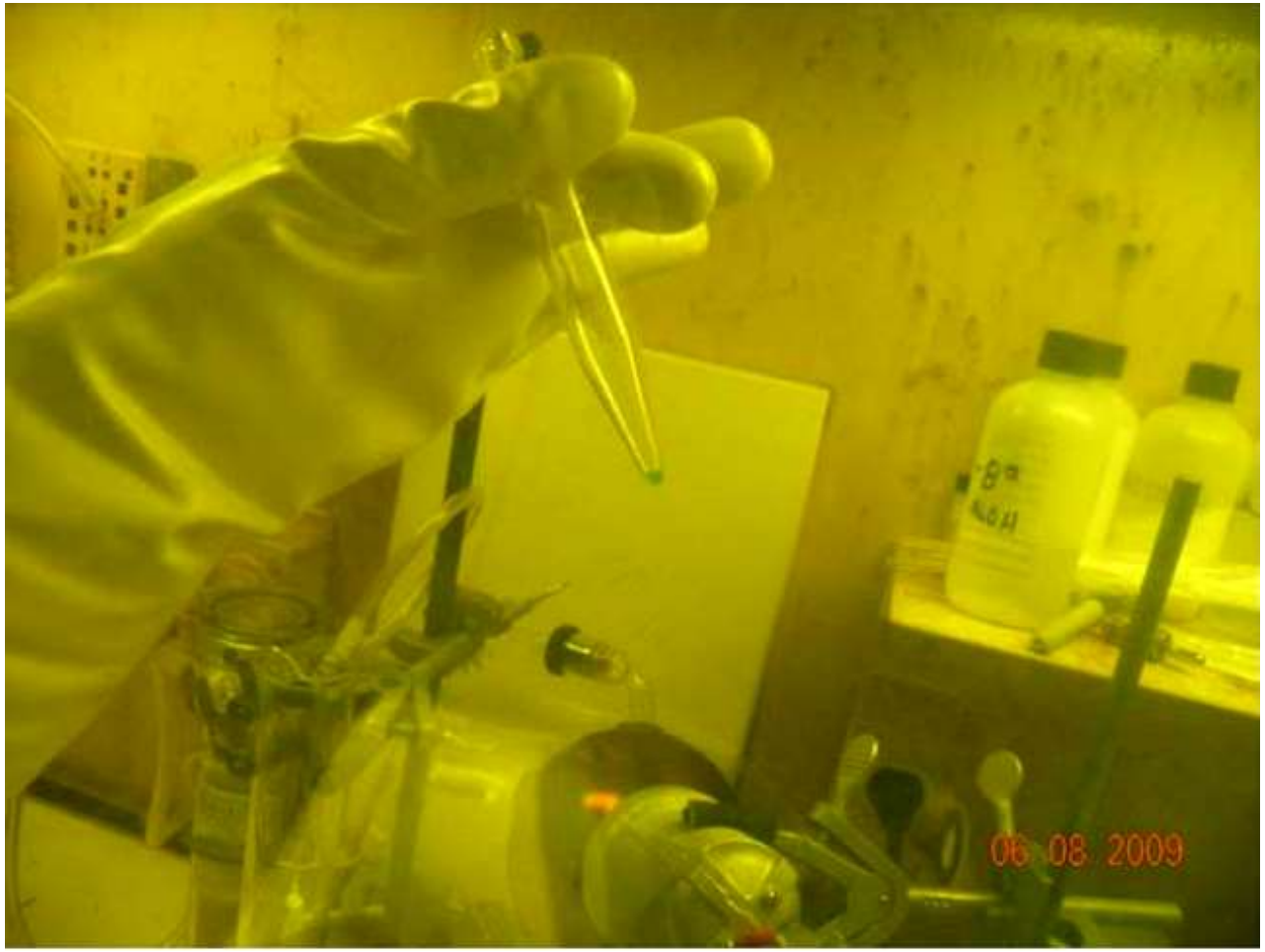
Reactors (target material)

HFIR, ORNL, Oak Ridge, USA, 85 MW



CM-3, IAR, Dimitrovgrad, Russia, 100 MW

22 mg of ^{249}Bk from Oak Ridge, Tennessee, USA

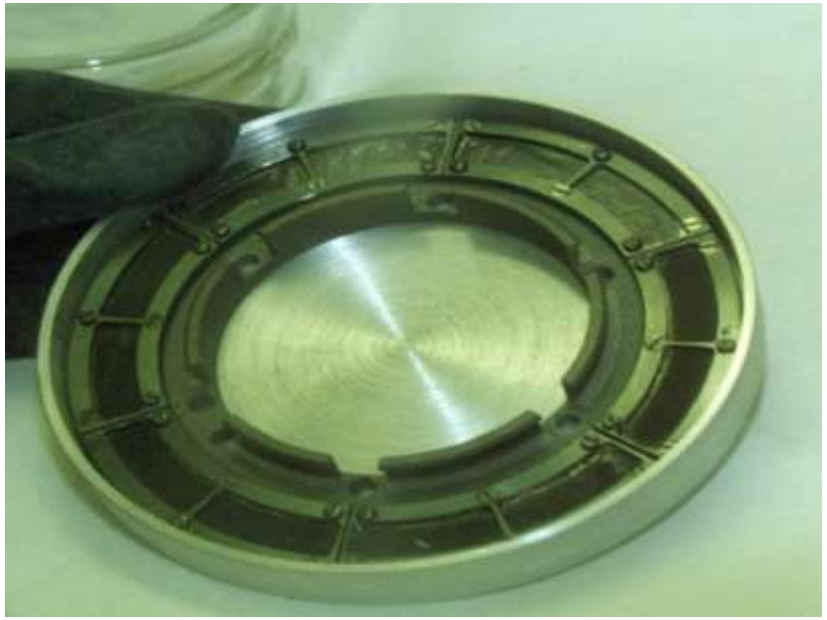


$Bk(NO_3)_3$Product

Annual production:

$_{97}$Bk, $_{98}$Cf: 10th of mg;
$_{99}$Es: few μg;
$_{100}$Es: < ng;

Target wheel (~15 mg)



