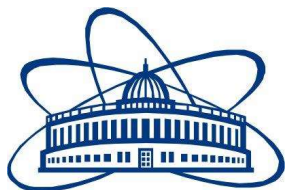




Flerov Laboratory of Nuclear Reactions



Alexander Karpov





FLNR's 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;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

2. Light exotic nuclei:

- properties and structure of light exotic nuclei;
- reactions with exotic nuclei.

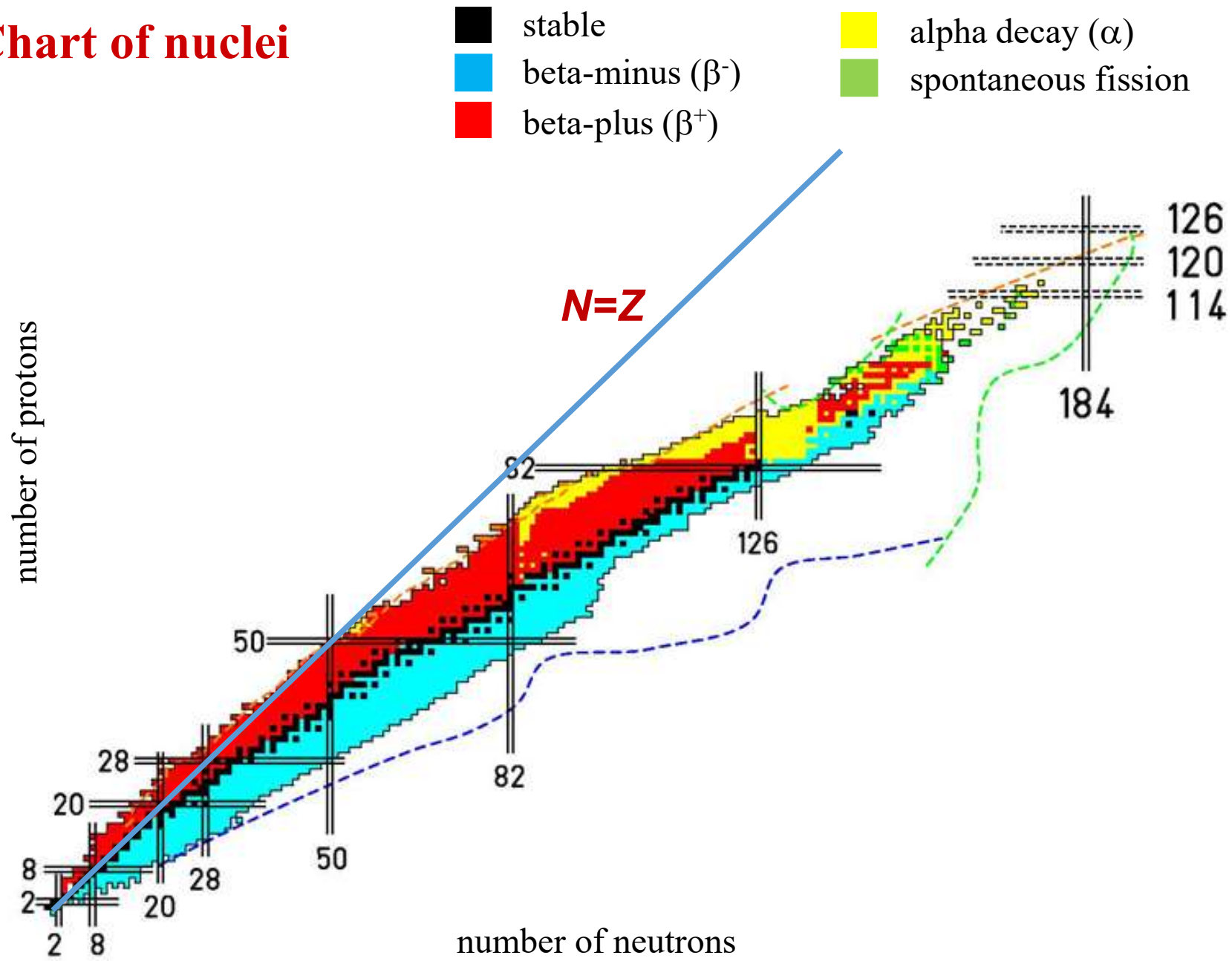
3. Radiation effects

and physical groundwork of nanotechnology.

4. Accelerator technologies.

Staff : ~450 people

Chart of nuclei



Mendeleev's Table (1869)

Представитель
 Высшего учебного заведения,
 Д. Менделѣевъ.

Менделѣевъ
 1869. II. 17

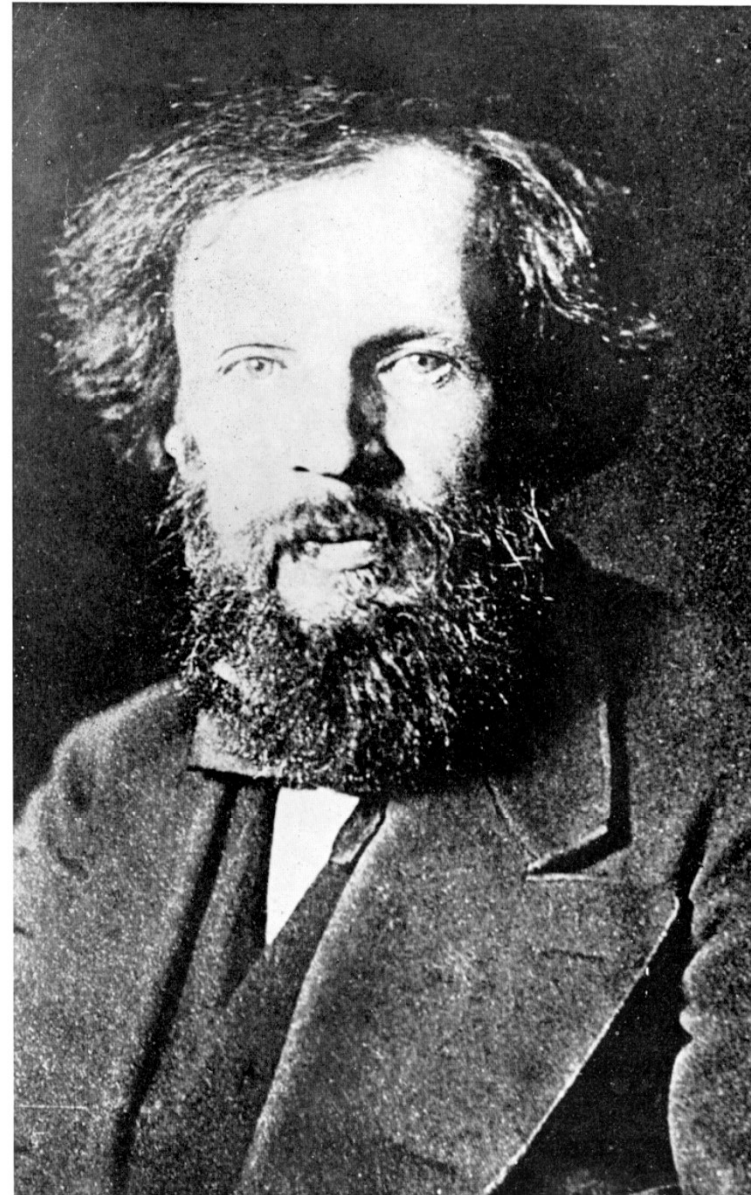
	Li=7	Be=9	B=10	C=12	N=14	O=16	F=19	Na=23	Mg=24	Al=27	Si=28	P=31	S=32	Cl=35	K=39	Ca=40	Sc=45	Ti=48	V=51	Cr=52	Mn=55	Fe=56	Ni=59	Cu=63	Zn=65	As=75	Se=78	Br=80	Kr=84	Rb=85	Sr=87	Zr=90	Nb=94	Mo=96	Ag=108	Pt=195	Au=197	Hg=200
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Essai d'un système des éléments d'après leurs poids atomiques et fonctions chimiques par D. Mendelѣeff.

