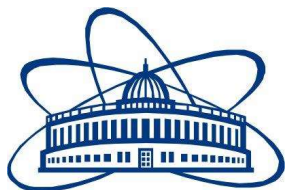




# Flerov Laboratory of Nuclear Reactions



**Alexander Karpov**



# LABORATORY FOUNDER

*Georgiy Nikolaevich FLEROV*



1913 – 1990

**1940**

Discovery of spontaneous fission of uranium

**1942-1950**

Participation in Russian atomic project

**1955**

First beams of accelerated heavy ions

**1957**

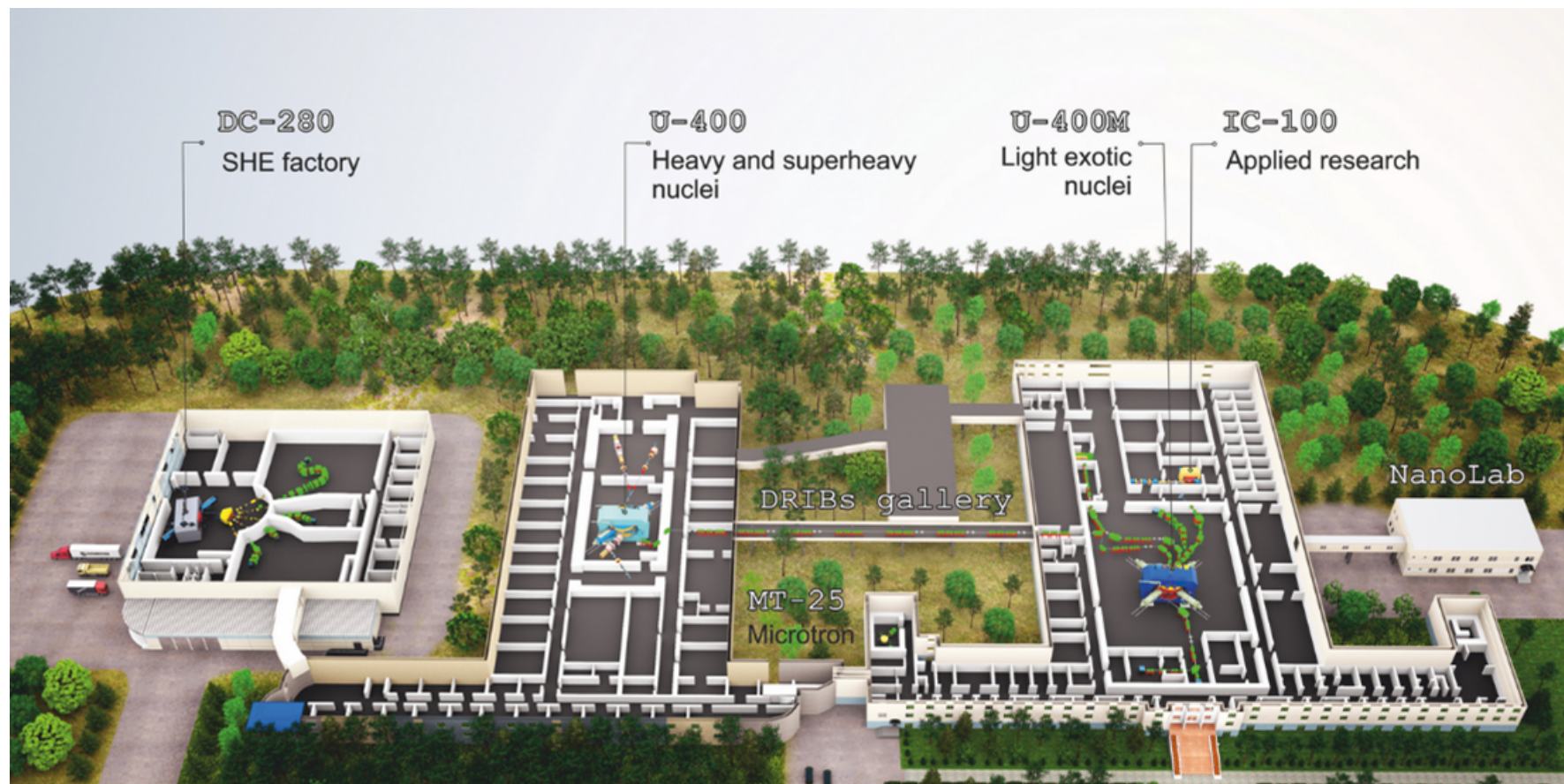
Foundation of Laboratory of Nuclear Reactions (Dubna)

**1962-1975**

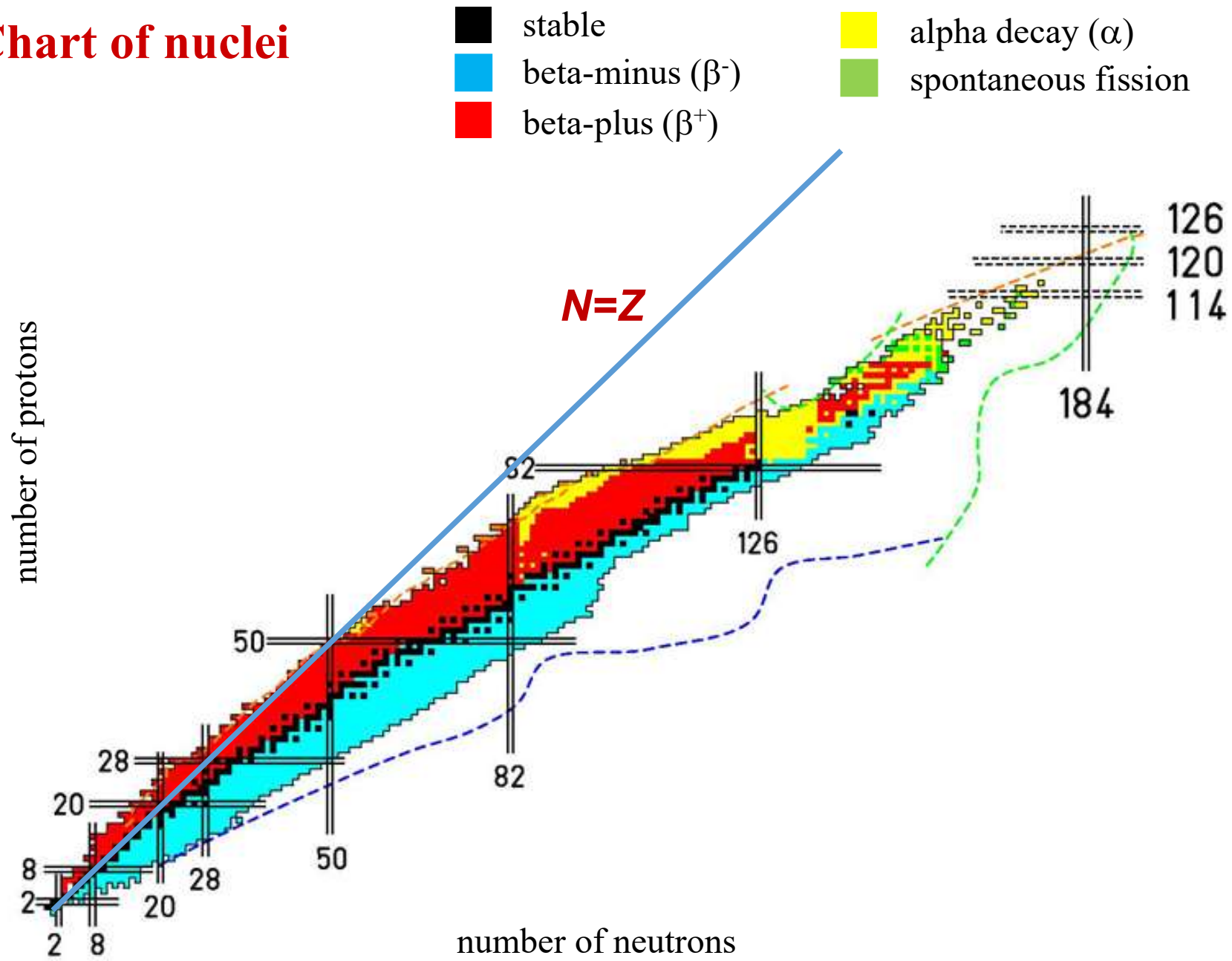
Synthesis of new elements: 102, 103, 104, 105 (Dubnium), 106, 107

**2012**

Element 114 named Flerovium



# Chart of nuclei



# 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

# Heavy and superheavy nuclei

# Mendeleev's Table (~150 years ago)

Описание системы элементовъ, составленной по сходству химическихъ свойствъ, и по числу атомовъ въ молекулахъ, Д. Менделѣевъ.