ECR ion sources. Careful consumption of calcium

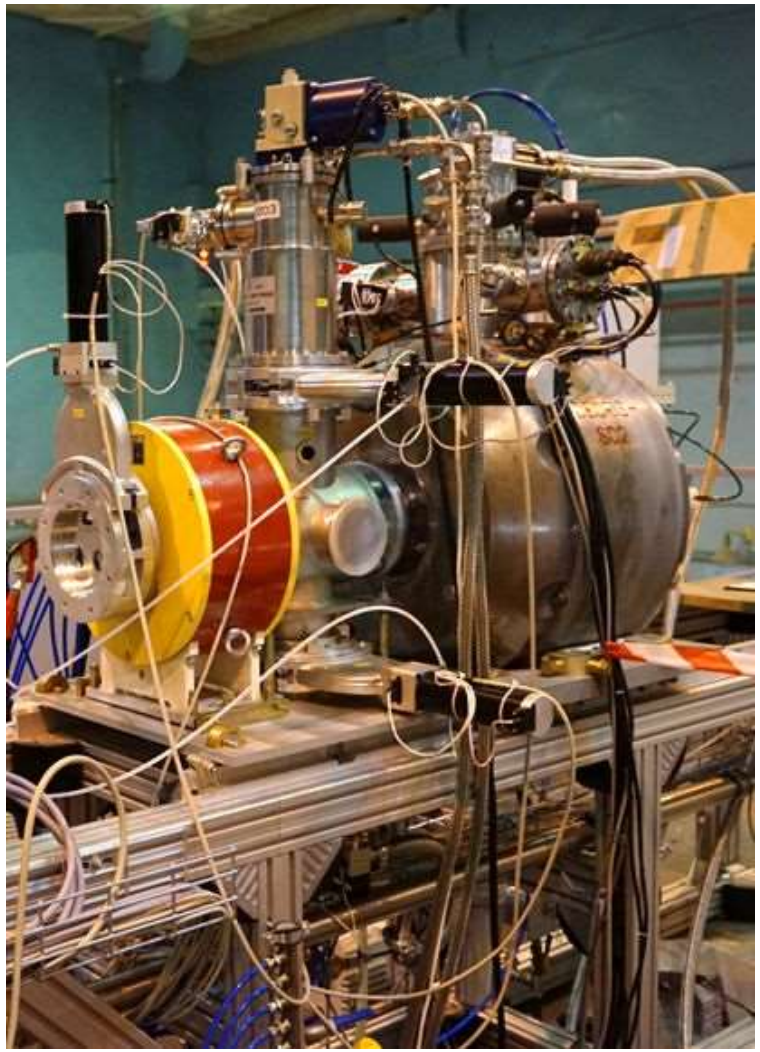
~2 gr. of ^{48}Ca

Consumption: 0.5-0.8 mg/h

Annual production: 10-12 grams

“Elektrokhimpribor”, Lesnoy, Sverdlovsk region, Russia

Ion source DECRIS-SC2



U-400 cyclotron at FLRN, JINR

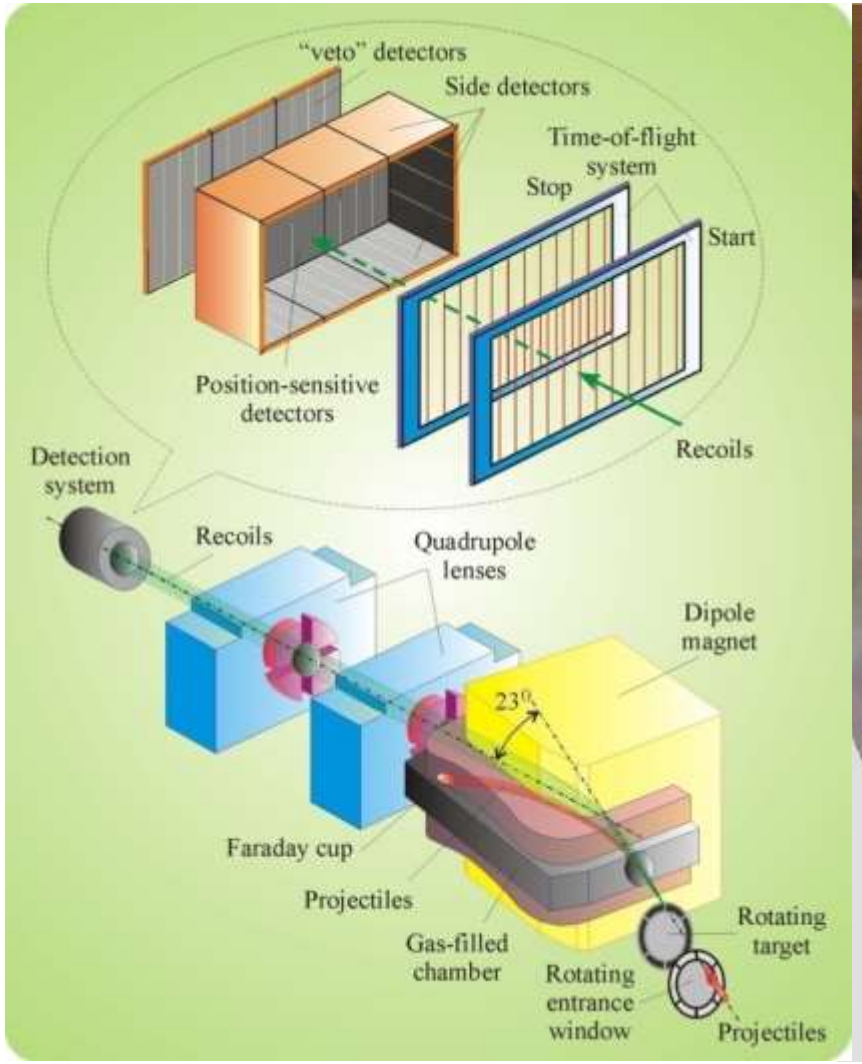
Beam of ^{48}Ca

Intensity:
$6 \cdot 10^{12}$ ion/s

Energy:
~300 MeV

Speed:
10% speed of light

Gas-filled separator



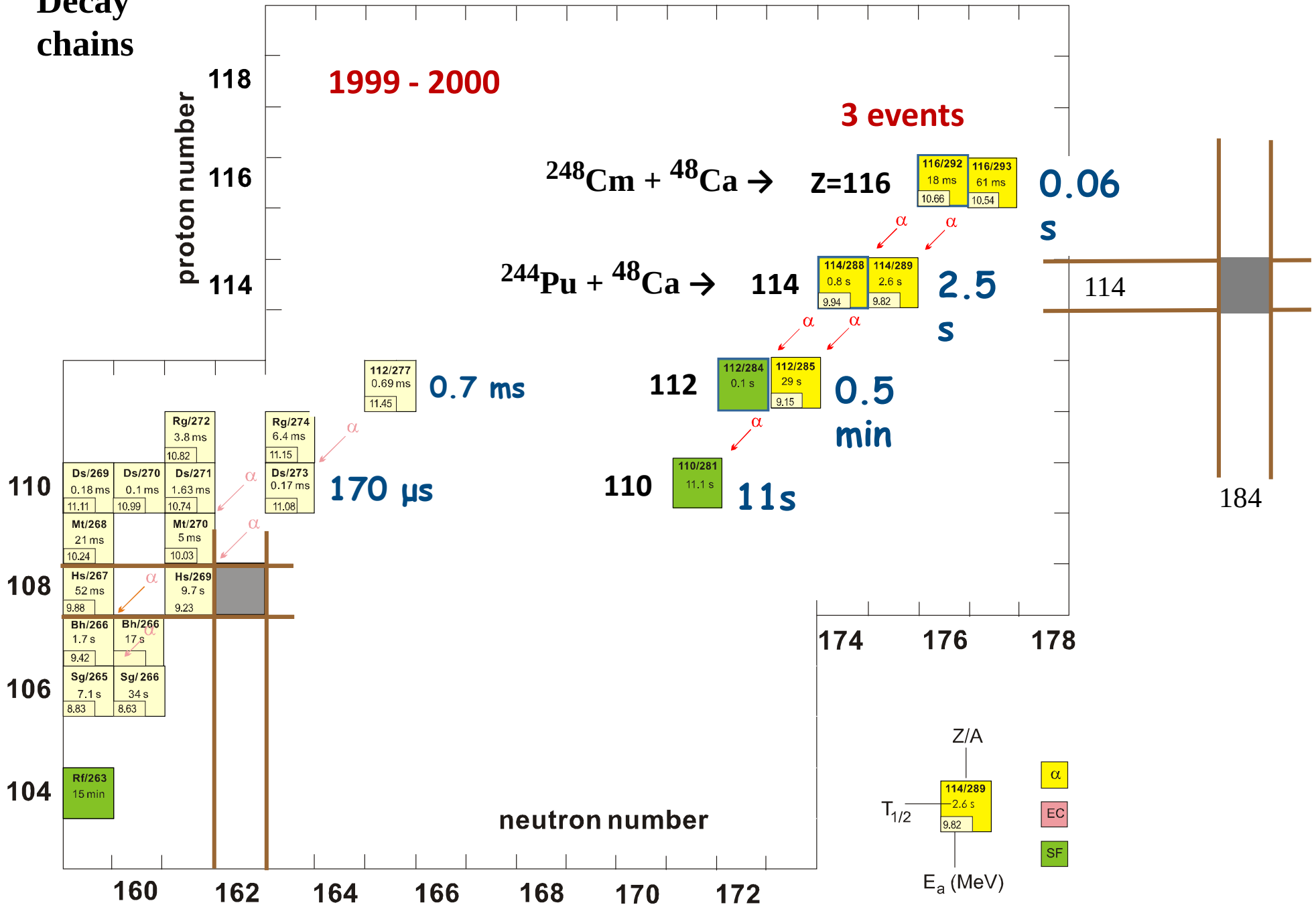
Looking for:
~1 event/day

Without separator:
10^{13} events/s

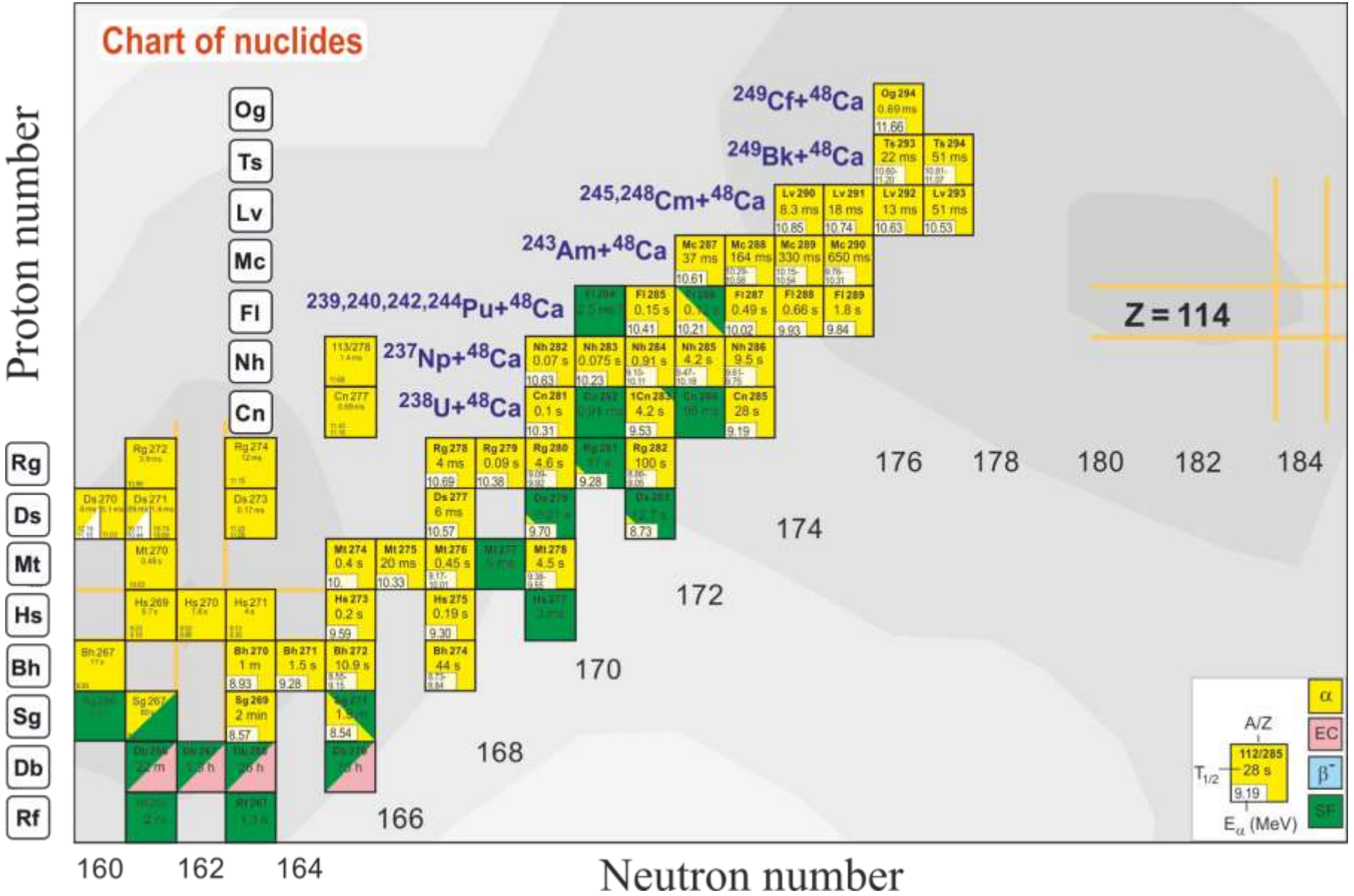
With separator:
100 events/s

Collecting efficiency:
~30%

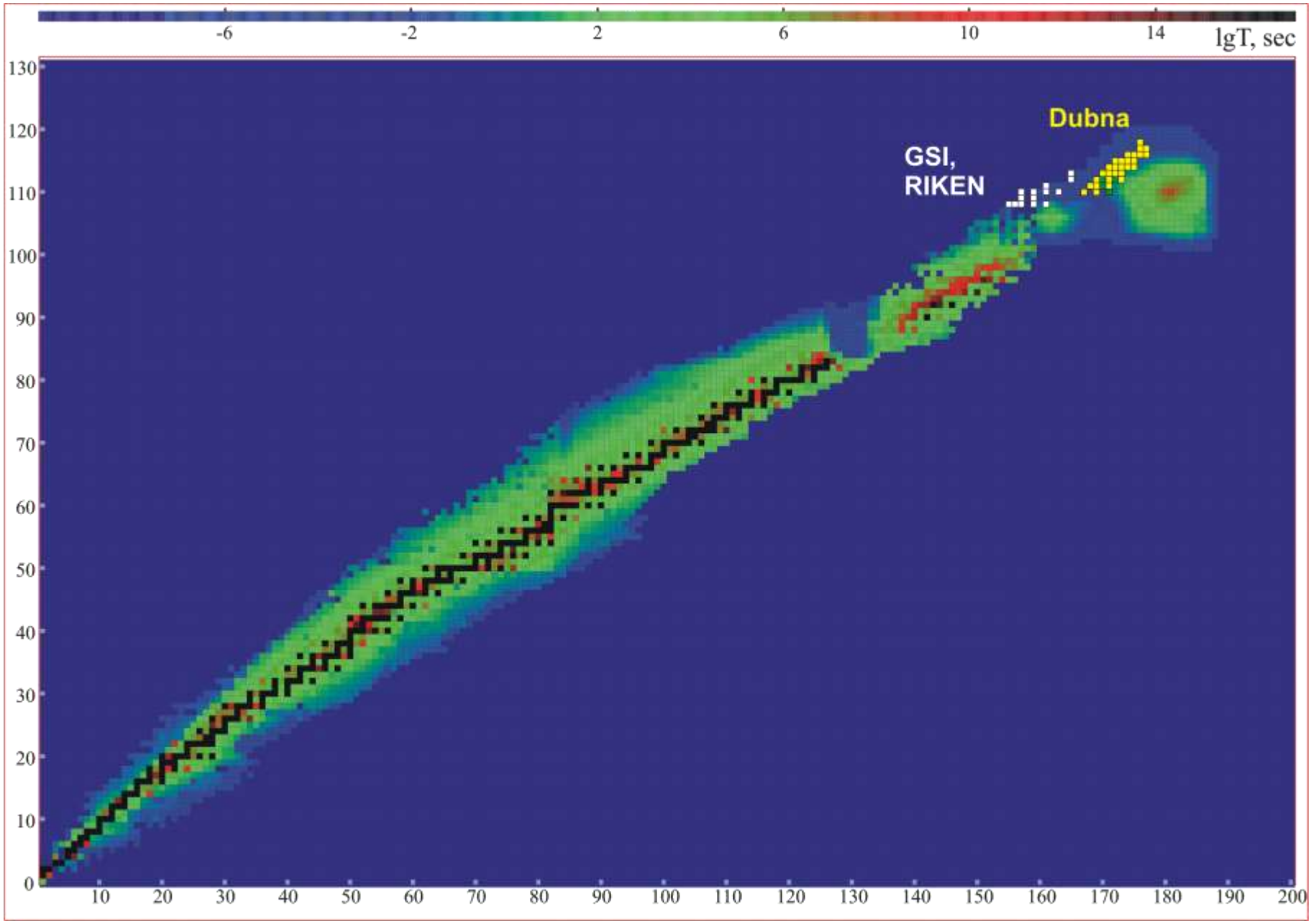
Decay chains



Synthesis of Superheavy Nuclei (*since 1999*)



Approaching the island of stability



Confirmations
(2007-2014)