Prof. de chimie à l'Université de Kazan.

18 II 69.

Представитель
 Высшего учебного заведения,
 Д. Менделѣевъ.



Mendeleev's Table Today (since Nov. 28, 2016)



Периодическая таблица элементов Д.И. Менделеева
D.I. Mendeleev's Periodic Table of Elements

1																	18	
Водород 1 H 1.00794 Hydrogen	2																	Гелий 2 He 4.0026 Helium
Литий 3 Li 6.941 Lithium	Бериллий 4 Be 9.01218 Beryllium																	Неон 10 Ne 20.1797 Neon
Натрий 11 Na 22.989769 Sodium	Магний 12 Mg 24.3050 Magnesium	3	4	5	6	7	8	9	10	11	12	Алюминий 13 Al 26.981539 Aluminum	Кремний 14 Si 28.0855 Silicon	Фосфор 15 P 30.97376 Phosphorus	Сера 16 S 32.066 Sulfur	Хлор 17 Cl 35.4527 Chlorine	Аргон 18 Ar 39.948 Argon	
Калий 19 K 39.0983 Potassium	Кальций 20 Ca 40.078 Calcium	Скандий 21 Sc 44.95591 Scandium	Титан 22 Ti 47.88 Titanium	Ванадий 23 V 50.9415 Vanadium	Хром 24 Cr 51.9961 Chromium	Марганец 25 Mn 54.93805 Manganese	Железо 26 Fe 55.847 Iron	Кобальт 27 Co 58.93320 Cobalt	Никель 28 Ni 58.6934 Nickel	Медь 29 Cu 63.546 Copper	Цинк 30 Zn 65.39 Zinc	Галлий 31 Ga 69.723 Gallium	Германий 32 Ge 72.61 Germanium	Мышьяк 33 As 74.92159 Arsenic	Селен 34 Se 78.96 Selenium	Бром 35 Br 79.904 Bromine	Криpton 36 Kr 83.90 Krypton	
Рубидий 37 Rb 85.4678 Rubidium	Стронций 38 Sr 87.62 Strontium	Иттрий 39 Y 88.90585 Yttrium	Цирконий 40 Zr 91.224 Zirconium	Нобий 41 Nb 92.90638 Niobium	Молибден 42 Mo 95.94 Molybdenum	Технеций 43 Tc 98 Technetium	Рутений 44 Ru 101.07 Ruthenium	Родий 45 Rh 102.90550 Rhodium	Палладий 46 Pd 106.42 Palladium	Серебро 47 Ag 107.8682 Silver	Кадмий 48 Cd 112.411 Cadmium	Индий 49 In 114.818 Indium	Олово 50 Sn 118.710 Tin	Сурьма 51 Sb 121.757 Antimony	Теллур 52 Te 127.60 Tellurium	Йод 53 I 126.90447 Iodine	Ксенон 54 Xe 131.29 Xenon	
Цезий 55 Cs 132.90543 Cesium	Барий 56 Ba 137.327 Barium	Лантан 57 La 138.9055 Lanthanum	Гафний 72 Hf 178.49 Hafnium	Тантал 73 Ta 180.9479 Tantalum	Вольфрам 74 W 183.84 Tungsten	Рений 75 Re 186.207 Rhenium	Осмий 76 Os 190.23 Osmium	Иридий 77 Ir 192.22 Iridium	Платина 78 Pt 195.08 Platinum	Золото 79 Au 196.96654 Gold	Ртуть 80 Hg 200.59 Mercury	Таллий 81 Tl 204.38833 Thallium	Свинец 82 Pb 207.2 Lead	Висмут 83 Bi 208.98037 Bismuth	Полюний 84 Po [209] Polonium	Астат 85 At [210] Astatine	Радон 86 Rn [222] Radon	
Франций 87 Fr [223] Francium	Радий 88 Ra [226] Radium	Актиний 89 Ac [227] Actinium	Резерфордий 104 Rf [261] Rutherfordium	Дубний 105 Db [262] Dubnium	Сгогдий 106 Sg [266] Seaborgium	Борий 107 Bh [267] Bohrium	Хассий 108 Hs [269] Hassium	Мейтнерий 109 Mt [271] Meitnerium	Дармштадтий 110 Ds [269] Darmstadtium	Рентгений 111 Rg [272] Roentgenium	Коперниковий 112 Cn [285] Copernicium	Нихоний 113 Nh	Флеровий 114 Fl	Московий 115 Mc	Ливерморий 116 Lv	Теннесси 117 Ts	Оганesson 118 Og	

Лантаноиды Lanthanoids

Церий 58 Ce 140.115 Cerium	Прометий 59 Pr 140.90765 Praseodymium	Неодим 60 Nd 144.24 Neodymium	Прометий 61 Pm [145] Promethium	Самарий 62 Sm 150.36 Samarium	Европий 63 Eu 151.965 Europium	Гадолиний 64 Gd 157.25 Gadolinium	Тербий 65 Tb 158.92534 Terbium	Диспрозий 66 Dy 162.50 Dysprosium	Гольмий 67 Ho 164.93032 Holmium	Эрбий 68 Er 167.26 Erbium	Тулий 69 Tm 168.93421 Thulium	Иттербий 70 Yb 173.04 Ytterbium	Лютеций 71 Lu 174.967 Lutetium
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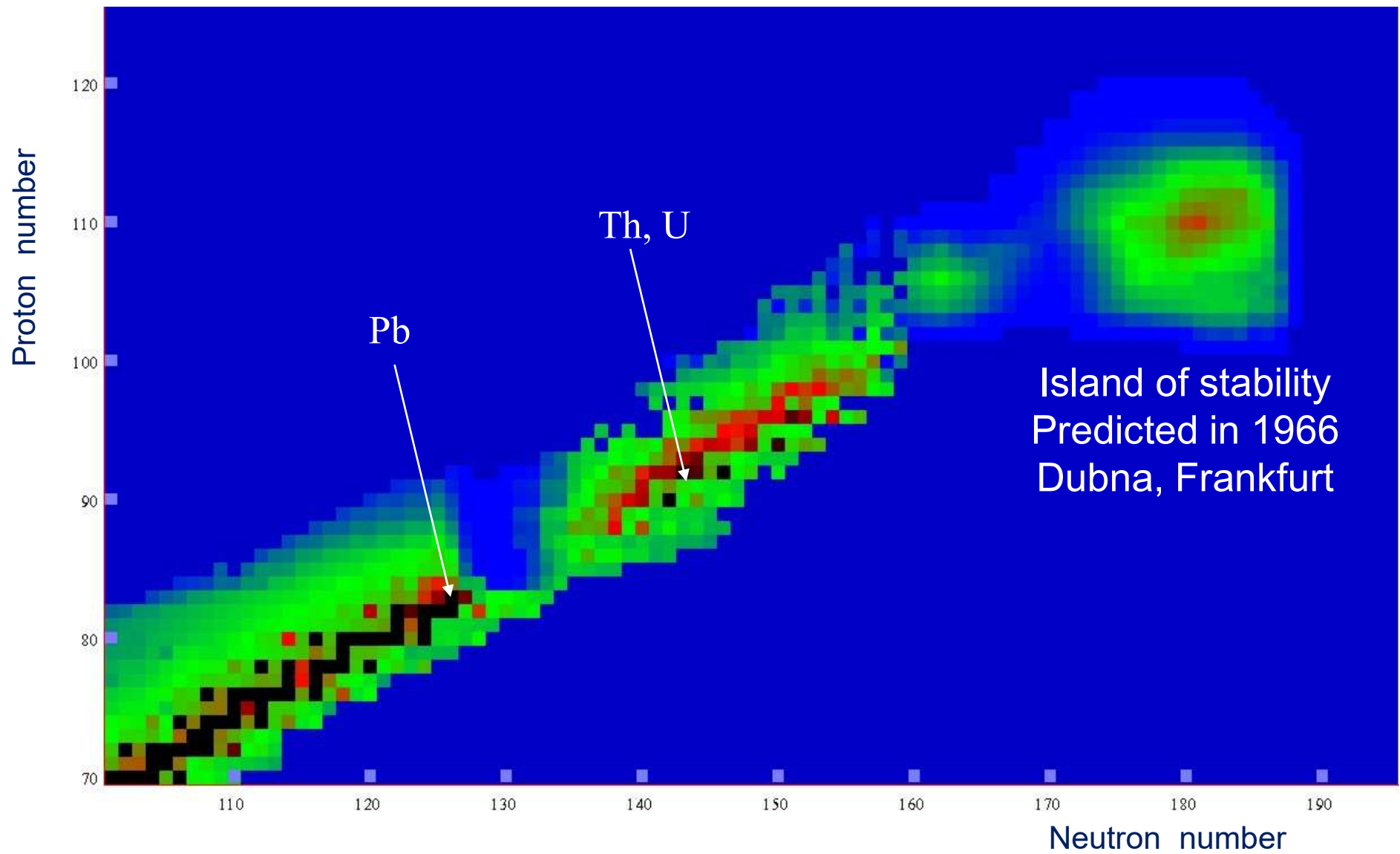
Водород 1 H 1.00794 Hydrogen
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Актиноиды Actinoids