Менделѣевъ  
1869 г. 17 февр.

|                                |              |             |             |             |               |
|--------------------------------|--------------|-------------|-------------|-------------|---------------|
|                                | $? = 8$      | $? = 32$    | $Cu = 63.4$ | $Ag = 108$  | $Hg = 200$    |
| $H = 1$                        | $Li = 7$     | $Na = 23$   | $K = 39$    | $Rb = 85.4$ | $Cs = 132.6$  |
| <del><math>B = 11</math></del> | $B = 11$     | $Al = 27.4$ | $? = 68$    | $Mn = 116$  | $Zn = 117.5?$ |
| $C = 12$                       | $Si = 28$    | $? = 70$    | $Ca = 40$   | $Sc = 118$  | $Ni = 91.0?$  |
| $N = 14$                       | $P = 31$     | $As = 75$   | $Fe = 56$   | $B = 122$   | $Co = 128?$   |
| $O = 16$                       | $S = 32$     | $Se = 79.4$ | $Ni = 58$   | $Cr = 128$  | $Cd = 153$    |
| $F = 19$                       | $Cl = 35.5$  | $Br = 80$   | $Ni = 59$   | $Ni = 85.4$ | $Pt = 204$    |
| $Li = 7$                       | $Na = 23$    | $K = 39$    | $Ca = 40$   | $Sc = 87.6$ | $Pb = 207$    |
|                                | $? = 75$     | $Ce = 92$   |             | $La = 137$  |               |
|                                | $? Ce = 56?$ | $La = 94$   |             |             |               |
|                                | $? Yt = 60?$ | $Si = 95$   |             |             |               |
|                                | $? Zn = 75?$ | $H = 118?$  |             |             |               |

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

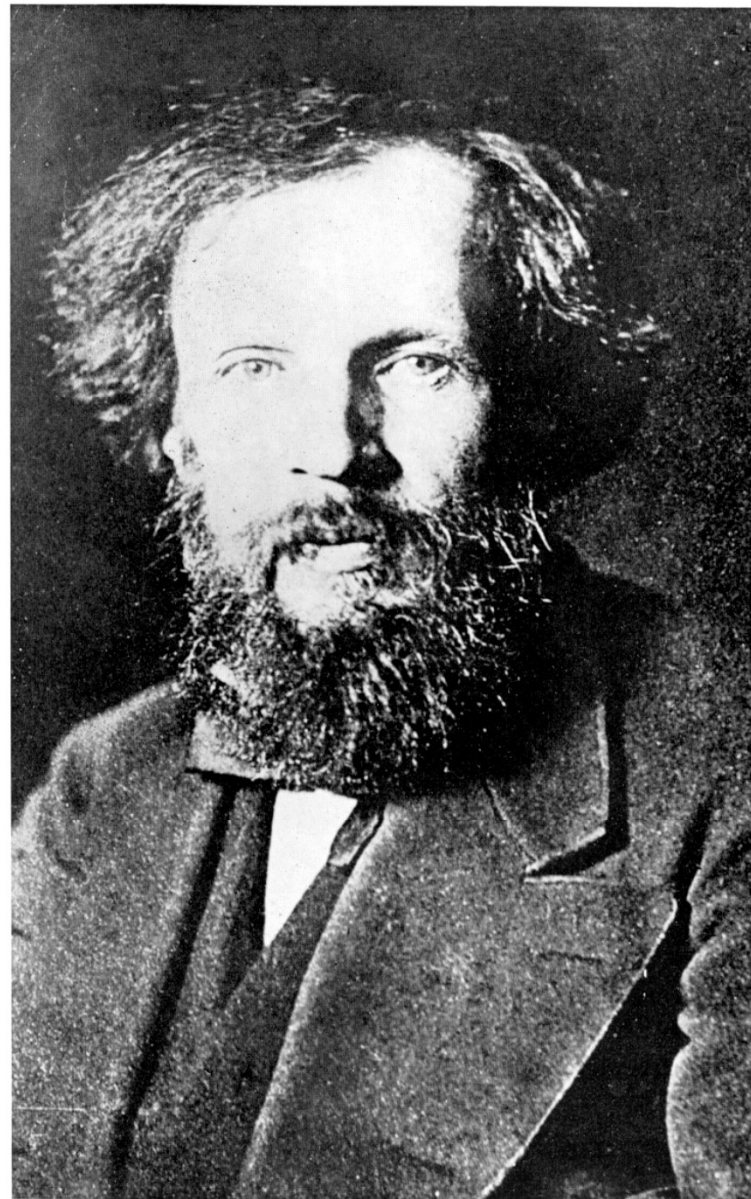
Prof. de chimie à l'Université de Kazan.

18 II 69.  
17

Надъясно б  
Амо се дало  
и суммарно  
описание  
Атомовъ въ молекулахъ  
и о химическомъ  
свойствѣ ихъ  
по числу атомовъ въ молекулахъ  
и по сходству химическихъ свойствъ  
Д. Менделѣевъ.

Ученый секретарь  
Казанскаго университета  
А. С. Сиверс.

Андрей К. Мельниковъ, Казань, 1869 г.



# 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<br><b>H</b><br>1.00794<br>Hydrogen   | 2   |   |  |  |   |   |  |   |   |  |   |   |   |   |   |  |  | Гелий 2<br><b>He</b><br>4.0026<br>Helium |
| Литий 3<br><b>Li</b><br>6.941<br>Lithium       | Бериллий 4<br><b>Be</b><br>9.01218<br>Beryllium |   |  |  |   |   |  |   |   |  |   |   |   |   |   |  |  | Неон 10<br><b>Ne</b><br>20.1797<br>Neon  |
| Натрий 11<br><b>Na</b><br>22.989768<br>Sodium  | Магний 12<br><b>Mg</b><br>24.3050<br>Magnesium  | 3   | 4  | 5  | 6   | 7   | 8  | 9   | 10  | 11   | 12  | Алюминий 13<br><b>Al</b><br>26.981539<br>Aluminum | Кремний 14<br><b>Si</b><br>28.0855<br>Silicon   | Фосфор 15<br><b>P</b><br>30.97376<br>Phosphorus | Сера 16<br><b>S</b><br>32.066<br>Sulfur             | Хлор 17<br><b>Cl</b><br>35.4527<br>Chlorine      | Аргон 18<br><b>Ar</b><br>39.948<br>Argon         |  |
| Калий 19<br><b>K</b><br>39.0983<br>Potassium   | Кальций 20<br><b>Ca</b><br>40.078<br>Calcium    | Скандий 21<br><b>Sc</b><br>44.95591<br>Scandium | Титан 22<br><b>Ti</b><br>47.88<br>Titanium             | Ванадий 23<br><b>V</b><br>50.9415<br>Vanadium  | Хром 24<br><b>Cr</b><br>51.9961<br>Chromium     | Марганец 25<br><b>Mn</b><br>54.93805<br>Manganese | Железо 26<br><b>Fe</b><br>55.847<br>Iron       | Кобальт 27<br><b>Co</b><br>58.93320<br>Cobalt     | Никель 28<br><b>Ni</b><br>58.6934<br>Nickel           | Медь 29<br><b>Cu</b><br>63.546<br>Copper           | Цинк 30<br><b>Zn</b><br>65.39<br>Zinc                 | Галлий 31<br><b>Ga</b><br>69.723<br>Gallium       | Германий 32<br><b>Ge</b><br>72.61<br>Germanium  | Мышьяк 33<br><b>As</b><br>74.92159<br>Arsenic   | Селен 34<br><b>Se</b><br>78.96<br>Selenium          | Бром 35<br><b>Br</b><br>79.904<br>Bromine        | Криpton 36<br><b>Kr</b><br>83.80<br>Krypton      |  |
| Рубидий 37<br><b>Rb</b><br>85.4678<br>Rubidium | Стронций 38<br><b>Sr</b><br>87.62<br>Strontium  | Иттрий 39<br><b>Y</b><br>88.90585<br>Yttrium    | Цирконий 40<br><b>Zr</b><br>91.224<br>Zirconium        | Нобий 41<br><b>Nb</b><br>92.90638<br>Niobium   | Молибден 42<br><b>Mo</b><br>95.94<br>Molybdenum | Технеций 43<br><b>Tc</b><br>[98]<br>Technetium    | Рутений 44<br><b>Ru</b><br>101.07<br>Ruthenium | Родий 45<br><b>Rh</b><br>102.90550<br>Rhodium     | Палладий 46<br><b>Pd</b><br>106.42<br>Palladium       | Серебро 47<br><b>Ag</b><br>107.8682<br>Silver      | Кадмий 48<br><b>Cd</b><br>112.411<br>Cadmium          | Индий 49<br><b>In</b><br>114.818<br>Indium        | Олово 50<br><b>Sn</b><br>118.710<br>Tin         | Сурьма 51<br><b>Sb</b><br>121.757<br>Antimony   | Теллур 52<br><b>Te</b><br>127.60<br>Tellurium       | Йод 53<br><b>I</b><br>126.90447<br>Iodine        | Ксенон 54<br><b>Xe</b><br>131.29<br>Xenon        |  |
| Цезий 55<br><b>Cs</b><br>132.90543<br>Cesium   | Барий 56<br><b>Ba</b><br>137.327<br>Barium      | Лантан 57<br><b>La</b><br>138.9055<br>Lanthanum | Гафний 72<br><b>Hf</b><br>178.49<br>Hafnium            | Тантал 73<br><b>Ta</b><br>180.9479<br>Tantalum | Вольфрам 74<br><b>W</b><br>183.84<br>Tungsten   | Рений 75<br><b>Re</b><br>186.207<br>Rhenium       | Осмий 76<br><b>Os</b><br>190.23<br>Osmium      | Иридий 77<br><b>Ir</b><br>192.22<br>Iridium       | Платина 78<br><b>Pt</b><br>195.08<br>Platinum         | Золото 79<br><b>Au</b><br>196.96654<br>Gold        | Ртуть 80<br><b>Hg</b><br>200.59<br>Mercury            | Таллий 81<br><b>Tl</b><br>204.3873<br>Thallium    | Свинец 82<br><b>Pb</b><br>207.2<br>Lead         | Висмут 83<br><b>Bi</b><br>208.98037<br>Bismuth  | Полюний 84<br><b>Po</b><br>[209]<br>Polonium        | Астат 85<br><b>At</b><br>[210]<br>Astatine       | Радон 86<br><b>Rn</b><br>[222]<br>Radon          |  |
| Франций 87<br><b>Fr</b><br>[223]<br>Francium   | Радий 88<br><b>Ra</b><br>[226]<br>Radium        | Актиний 89<br><b>Ac</b><br>[227]<br>Actinium    | Резерфордий 104<br><b>Rf</b><br>[261]<br>Rutherfordium | Дубний 105<br><b>Db</b><br>[262]<br>Dubnium    | Сгегей 106<br><b>Sg</b><br>[266]<br>Seaborgium  | Борий 107<br><b>Bh</b><br>[267]<br>Bohrium        | Хассий 108<br><b>Hs</b><br>[269]<br>Hassium    | Мейтнерий 109<br><b>Mt</b><br>[270]<br>Meitnerium | Дармштадтий 110<br><b>Ds</b><br>[271]<br>Darmstadtium | Рентгений 111<br><b>Rg</b><br>[272]<br>Roentgenium | Коперниковий 112<br><b>Cn</b><br>[285]<br>Copernicium | Нихоний 113<br><b>Nh</b><br>[286]<br>Nihonium     | Флеровий 114<br><b>Fl</b><br>[289]<br>Flerovium | Московий 115<br><b>Mc</b><br>[290]<br>Moscovium | Ливерморий 116<br><b>Lv</b><br>[293]<br>Livermorium | Теннесси 117<br><b>Ts</b><br>[294]<br>Tennessine | Оганesson 118<br><b>Og</b><br>[294]<br>Oganesson |  |