A, Z	Setup	Laboratory	Published
^{283}112	SHIP	GSI Darmstadt	Eur. Phys. J. A 32, 251 (2007)
^{283}112	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
$^{286,\ 287}$114	BGS	LRNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
$^{288,\ 289}$114	TASCA	GSI – Mainz	P.R. Lett. 104, 252701 (2010)
$^{292,\ 293}$116	SHIP	GSI Darmstadt	Eur. Phys. J. A 48: 62 (2012)
$^{287,\ 288}$115	TASCA	GSI – Mainz	P.R. Lett. 111, 112502 (2013)
^{294}117	TASCA	GSI-Mainz	P.R. Lett. 112, 172501 (2014)

International Union of Pure and Applied Chemistry

May 2012:

Official approval of the name *Flerovium* for element *114*
and the name *Livermorium* for element *116*

30th December 2015:

Approval of the discovery of new elements *113, 115, 117, and 118*

- element 113: RIKEN (Japan)
- elements *115* and *117*: JINR (Dubna) - LLNL (USA) – ORNL (USA) collaboration
- element *118:* JINR (Dubna) – LLNL collaboration.

28th November 2016:

IUPAC formally approved names and symbols of new elements:

Nihonium (Nh) for element 113,
Moscovium (Mc) for element **115**,
Tennessine (Ts) for element **117,** and
Oganesson (Og) for element **118**.

G. Flerov

All these elements were synthesized for the first time at the U-400 accelerator complex of the Flerov Laboratory of Nuclear Reactions of JINR.

Yu. Oganessian

In pursuit of new elements

USA, California, Berkeley:
101(Md), **102**(No), **103**(Lr), **104** (Rf), **105 (Db)**, **106** (Sg)
G. Seaborg, A. Ghiorso, et al.

Dubna: 1964 - 1975 – **102** (No), **103** (Lr), **104** (Rf), **105 (Dubnium)**, **106** (Sg), **107** (Bh), **108** (Hs)
G.N. Flerov, Yu.Ts. Oganessian, et al.