Торий 90 Th 232.0381 Thorium	Протактиний 91 Pa 231.03689 Protactinium	Уран 92 U 238.02891 Uranium	Нептуний 93 Np 237.04817 Neptunium	Плутоний 94 Pu 239.05216 Plutonium	Америций 95 Am 243.06138 Americium	Кюрий 96 Cm 247.07724 Curium	Берклий 97 Bk 247.07724 Berkelium	Калифорний 98 Cf [251] Californium	Эйнштейний 99 Es [252] Einsteinium	Фермий 100 Fm [257] Fermium	Менделеевий 101 Md [261] Mendelevium	Нобелий 102 No [262] Nobelium	Лоуренсий 103 Lr [262] Lawrencium
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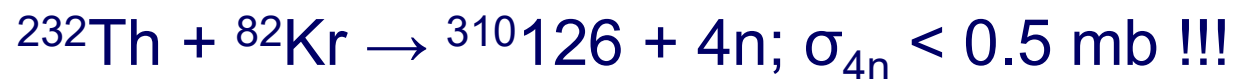
H - символ / symbol
1.00794 - атомная масса / atomic mass
[54] - электронная конфигурация / electron configuration
13.59844 - 1-й потенциал ионизации, эВ / 1st ionization potential, eV
0.0899 - плотность, кг/м³ / density, kg/m³
-259.24 - температура плавления, °C / melting temperature, °C
-252.87 - температура кипения, °C / boiling temperature, °C

Chart of Nuclei



Synthesis of SHE with accelerators

- 1971; Orce, France:



- 1971; Dubna: $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{276}112 + 2n; \sigma_{2n} < 0.1 \text{ mb} !!!$
(1996, GSI, Germany);

- 1971-1975; Dubna: $^{76}\text{Ge}, ^{136}\text{Xe} + ^{238}\text{U}$;

- 1975; Dubna: $^{48}\text{Ca} + \text{Actinides}$:

Questions:

- Do SHE exist?
- Where is the region of SHE?
- How can SHE be synthesized?
- Do long-living SHE exist?
- Can SHE be produced in nature?

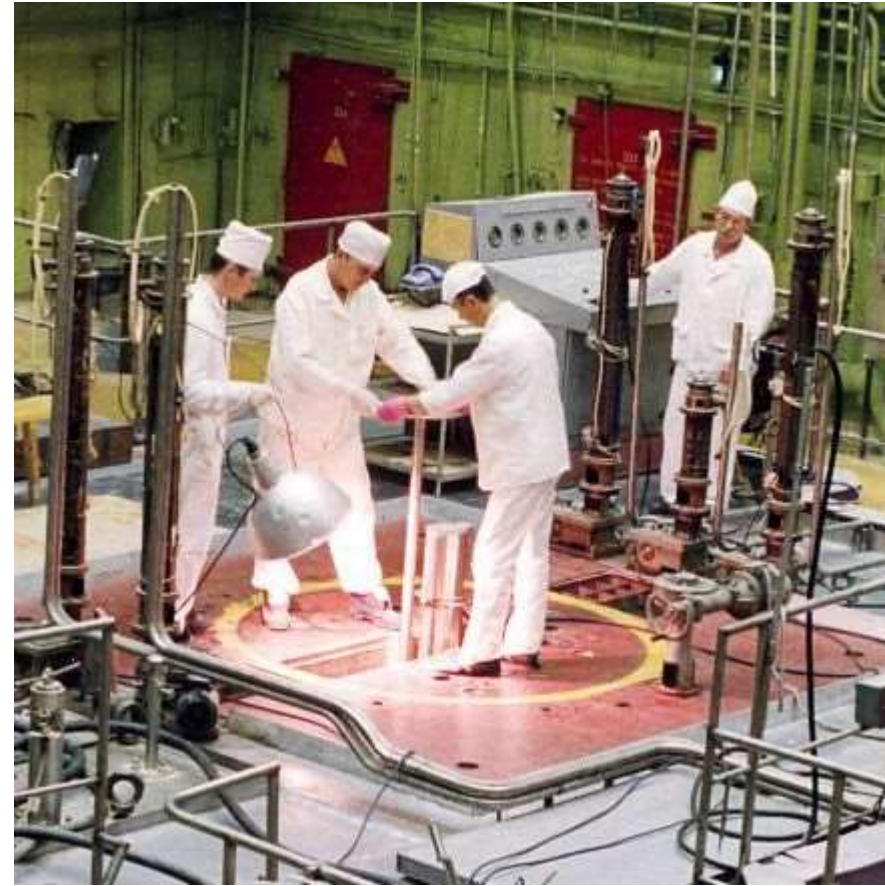
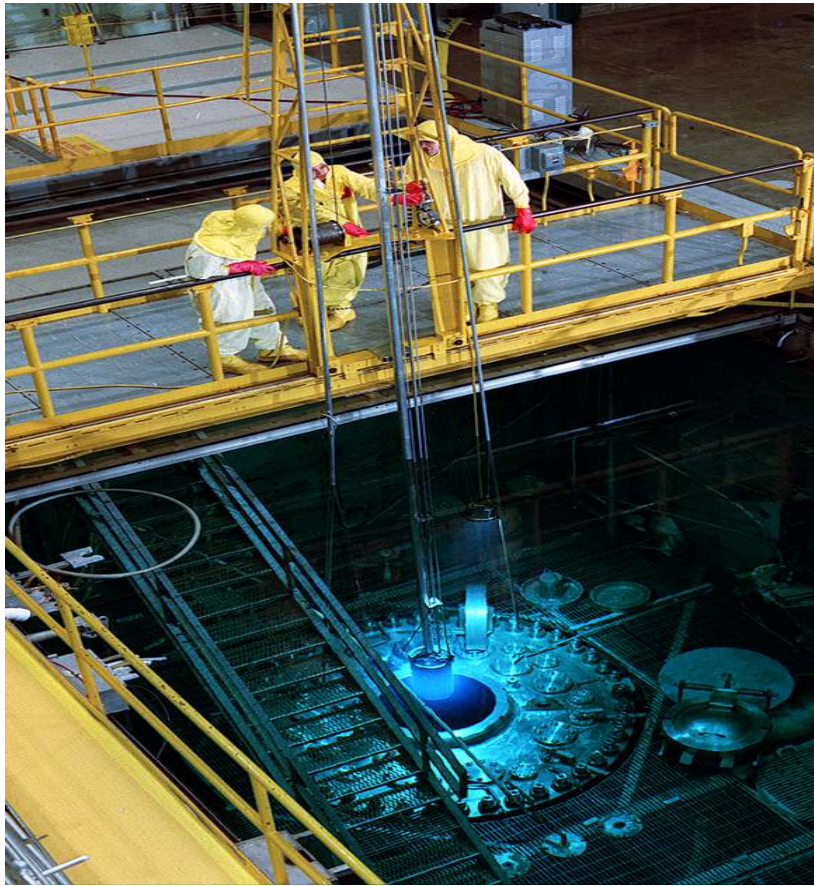
Why SHE are interesting?