## Лантаноиды Lanthanoids

|  |   |  |   |   |  |   |  |   |   |   |   |   |  |
|--|---|--|---|---|--|---|--|---|---|---|---|---|--|
| Церий 58<br><b>Ce</b><br>140.115<br>Cerium | Прометий 59<br><b>Pr</b><br>140.90765<br>Praseodymium | Неодим 60<br><b>Nd</b><br>144.242<br>Neodymium | Прометий 61<br><b>Pm</b><br>[145]<br>Promethium | Самарий 62<br><b>Sm</b><br>150.36<br>Samarium | Европий 63<br><b>Eu</b><br>151.965<br>Europium | Гадолиний 64<br><b>Gd</b><br>157.25<br>Gadolinium | Тербий 65<br><b>Tb</b><br>158.92534<br>Terbium | Диспрозий 66<br><b>Dy</b><br>162.59<br>Dysprosium | Гольмий 67<br><b>Ho</b><br>164.93032<br>Holmium | Эрбий 68<br><b>Er</b><br>167.26<br>Erbium | Тулий 69<br><b>Tm</b><br>168.93421<br>Thulium | Иттербий 70<br><b>Yb</b><br>173.04<br>Ytterbium | Лютеций 71<br><b>Lu</b><br>174.967<br>Lutetium |
|--|---|--|---|---|--|---|--|---|---|---|---|---|--|

|  |
|--|
| Водород 1<br><b>H</b><br>1.00794<br>Hydrogen |
|--|

## Актиноиды Actinoids

|  |  |  |  |  |  |  |   |  |  |   |  |   |   |
|--|--|--|--|--|--|--|---|--|--|---|--|---|---|
| Торий 90<br><b>Th</b><br>232.0381<br>Thorium | Протактиний 91<br><b>Pa</b><br>[231]<br>Protactinium | Уран 92<br><b>U</b><br>238.0289<br>Uranium | Нептуний 93<br><b>Np</b><br>[237]<br>Neptunium | Плутоний 94<br><b>Pu</b><br>[244]<br>Plutonium | Америций 95<br><b>Am</b><br>[243]<br>Americium | Кюрий 96<br><b>Cm</b><br>[247]<br>Curium | Берклий 97<br><b>Bk</b><br>[247]<br>Berkelium | Калифорний 98<br><b>Cf</b><br>[251]<br>Californium | Эйнштейний 99<br><b>Es</b><br>[252]<br>Einsteinium | Фермий 100<br><b>Fm</b><br>[257]<br>Fermium | Менделеевий 101<br><b>Md</b><br>[261]<br>Mendelevium | Нобелий 102<br><b>No</b><br>[262]<br>Nobelium | Лоуренсий 103<br><b>Lr</b><br>[262]<br>Lawrencium |
|--|--|--|--|--|--|--|---|--|--|---|--|---|---|

H - символ / symbol  
1.00794 - атомная масса / atomic mass  
1s<sup>1</sup> - электронная конфигурация / electron configuration  
13.59844 - 1-я потенциальная ионизация, эВ / 1st ionization potential, eV  
0.0899 - плотность, кг/м<sup>3</sup> / density, kg/m<sup>3</sup>  
-259.24 - 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**





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**

**30<sup>th</sup> 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.

**28<sup>th</sup> November 2016:**

IUPAC formally approved names and symbols of new elements:

**Nihonium** (Nh) for element **113**,

**Moscovium** (Mc) for element **115**,

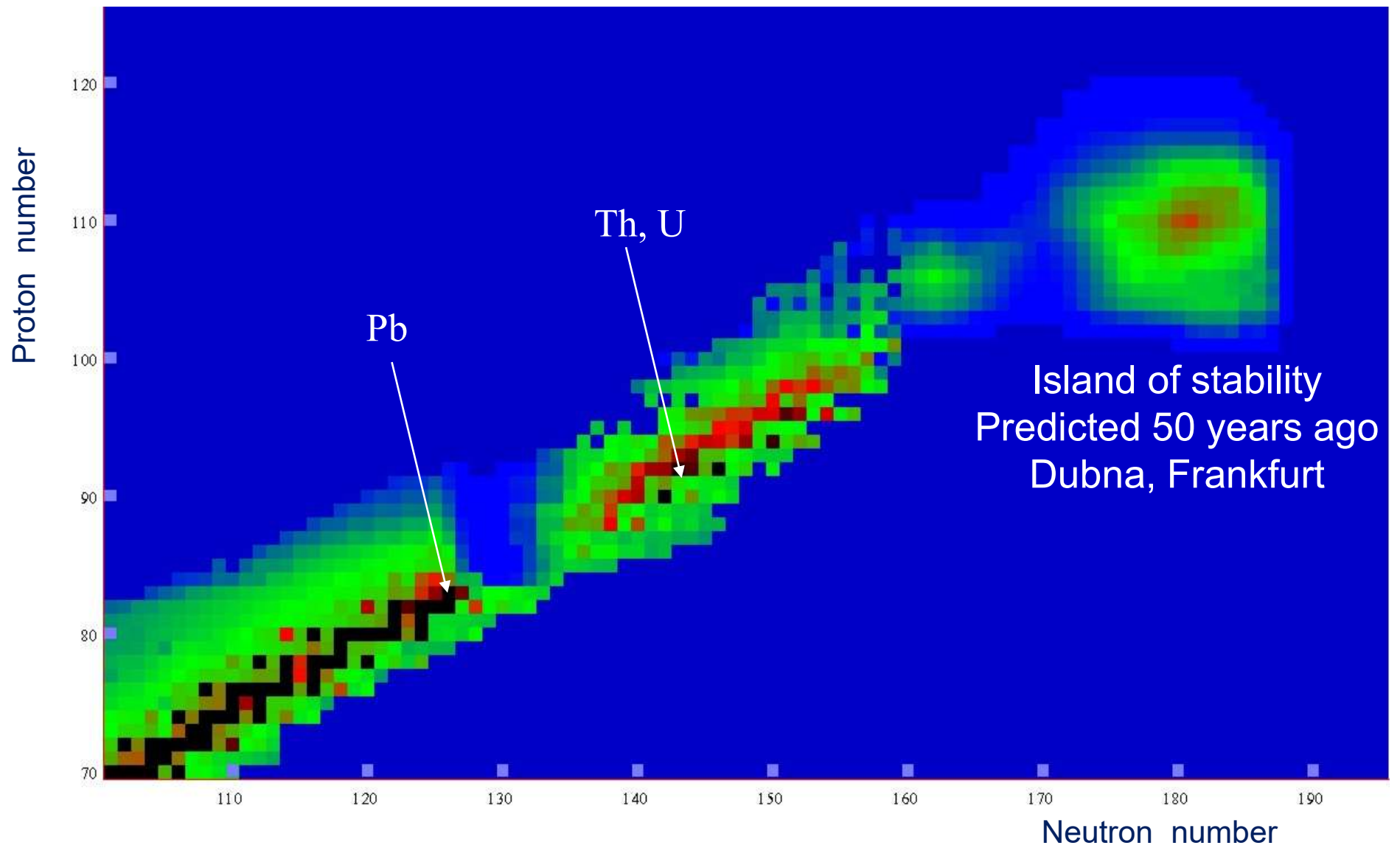
**Tennessine** (Ts) for element **117**, and

**Oganesson** (Og) for element **118**.

|                     |                       |                       |                      |                     |
|---------------------|-----------------------|-----------------------|----------------------|---------------------|
| Флеровий <b>114</b> | Московский <b>115</b> | Ливерморий <b>116</b> | Теннессин <b>117</b> | Оганесон <b>118</b> |
| <b>Fl</b>           | <b>Mc</b>             | <b>Lv</b>             | <b>Ts</b>            | <b>Og</b>           |
| 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.*