2000 – **114** (Fl), 2002 – **116** (Lv), 2003 – **113** (Nh), **118** (Og), 2009 – **115** (Mc), **117** (Ts)
Yu.Ts. Oganessian, et al.

Germany, Darmstadt, GSI:
1989 - 2000 – **107** (Bh), **108** (Hs), **109** (Mt), **110** (Ds), **111** (Rg), **112** (Cn)
P. Armbruster, G. Münzenberg , S. Hofmann, et al.

Japan, Tokyo, RIKEN:
2003 - 2012 – **110** (Ds), **111** (Rg), **112** (Cn), **113** (Nh)
K. Morita, et al.

Mendeleev's Table Today

10 of 18 elements synthesized since 1955

were discovered in Dubna

Questions and answers:

✓ **Do the superheavy elements exist? – YES!**

✓ **Does the “Island of stability” of superheavy elements exist? – YES!**

✓ **How superheavy elements can be synthesized? – fusion of ^{48}Ca with Actinides works**

? **How many new elements can be synthesized in the nearest future – 119?, 120?, ??? How many they are?**

? **What are the properties (atomic, nuclear) of already known SHE?**

? **How to reach the center of the Island of stability? – ???**

? **How long do the most stable nuclei from the Island of stability live - ???**

? **Can superheavy elements be produced in nature? - ???**

Superheavy Element Factory

Superheavy Element Factory

Cyclotron DC-280:

- **Dec., 26 2018:** first beam was obtained;
- **Jan.-June 2019:** design parameters are nearly reached.

designed: beam intensity – 10 pμA with 50% efficiency

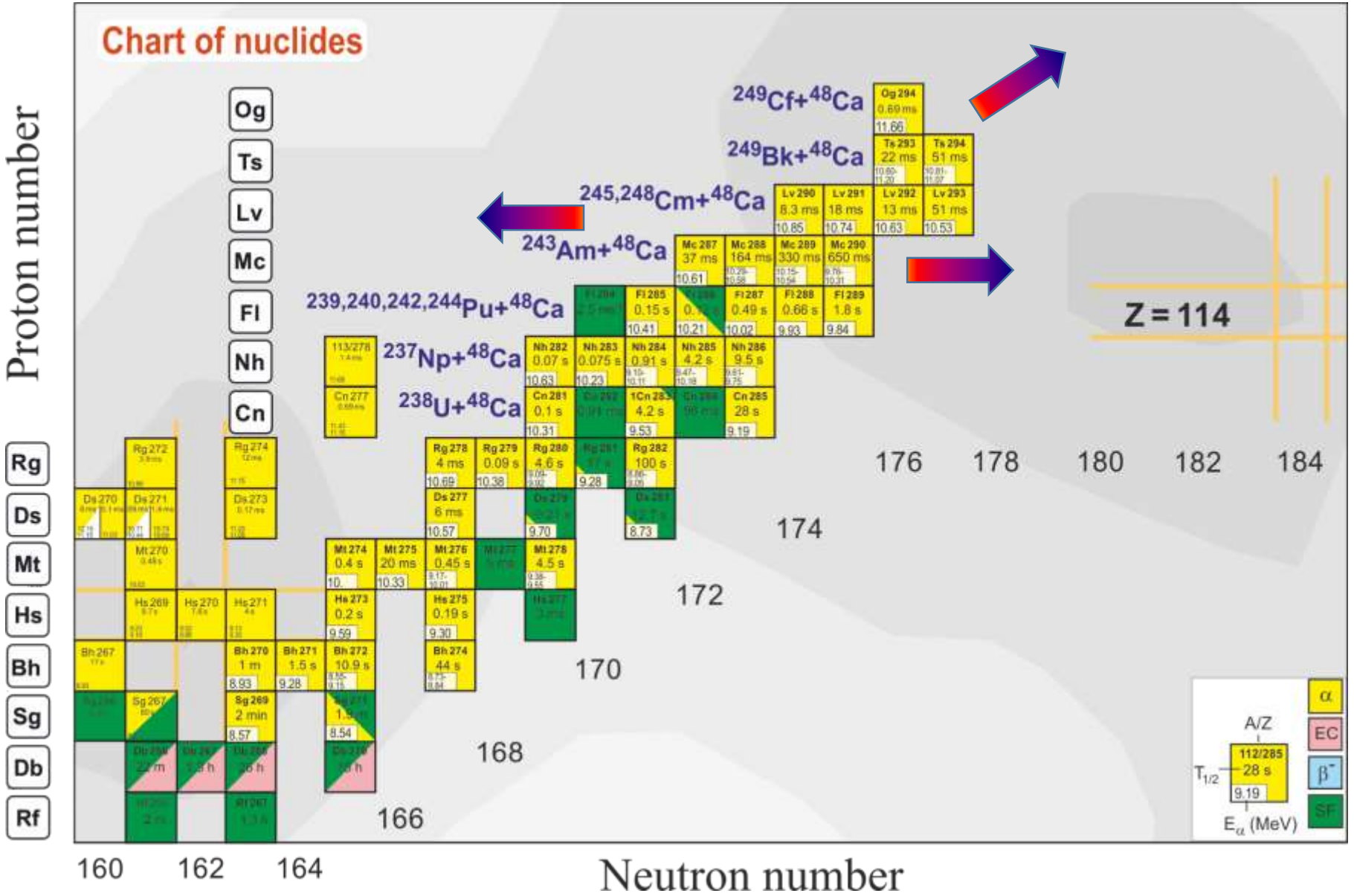
Gas-filled recoil separator (GFRS-2):