- Nuclear physics;
- Electrodynamics of superstrong fields;
- Atomic physics;
- Relativistic chemistry;
- Astrophysical nucleosynthesis;
- ...
- Can be easily understood by taxpayers.

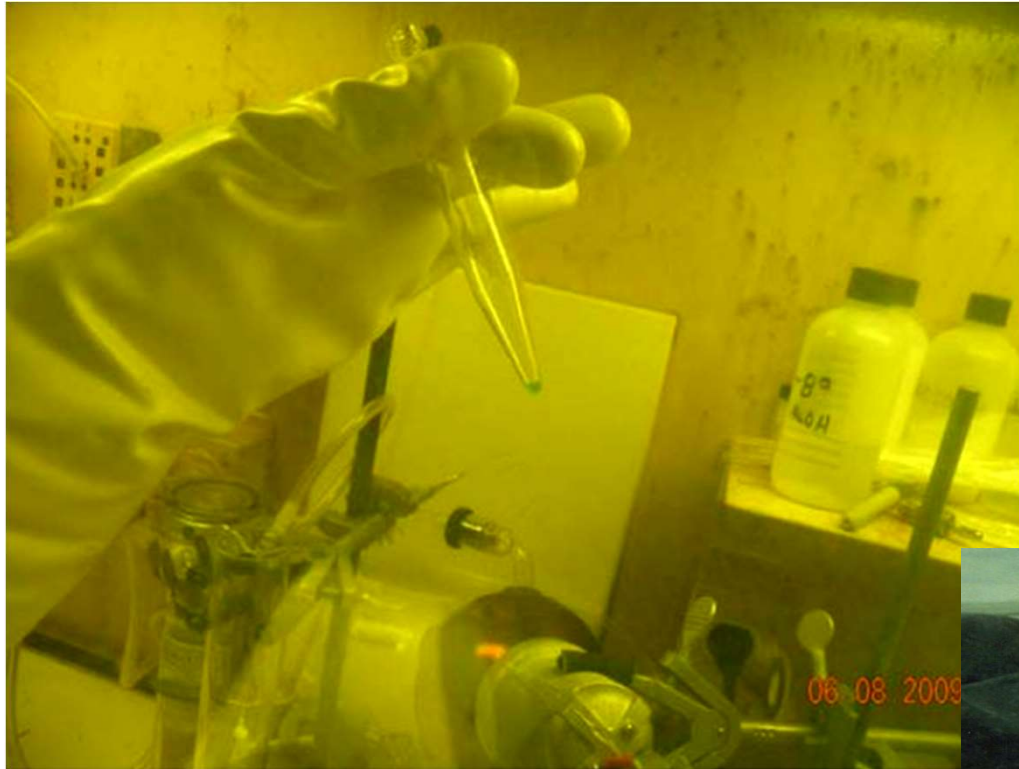
Isotope reactors

HFIR, ORNL, Oak Ridge, USA, 85 MW

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



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



$\text{Bk}(\text{NO}_3)_3$ Product

Prices per 1 mg

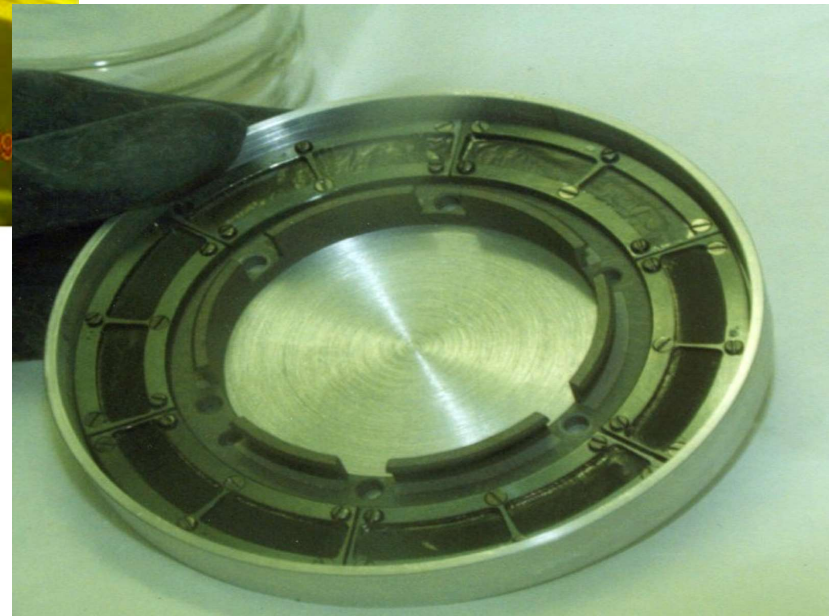
$^{197}\text{Au} \approx 0.045$ US\$

$\text{natU}_3\text{O}_8 \approx 0.03$ US\$