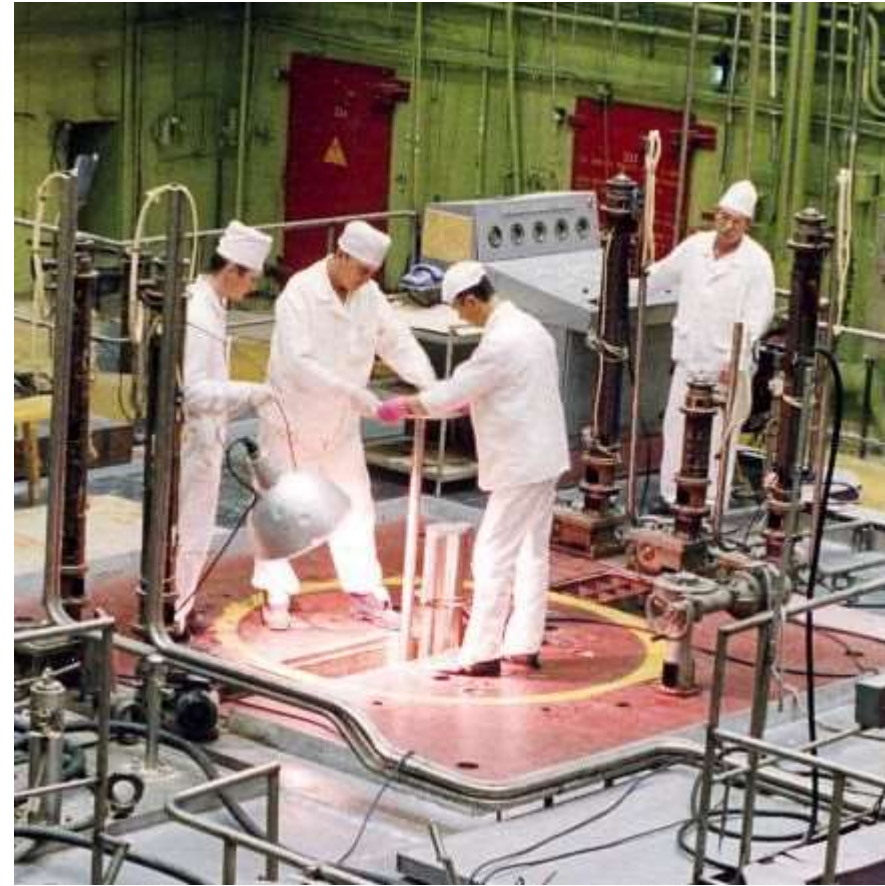
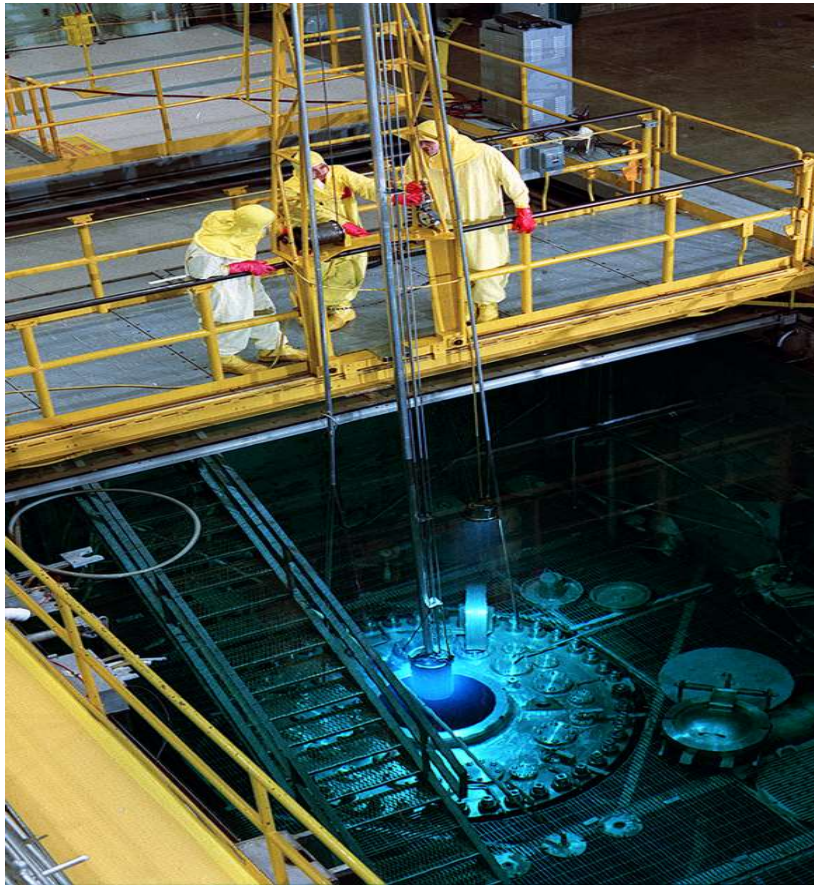
# Chart of Nuclei



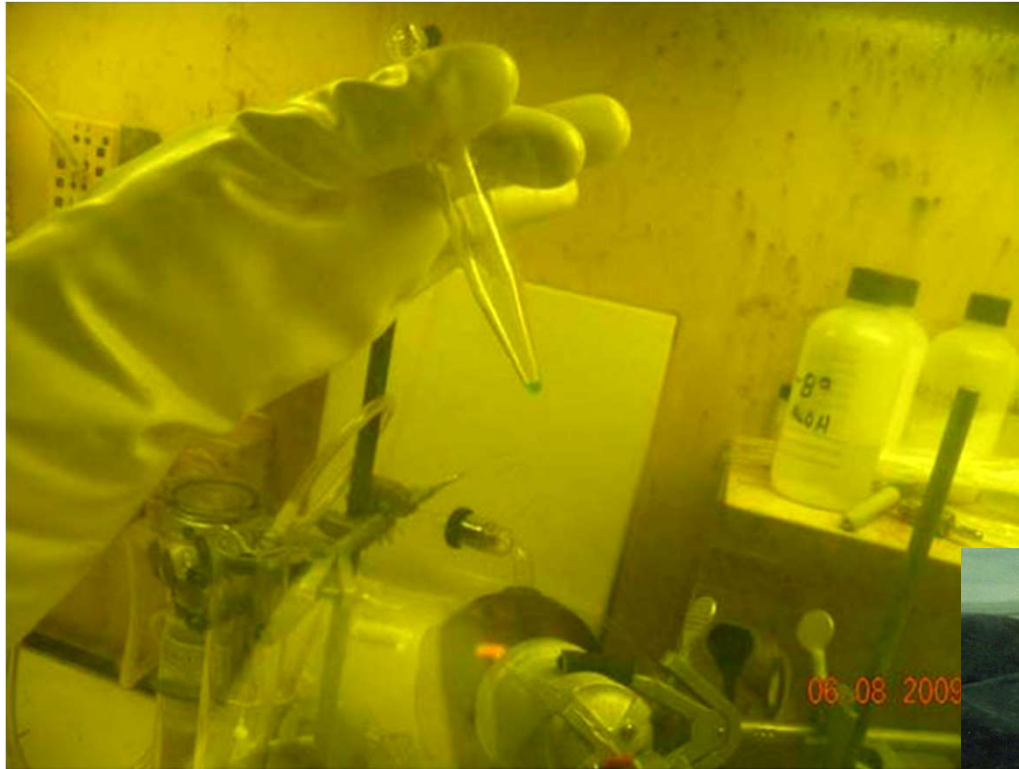
# Isotope reactors

HFIR, ORNL, Oak Ridge, USA, 85 MW

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



# 22 mg of $^{249}\text{Bk}$ have been produced in HIFR ORNL



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

## Prices per 1 mg

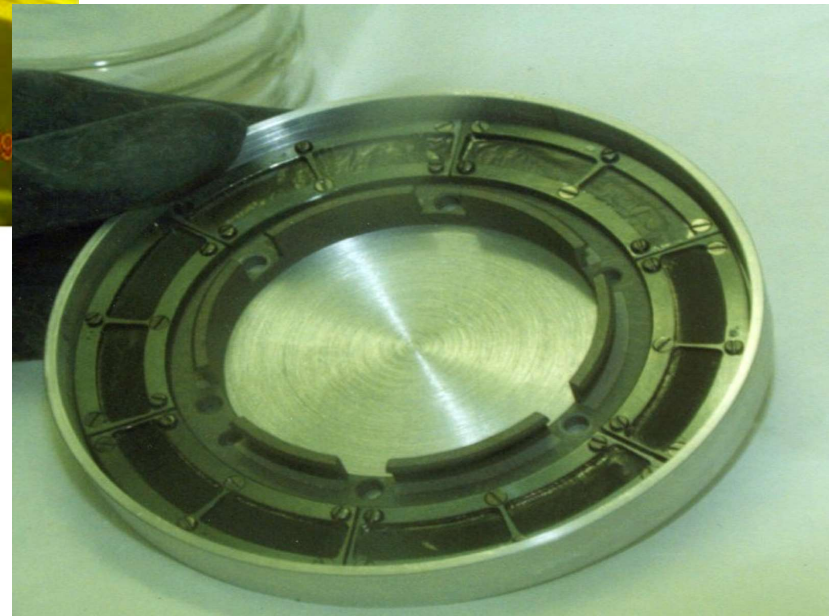
$^{197}\text{Au} \approx 0.045$  US\$

$\text{natU}_3\text{O}_8 \approx 0.03$  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  $^{48}\text{Ca}$