- under commissioning

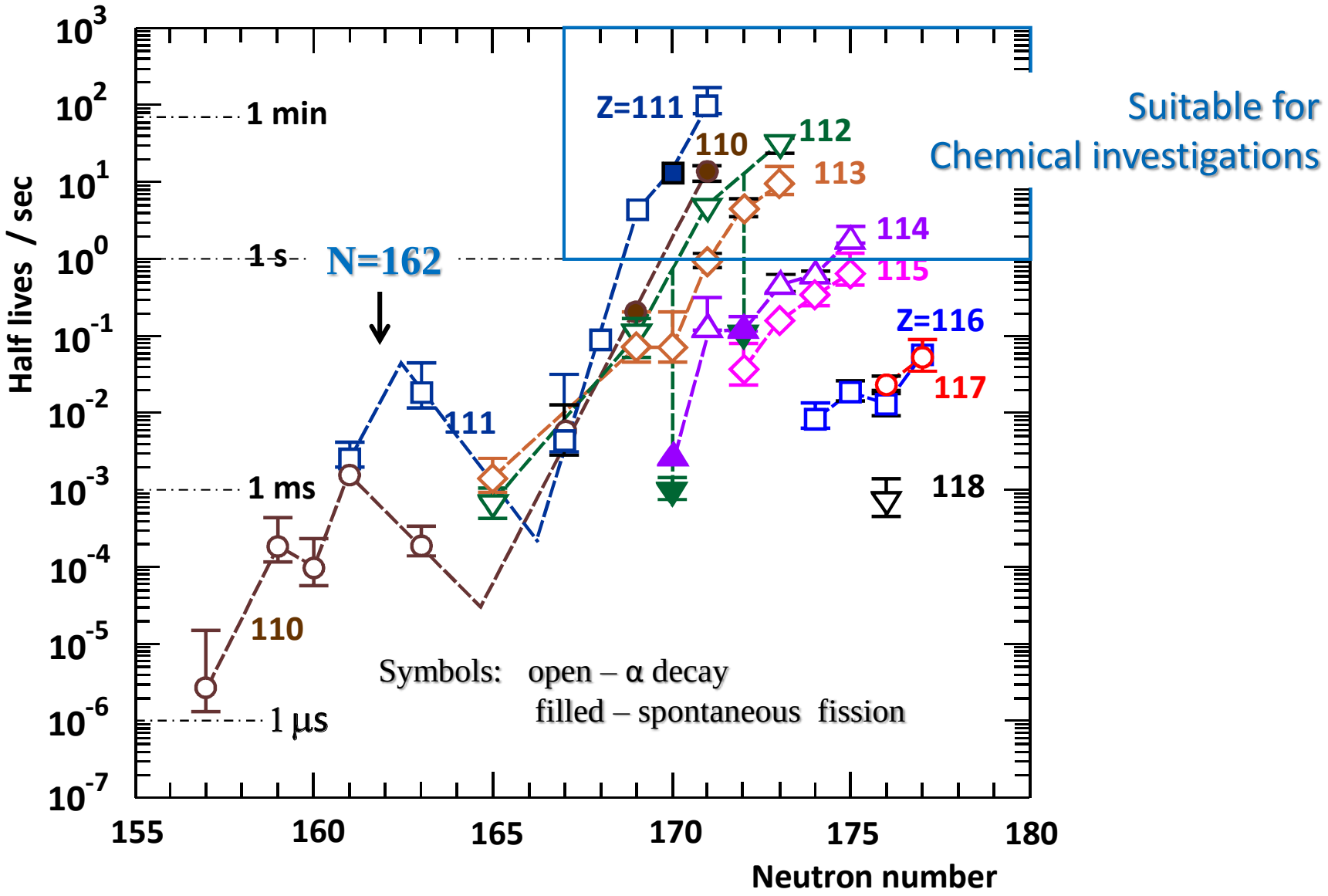
plans for the end of 2019:

- **now:** separator testing and tuning;
- **next:** First experiment ^{48}**Ca+**^{243}**Am;**
- Preparing the experiment aimed at synthesis of element **120** in the ^{50}**Ti+**$^{249\text{-}251}$**Cf** reaction;