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

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

Target wheel



Superconducting 18 GHz ECR ion sources

~2 grams of ^{48}Ca

Ion source DECRIS-SC2



Consumption: 0.5-0.8 mg/h

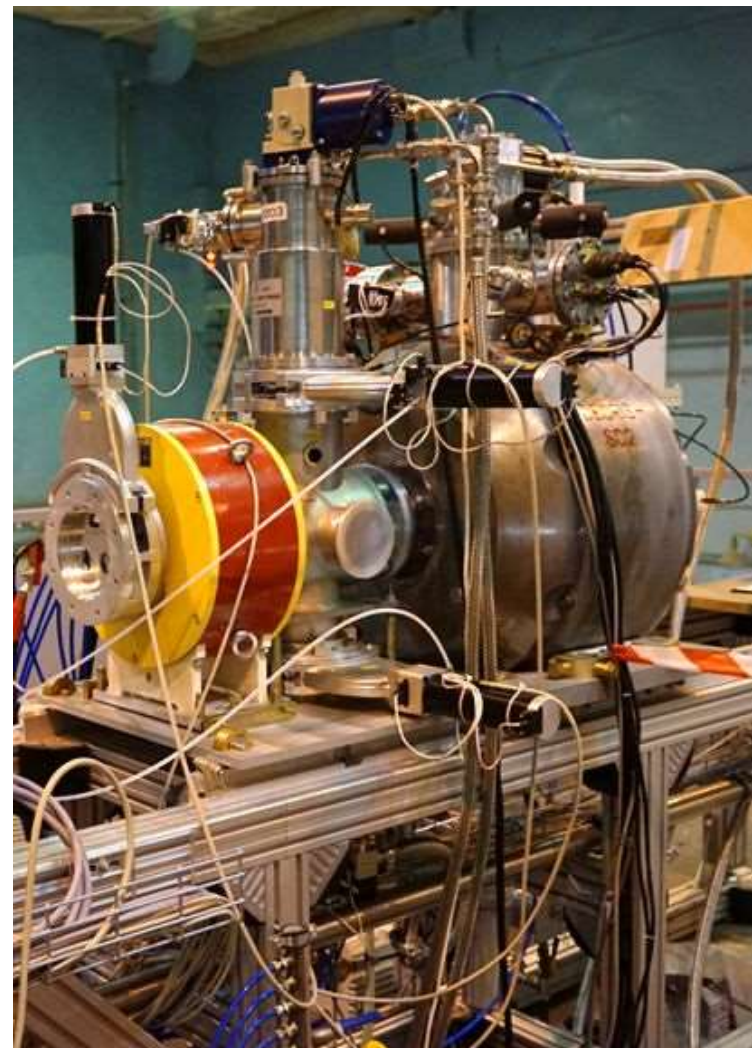
Prices per 1 mg

$^{197}\text{Au} \approx 0.045 \text{ US\$}$

$\text{natU}_3\text{O}_8 \approx 0.03 \text{ US\$}$

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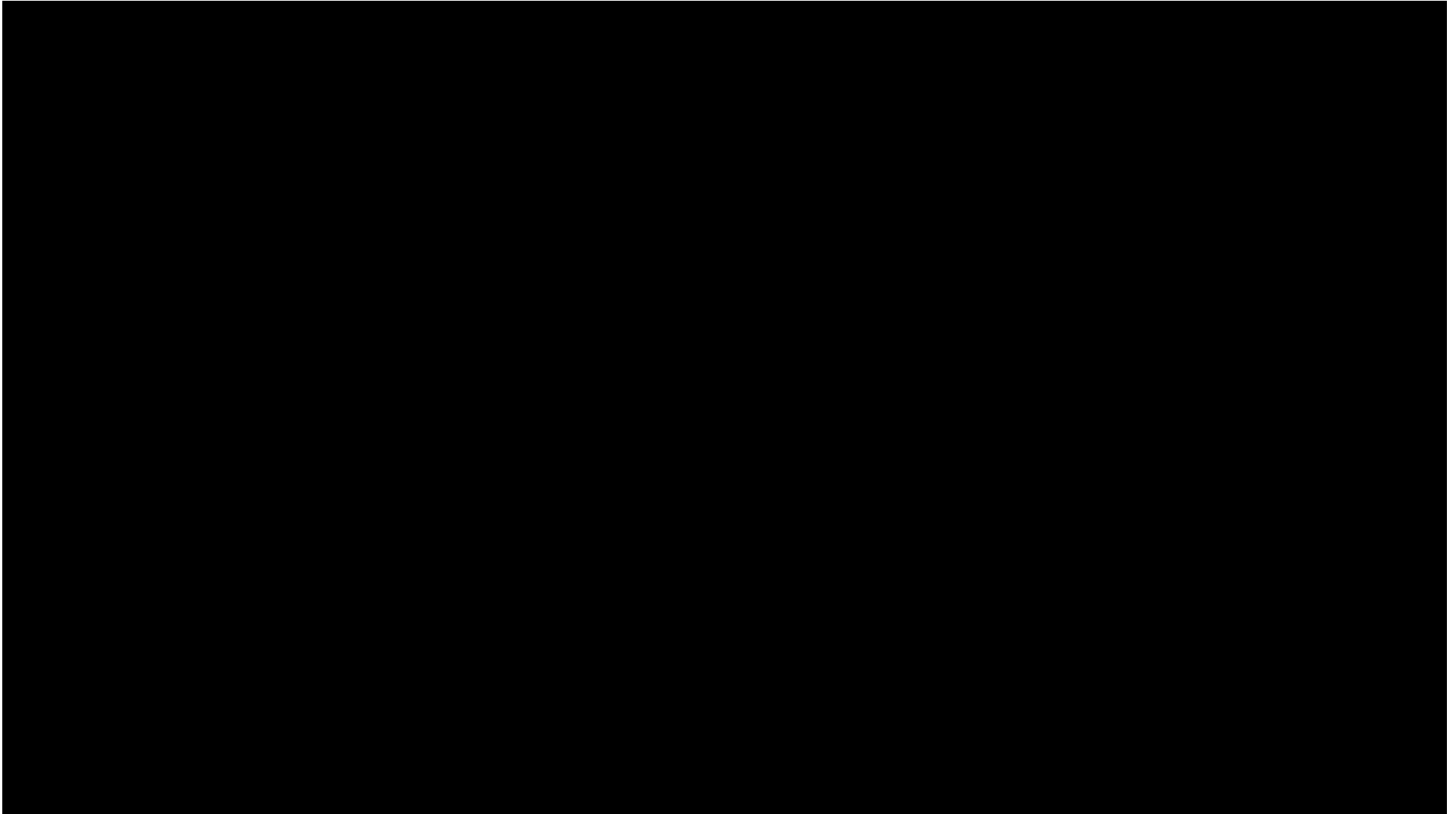
$^{48}\text{Ca} \approx 250 \text{ US\$}$



Synthesis of Superheavy Elements (U-400)