Ion source DECRIS-SC2



Consumption: 0.5-0.8 mg/h

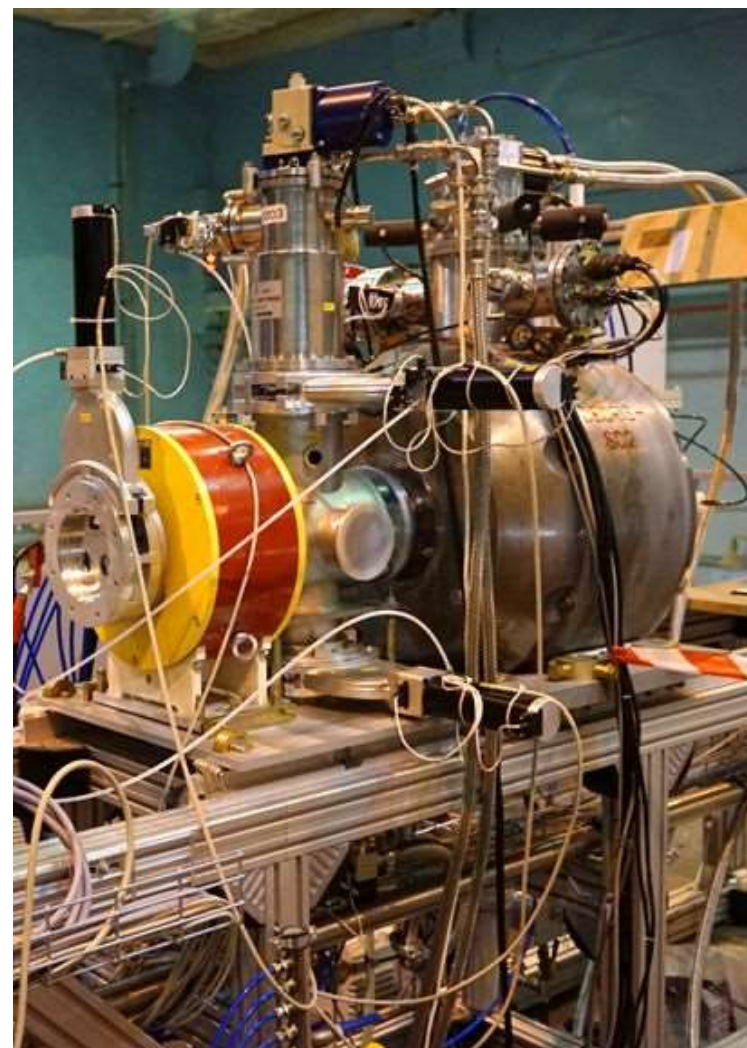
Prices per 1 mg

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

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

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

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



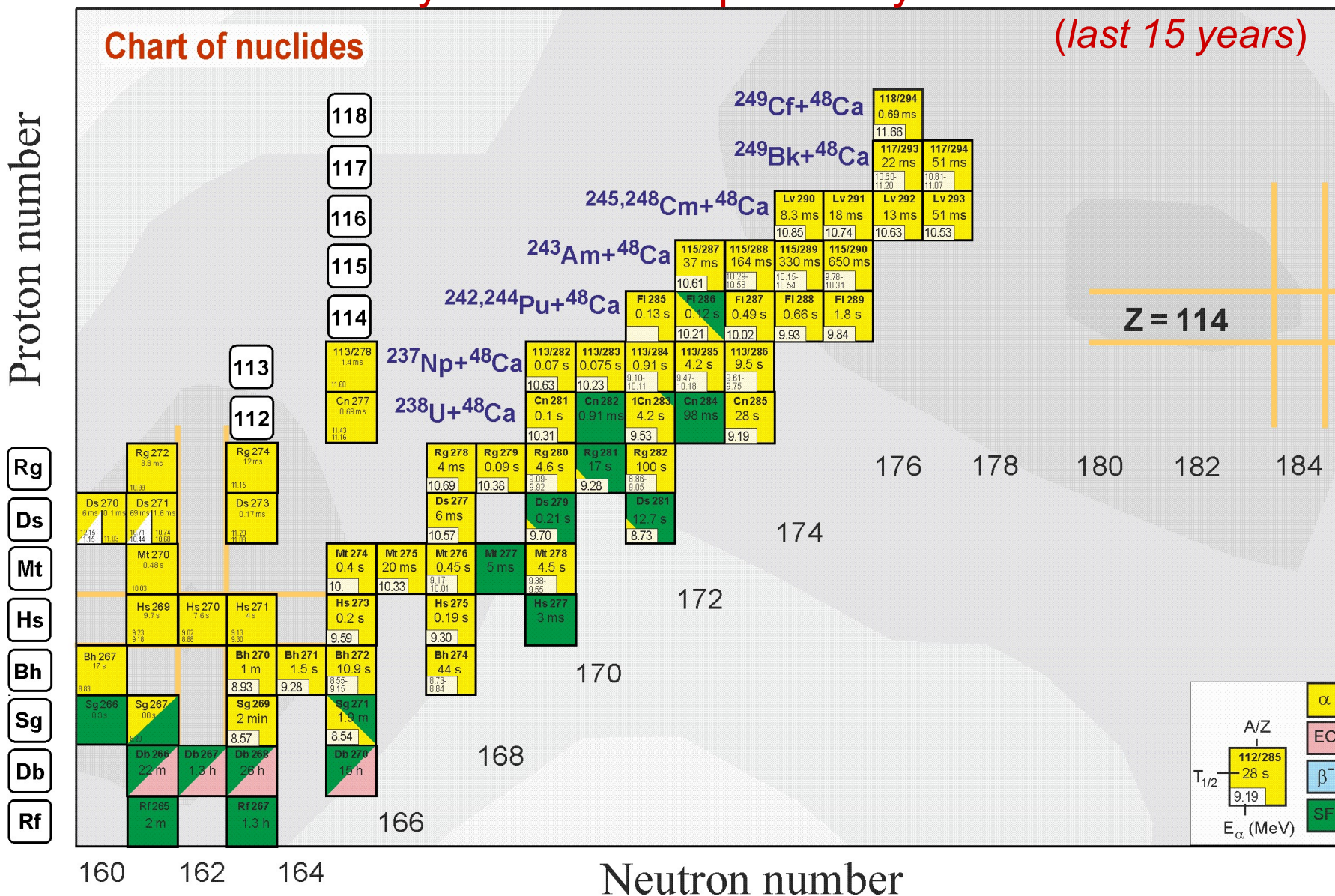
# Synthesis of Superheavy Elements (U-400)



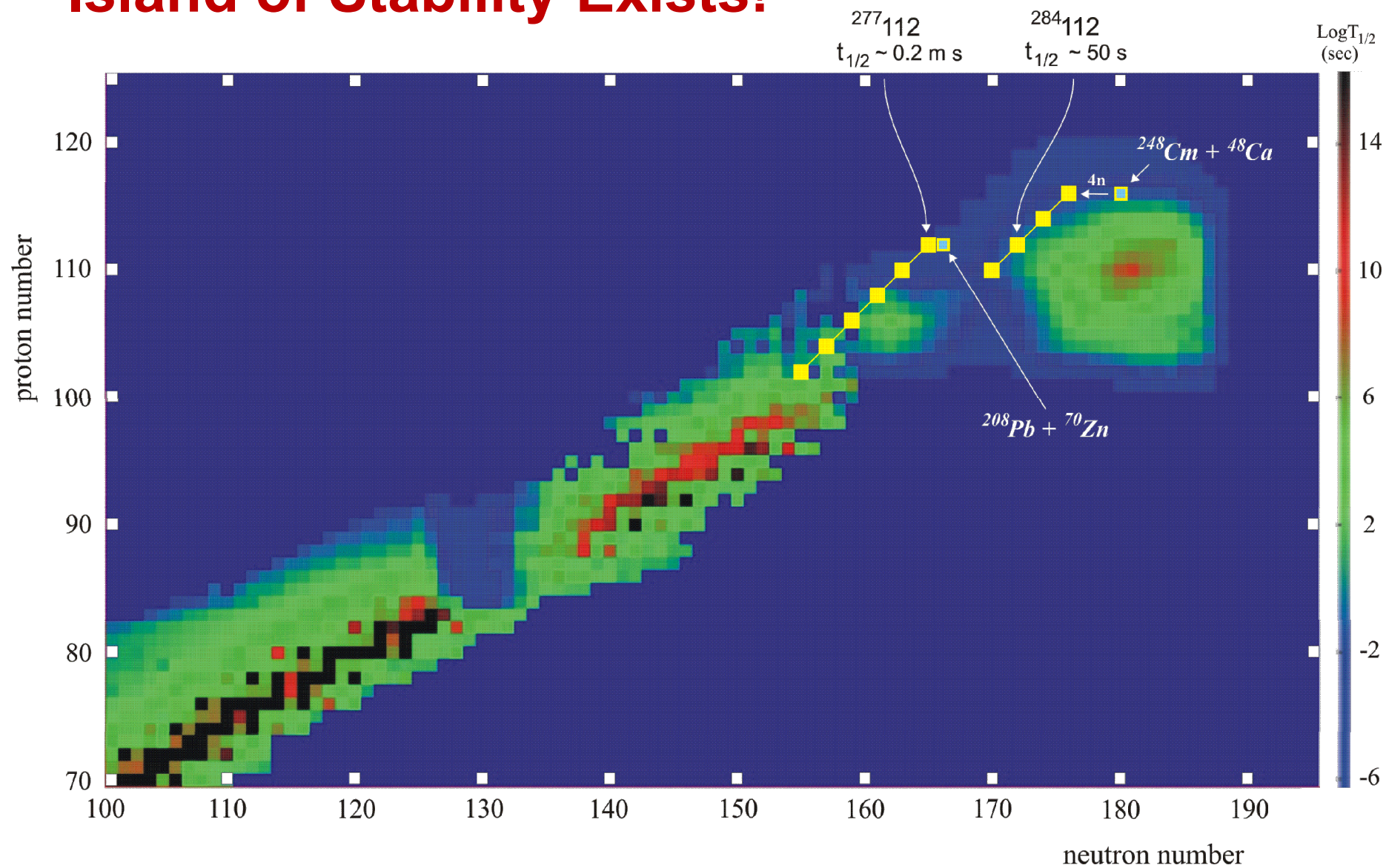
# GREAT PROGRESS

## in Synthesis of Superheavy Nuclei

(last 15 years)