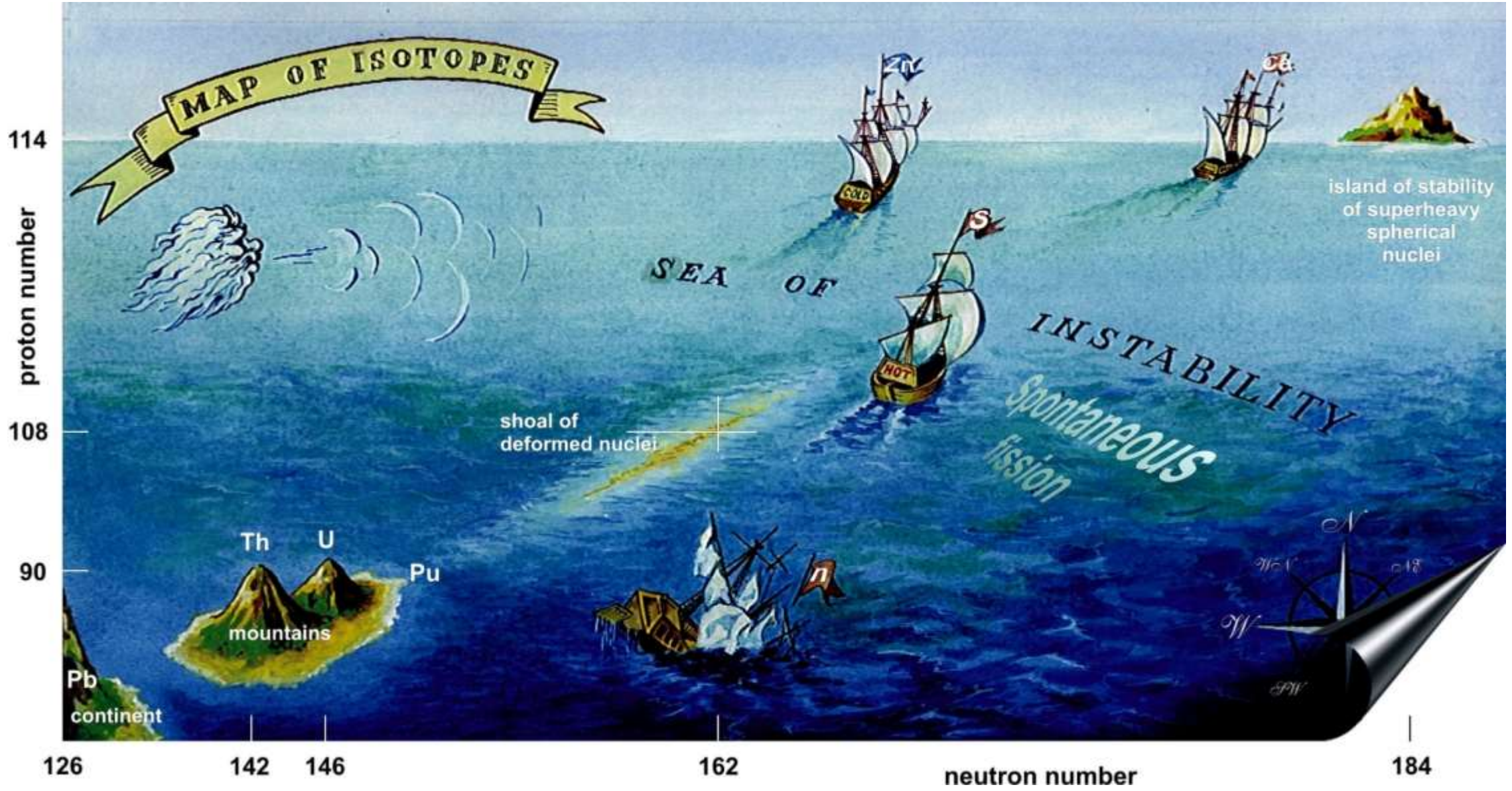
Fusion reactions: *left, right or up?*



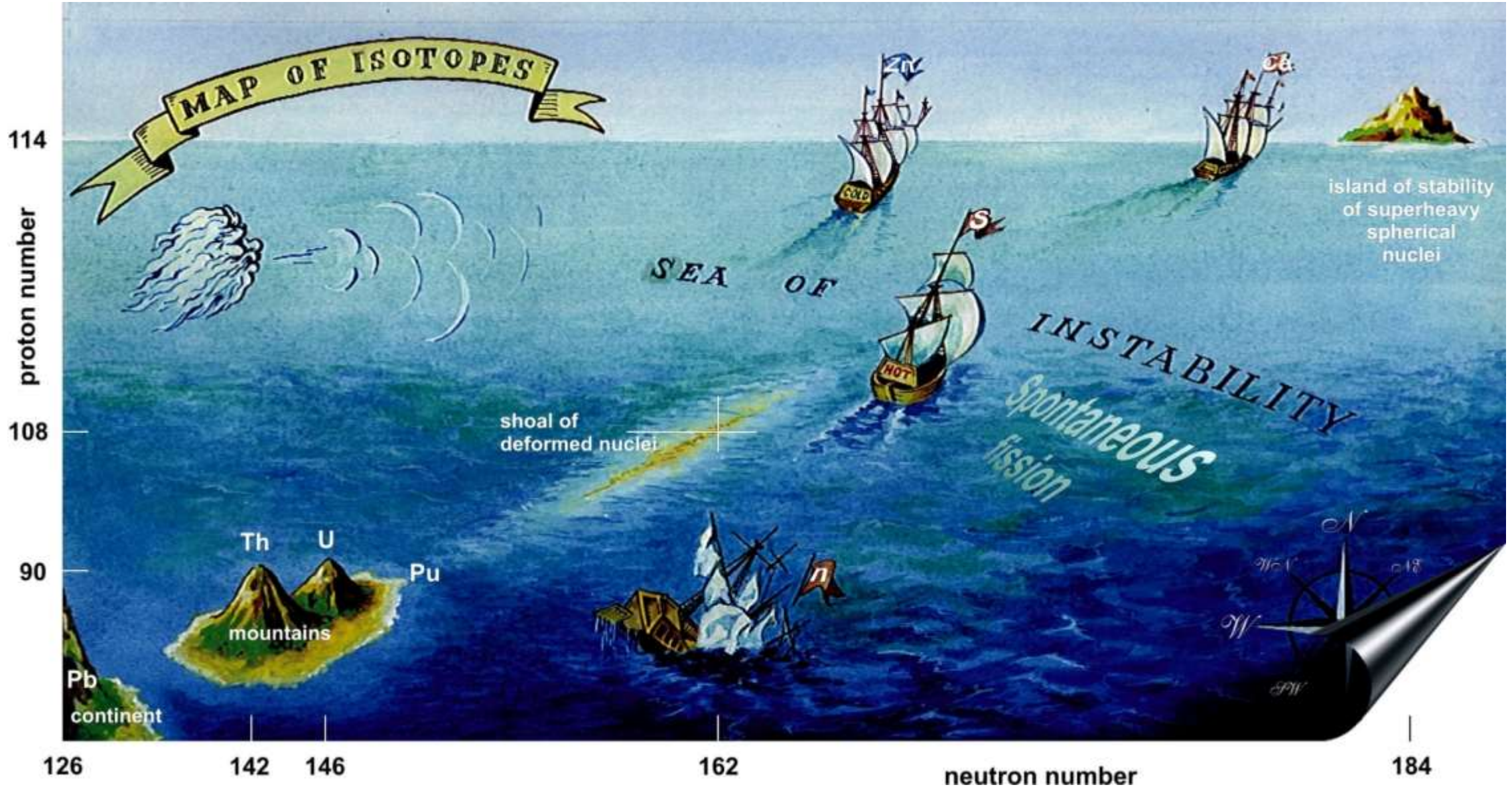
Half-lives of nuclides with Z ≥ 110



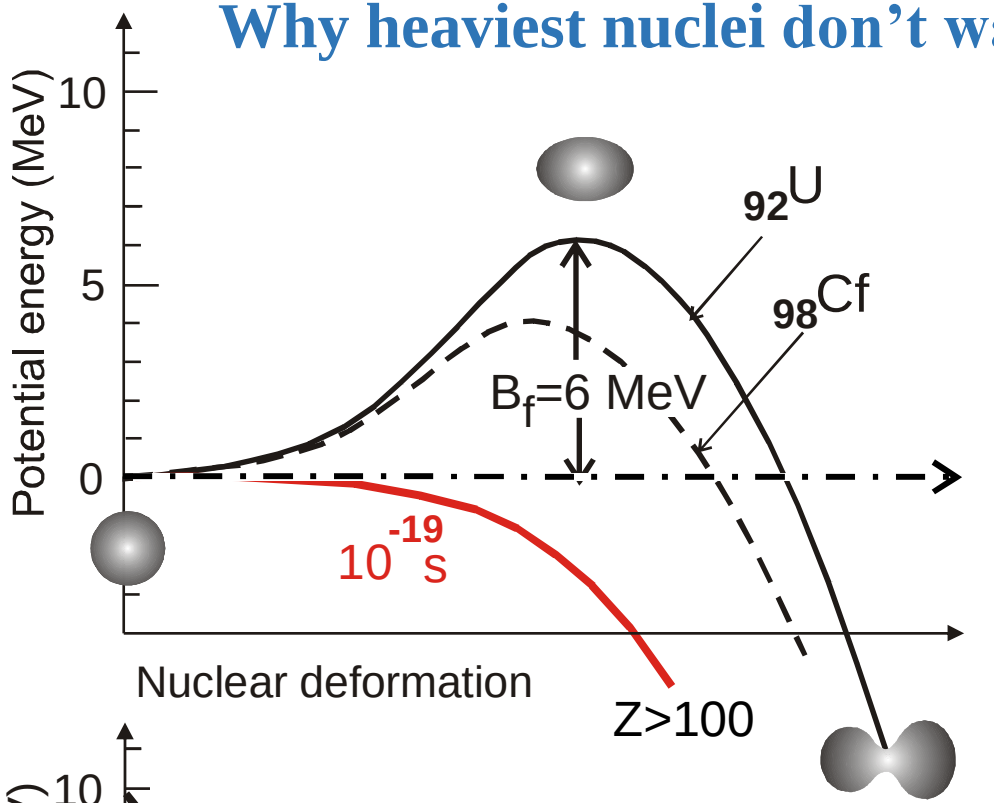