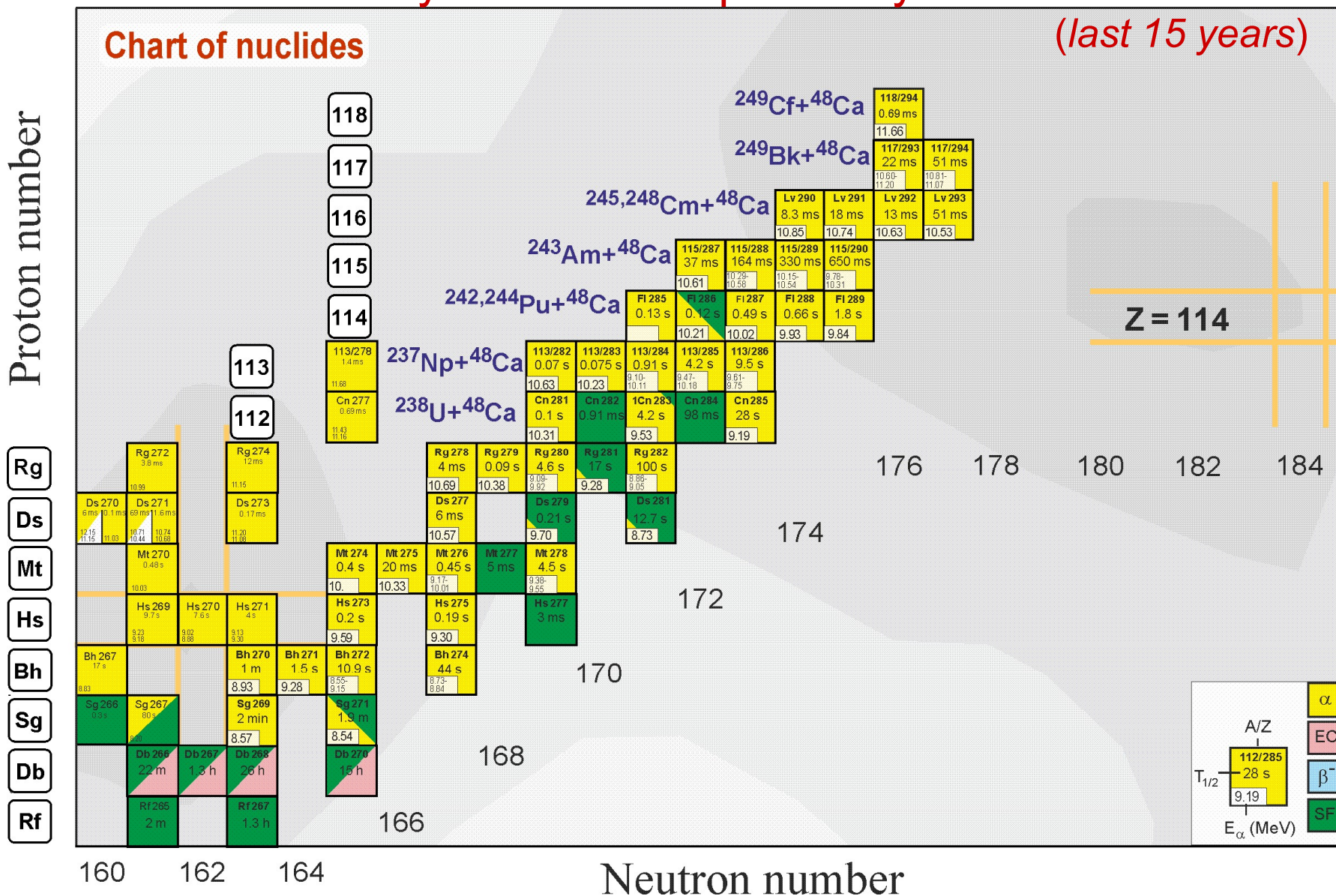
Synthesis of one SH nucleus



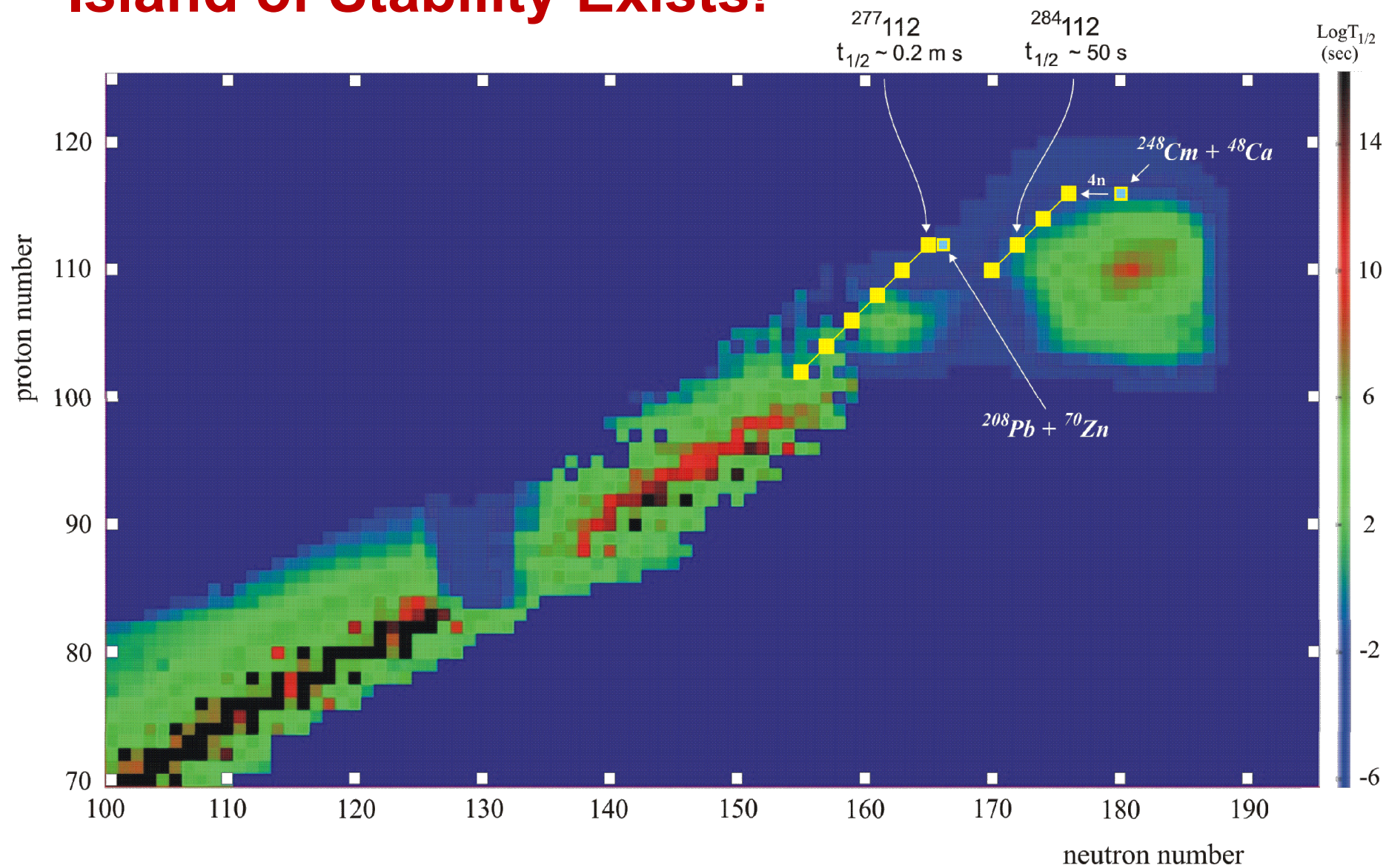
GREAT PROGRESS

in Synthesis of Superheavy Nuclei

(last 15 years)



Island of Stability Exists!



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**.

Флеровий 114	Московский 115	Ливерморий 116	Теннессин 117	Оганесон 118
Fl	Mc	Lv	Ts	Og
Flerovium	Moscovium	Livermorium	Tennessine	Oganesson

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

In pursuit of new elements



Berkeley Lab

USA, California, Berkeley:

1958 – **102**(No), 1961 – **103**(Lr), ...

Glenn Seaborg, Albert Ghiorso



USSR, Dubna: 1964-1975 – 102,103,104,105 (Dubnium), 106,107,108

G.N. Flerov, Yu.Ts. Oganessian

2000 – **114**, 2002 – **116**, 2003 – **113, 115, 118**, 2009 - **117**



Germany, Darmstadt, GSI:

1989 - 2000 – **108, 109, 110, 111, 112**

P. Armbruster, G. Münzenberg, S. Hofmann



Japan, Tokyo, RIKEN:

2002 – **110, 111, 112**, 2004 – **113**

K. Morita

Mendeleev's Table Today



Периодическая таблица элементов Д.И. Менделеева
D.I. Mendeleev's Periodic Table of Elements

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Актиноиды Actinoids

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Водород 1 H 1.00794 Hydrogen																	
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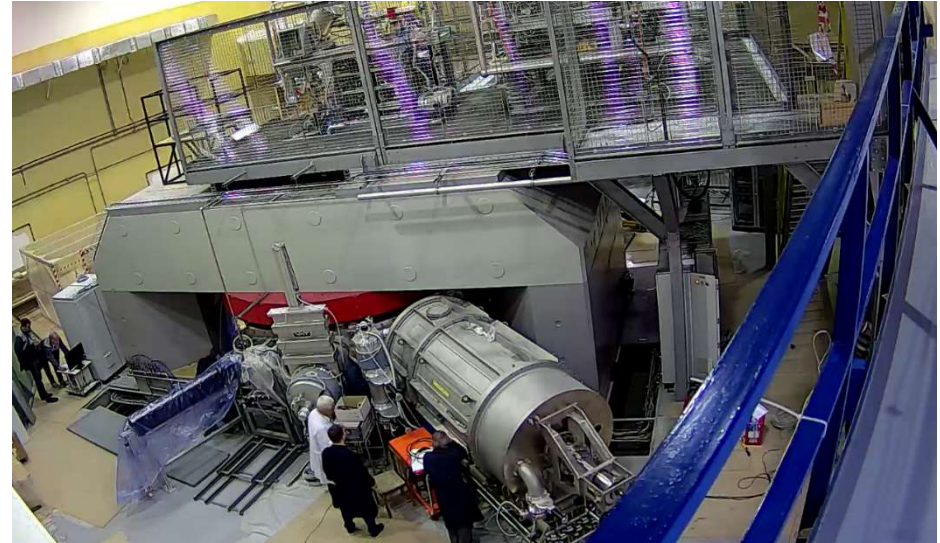
H - символ / symbol
1.00794 - атомная масса / atomic mass
1s¹ - электронная конфигурация / electron configuration
13.59844 - 1-я потенциальная ионизация, эВ / 1st ionization potential, eV
0.0899 - плотность, кг/м³ / density, kg/m³
-252.87 - температура плавления, °C / melting temperature, °C
-252.87 - температура кипения, °C / boiling temperature, °C

10 of 18 elements discovered during last 60 years were first synthesized in Dubna

Questions and answers:

- Do the SHE exist? – **YES!**
- Does the “Island of stability” of SHE exist? – **YES!**
- How to synthesis SHE? –
fusion reactions are yet the only working method
- How many new elements can be synthesized in the nearest nature –
119?, 120?, ???
- How many elements are in Mendeleev Periodic Table of Elements? -
???
- How to reach the center of the Island of stability? – **???**
- How long do live the most stable nuclei from the Island of stability -
???
- Can SHE be produced in nature? - **???**