# Island of Stability Exists!





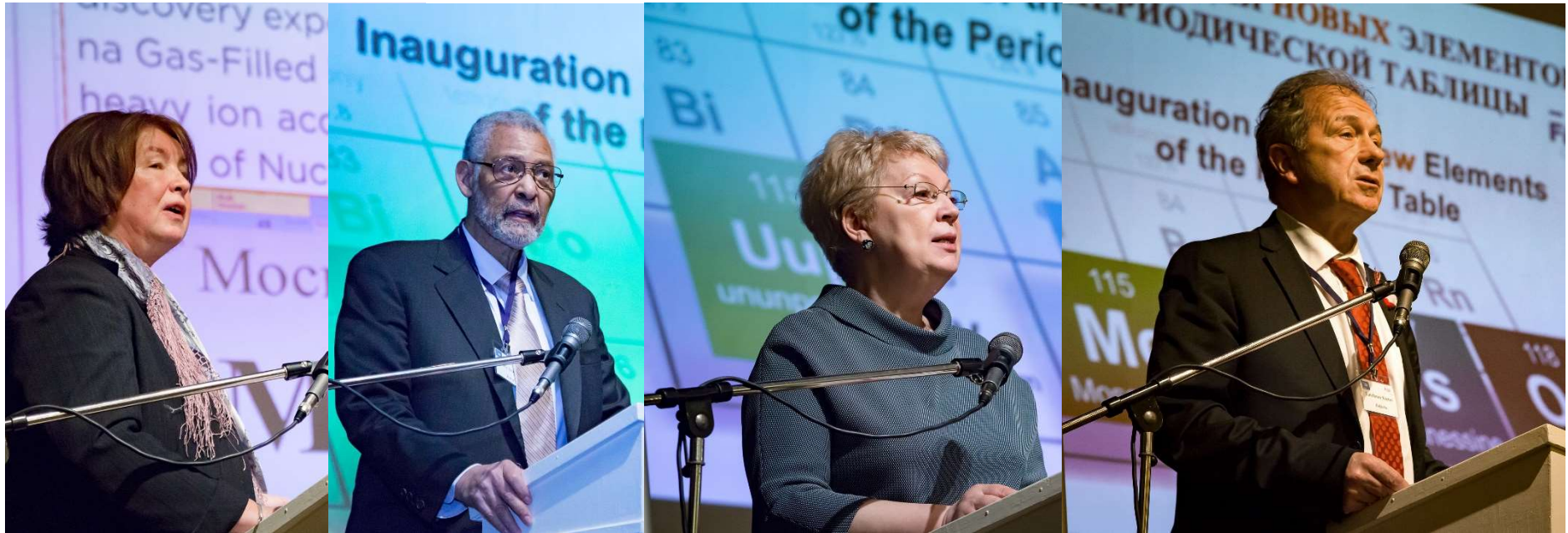
# Inauguration of elements 115 (Moscovium), 117 (Tennessine), 118 (Oganesson)