Long way to new Lands

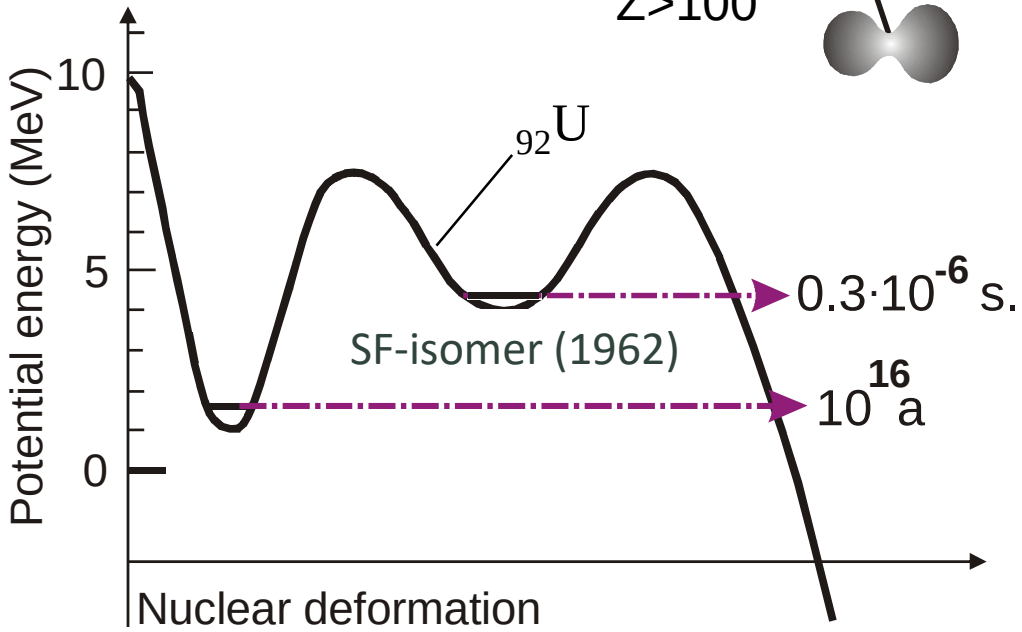


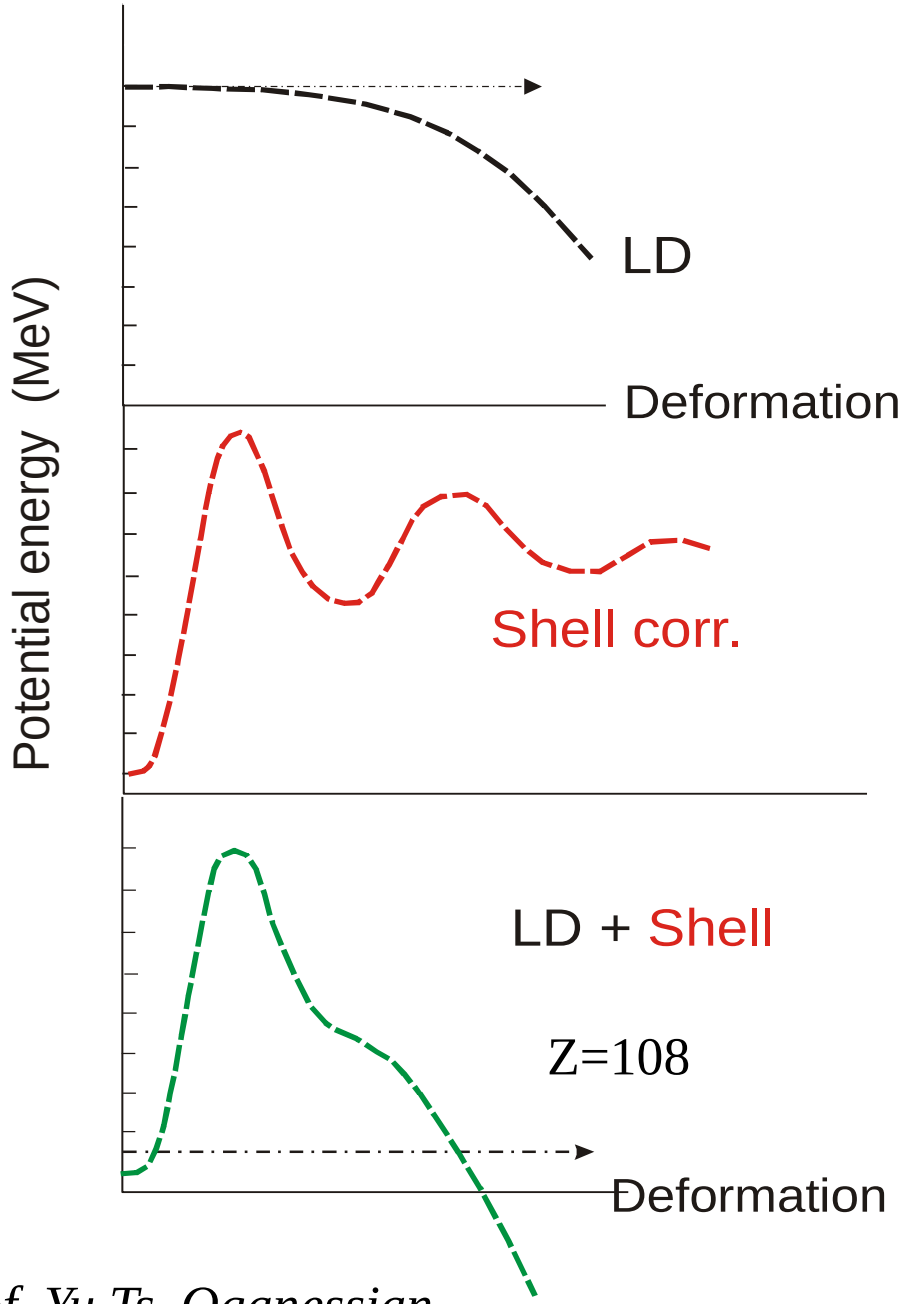
Long way to new Lands



Why heaviest nuclei don't want to live long?







Courtesy: Prof. Yu.Ts. Oganessian