Фабрика сверхтяжелых элементов



ЗАВЕРШАЕТСЯ СОЗДАНИЕ
запуск: 2018 год



**Study of exotic nuclei
close and beyond the nucleon stability limits**



January 2015

ACCULLINA-2

New separator
for study light exotic nuclei
and reactions with them

2015/16: *commissioning tests, 1st runs*

2016: *zero angle spectrometer*

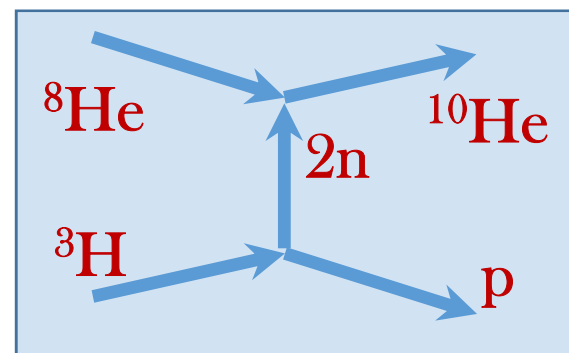
2018/19: *unique cryogenic tritium target*



Directions of the future researches:

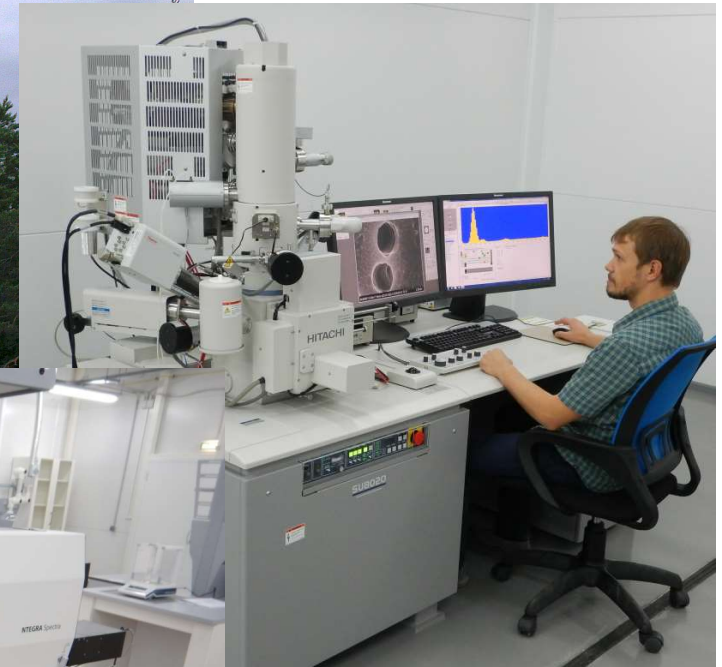
- structure of light exotic nuclei
- reactions with exotic nuclei
- study of rare decay modes

^{10}He : 2n-transfer



Applied research

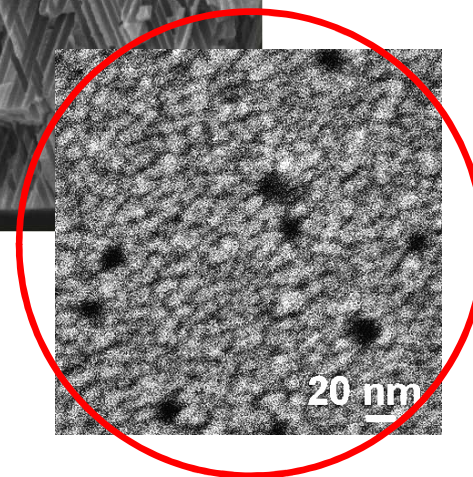
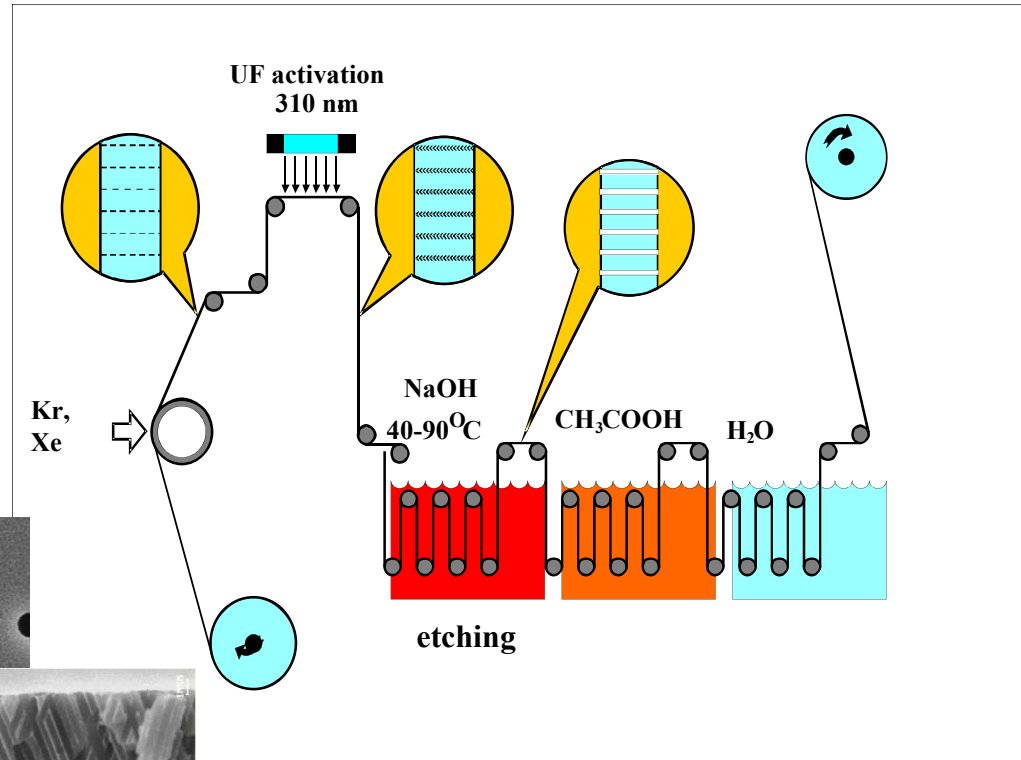
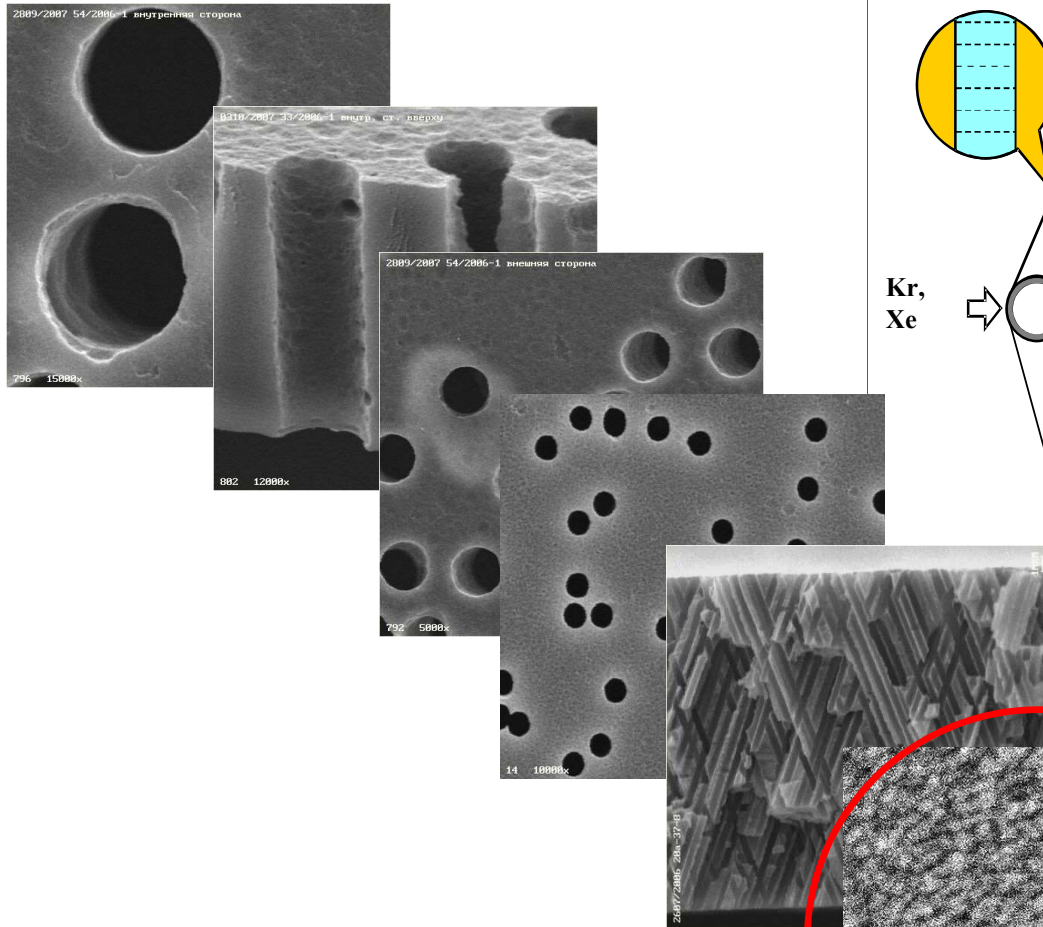
Nano Laboratory



- Scanning electron microscopes
- Atomic force microscopy
- X-Ray photoelectron spectroscopy
- Equipment for sample preparation
- ...