Prof. N. Tarasova  
IUPAC

Dr. K. Reed  
IUPAP

Prof. O. Vasilieva  
Minister of S&E, Russia

Prof. L. Kostov  
CPP of JINR Member States



Moscow  
Central House of Scientists  
of RAS  
March 2, 2017

**SuperHeavy Elements (SHE) Factory**  
*included into the NuPECC Long-Range Plan*

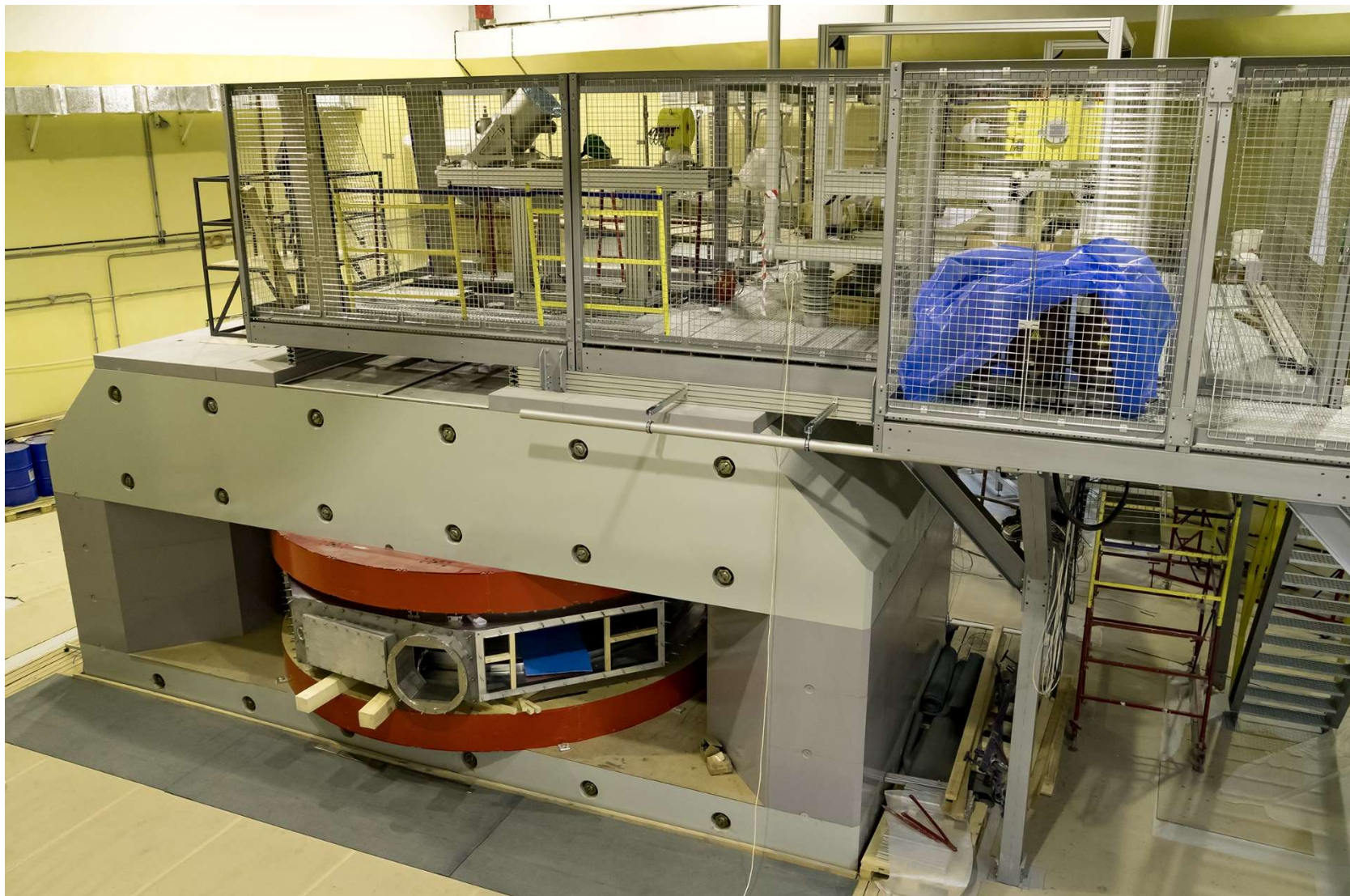


**SHE Factory Building**



# SuperHeavy Elements (SHE) Factory

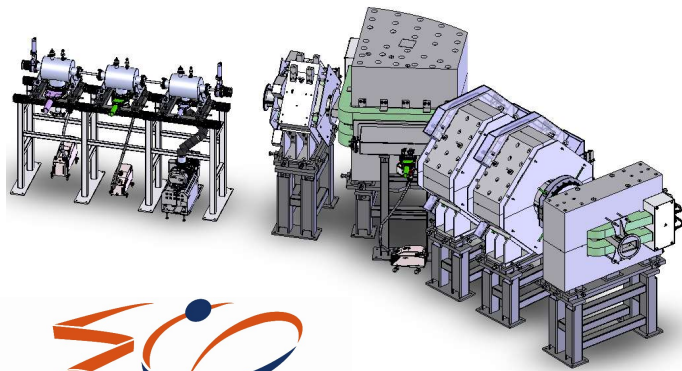
## DC-280 cyclotron



# SuperHeavy Elements (SHE) Factory

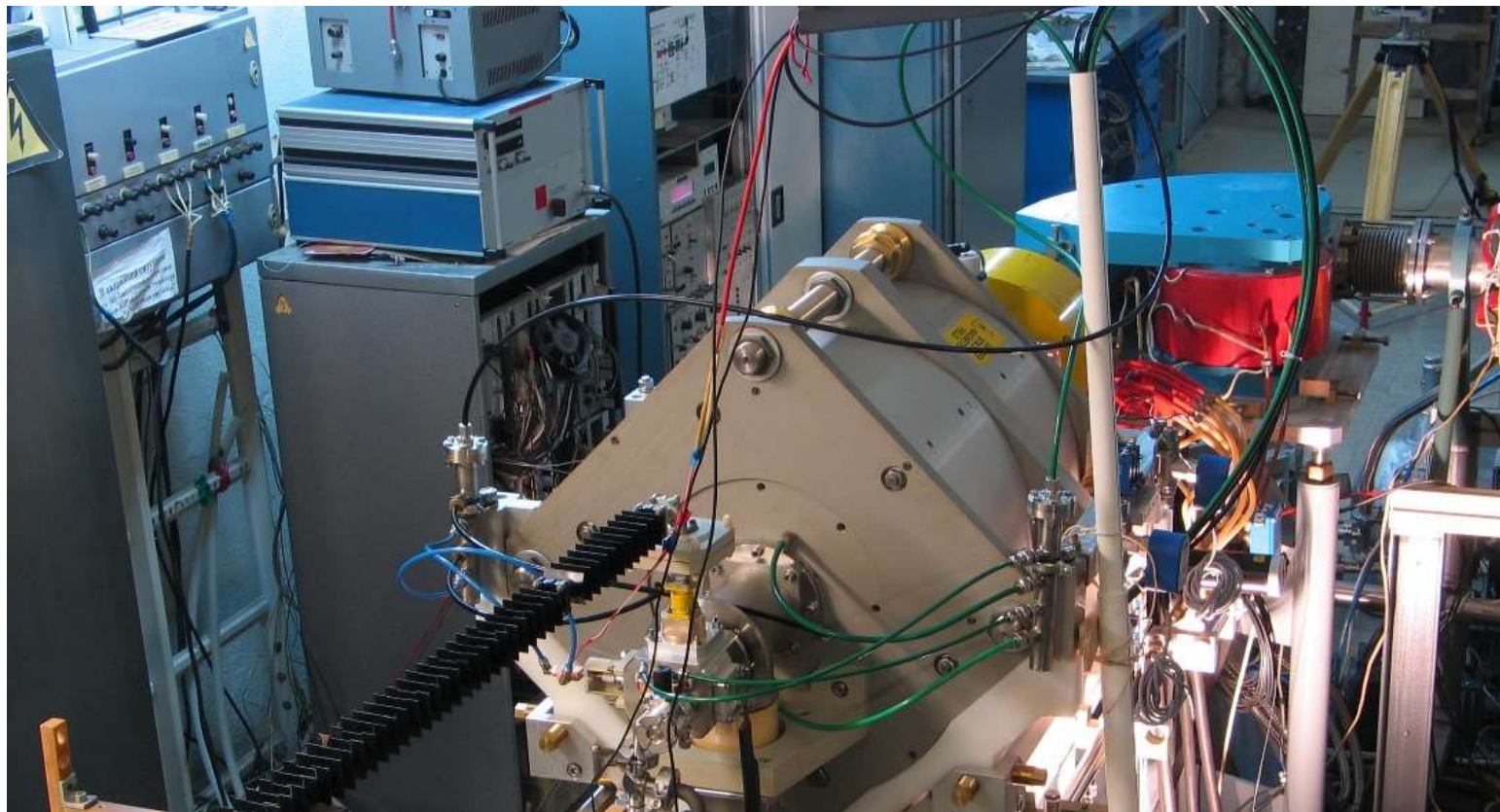


New gas-filled separator



# SuperHeavy Elements (SHE) Factory

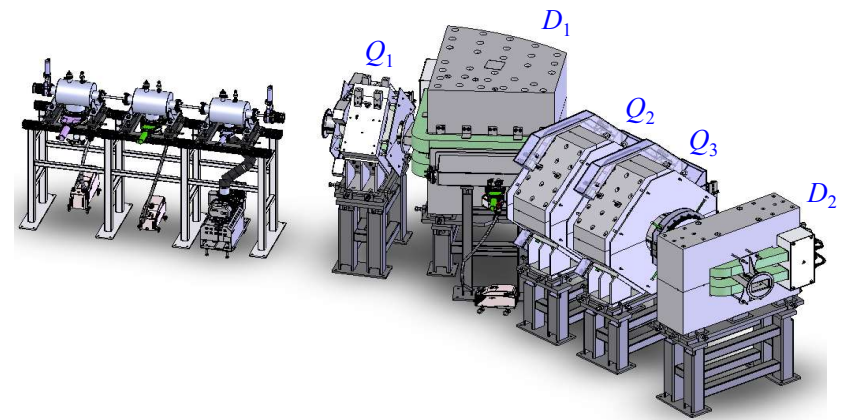
## Ion source



## SuperHeavy Elements (SHE) Factory



- Assembling the **DC-280** cyclotron.  
Installation of new **Gas-Filled Recoil Separator**.  
(2017 – 1<sup>st</sup> half of 2018)
- **First experiments** (2<sup>nd</sup> half of 2018)



**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, 1<sup>st</sup> runs*

**2016:** *zero angle spectrometer*

**2018/19:** *unique cryogenic tritium target*

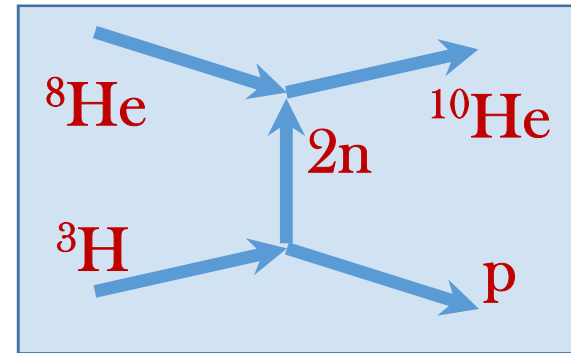


*Directions of the future researches:*

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



# $^{10}\text{He}$ : 2n-transfer



**Applied research**

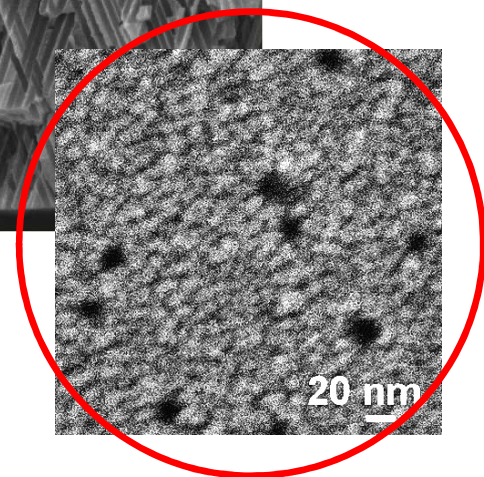
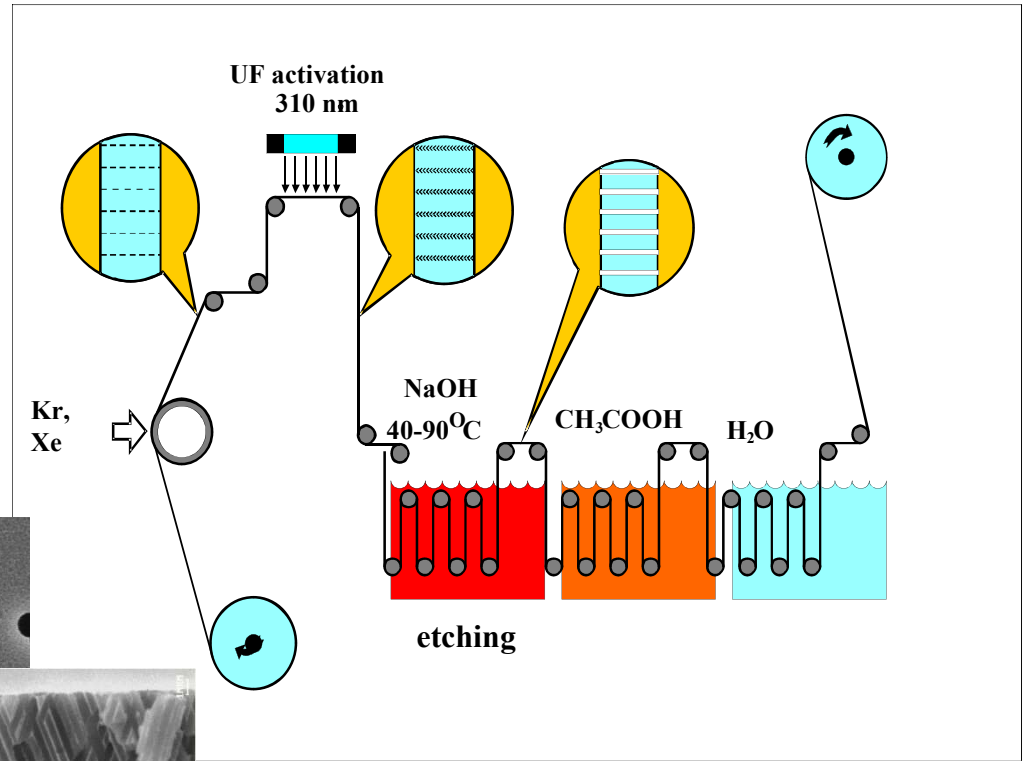
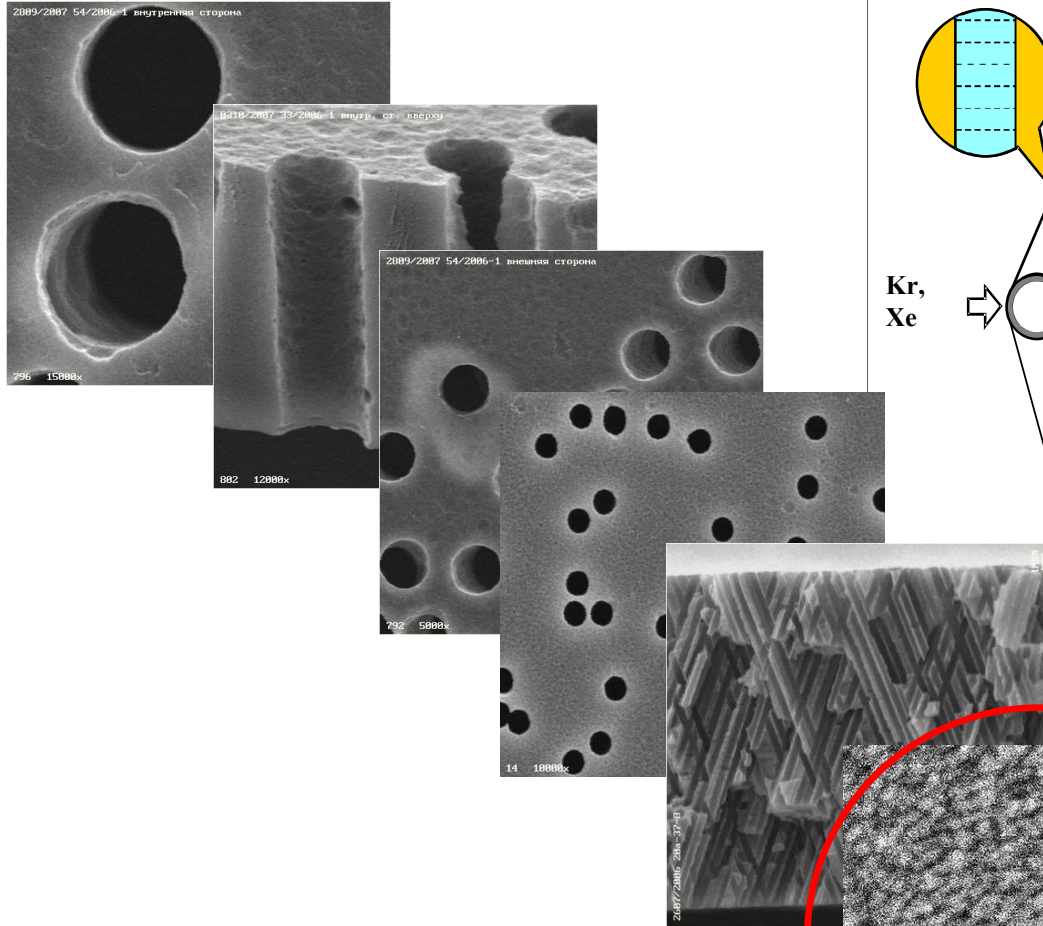
# Nano Laboratory