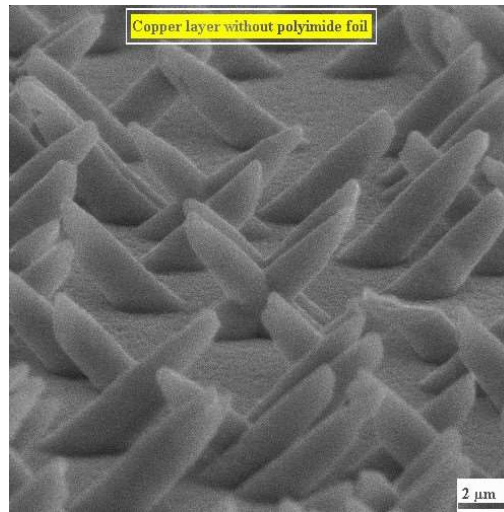
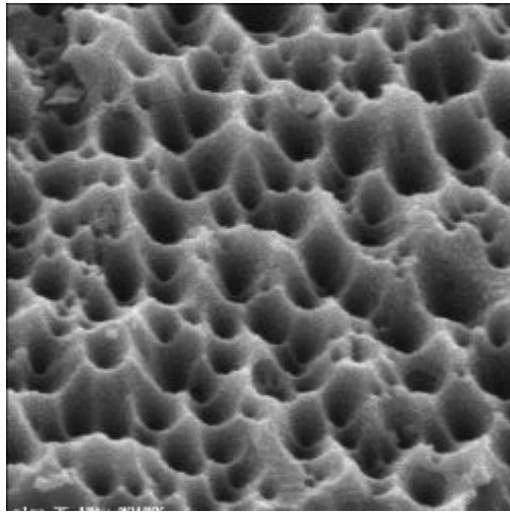
Production of track membranes (IC-100)

Micrometers



Nanometers

Accelerators-born nanostructures



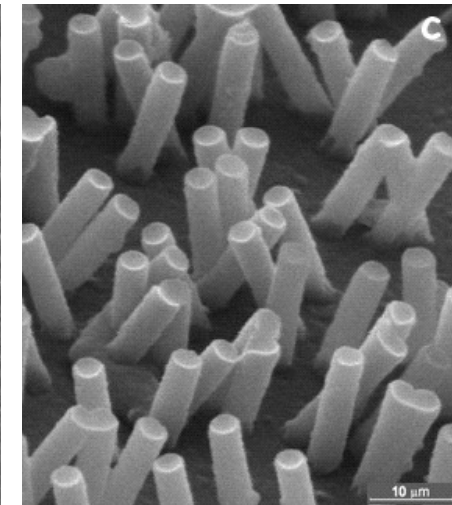
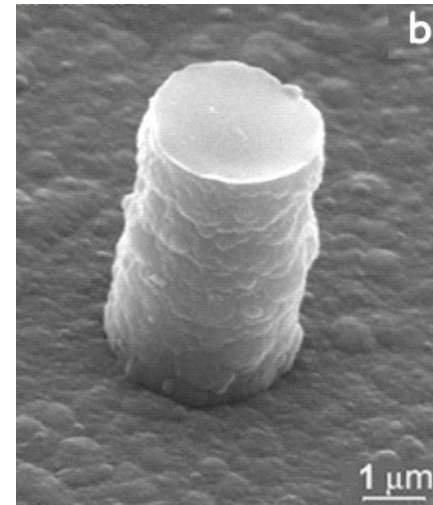
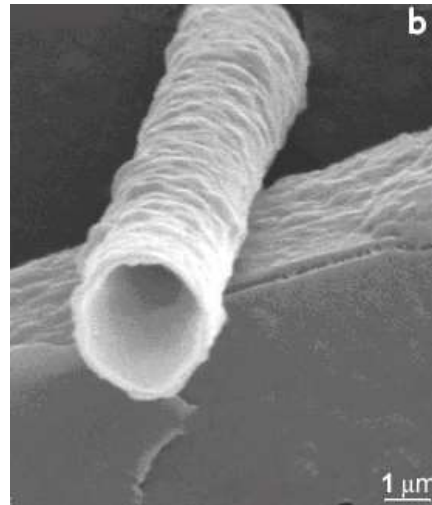
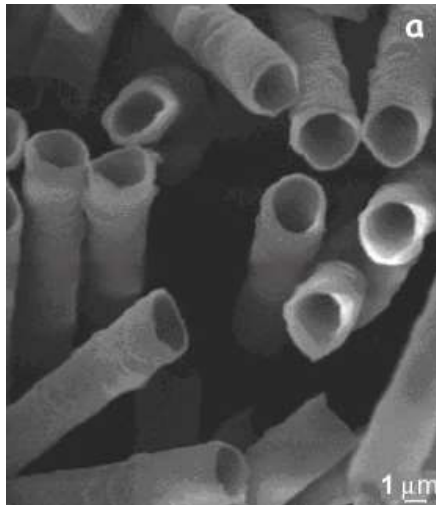
new composite materials:

- extended layers adhesion strength
- increased thermal resistance
- flexible printed circuit boards

Polymer composites produced with the use of track membranes

nanotubes

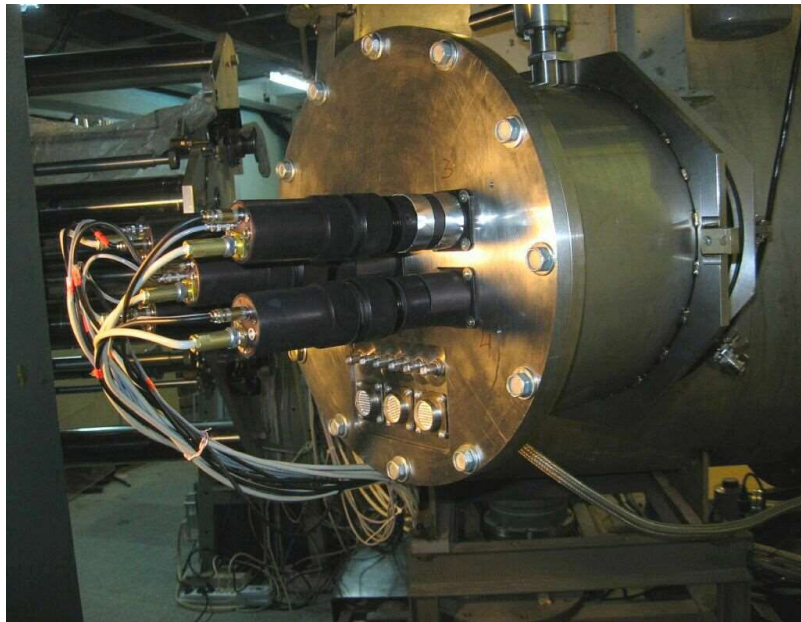
nanowires



Radiation Hardness Tests For Electronic Components

Development of radiation-proofed electronic components is the first priority task of the modern high-class electronic industry.

Long-distance space flights, long-lived sputniks, etc. are extremely critical to the quality of electronic chips.



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