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

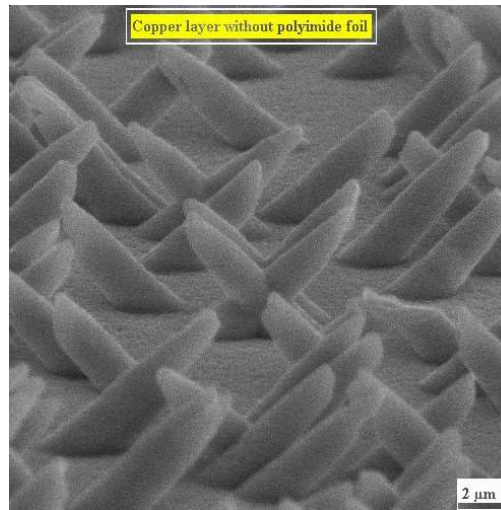
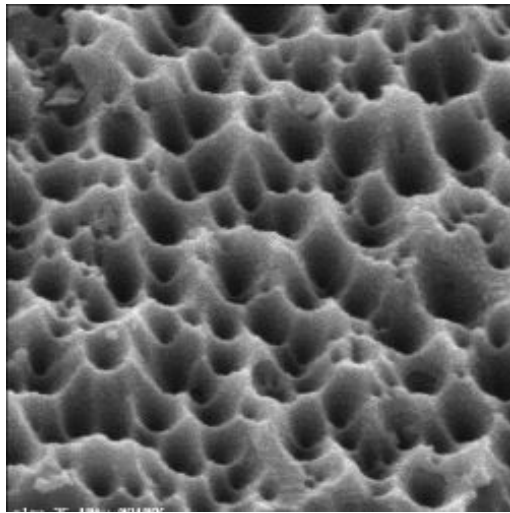
# Production of track membranes (IC-100)

## Micrometers



## Nanometers

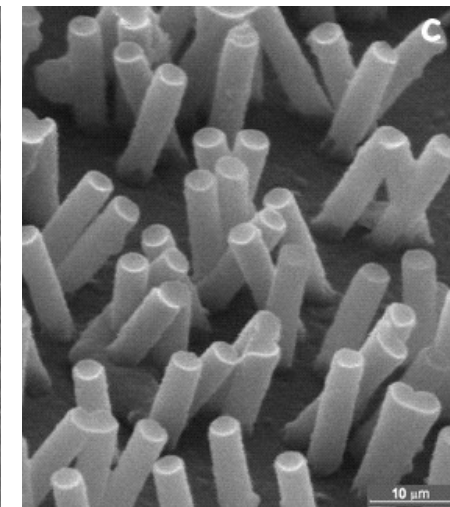
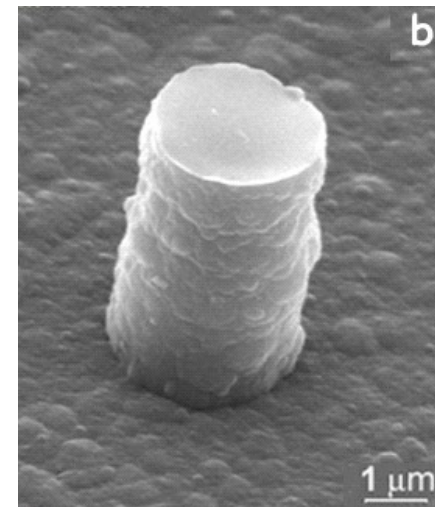
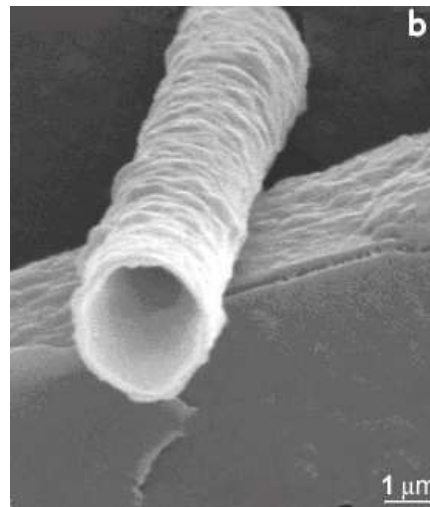
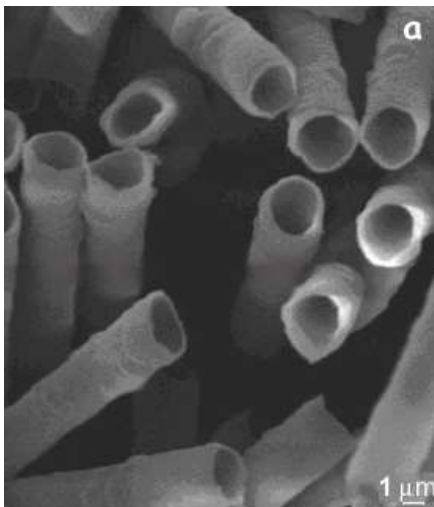
# Accelerators-born nanostructures



## *new composite materials:*

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

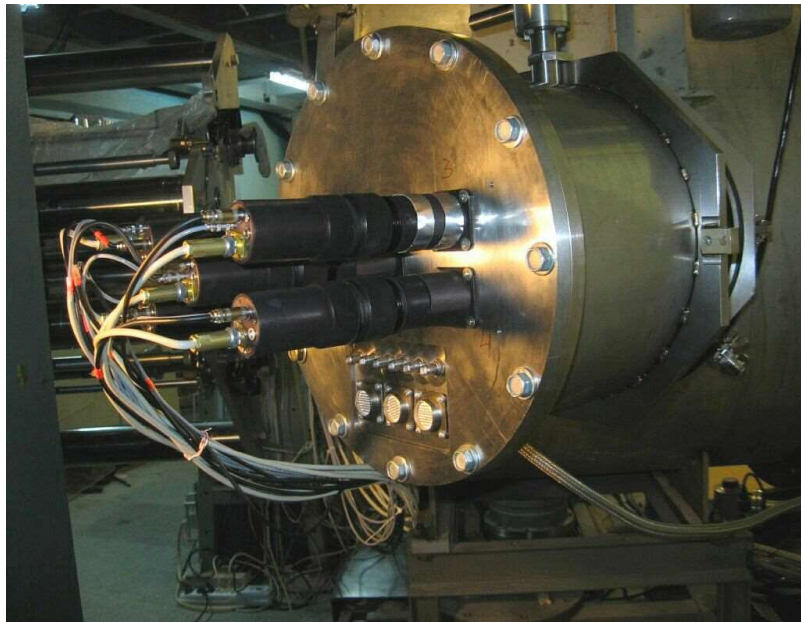
## *Polymer composites produced with the use of track membranes* nanotubes nanowires



# 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.



# Welcome to DUBNA!

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