

Alexander Karpov
FLNR, JINR



**Superheavy elements research at Dubna:
achievements and perspectives**



DRIBS-III ACCELERATOR COMPLEX

FLEROV LABORATORY OF NUCLEAR REACTIONS

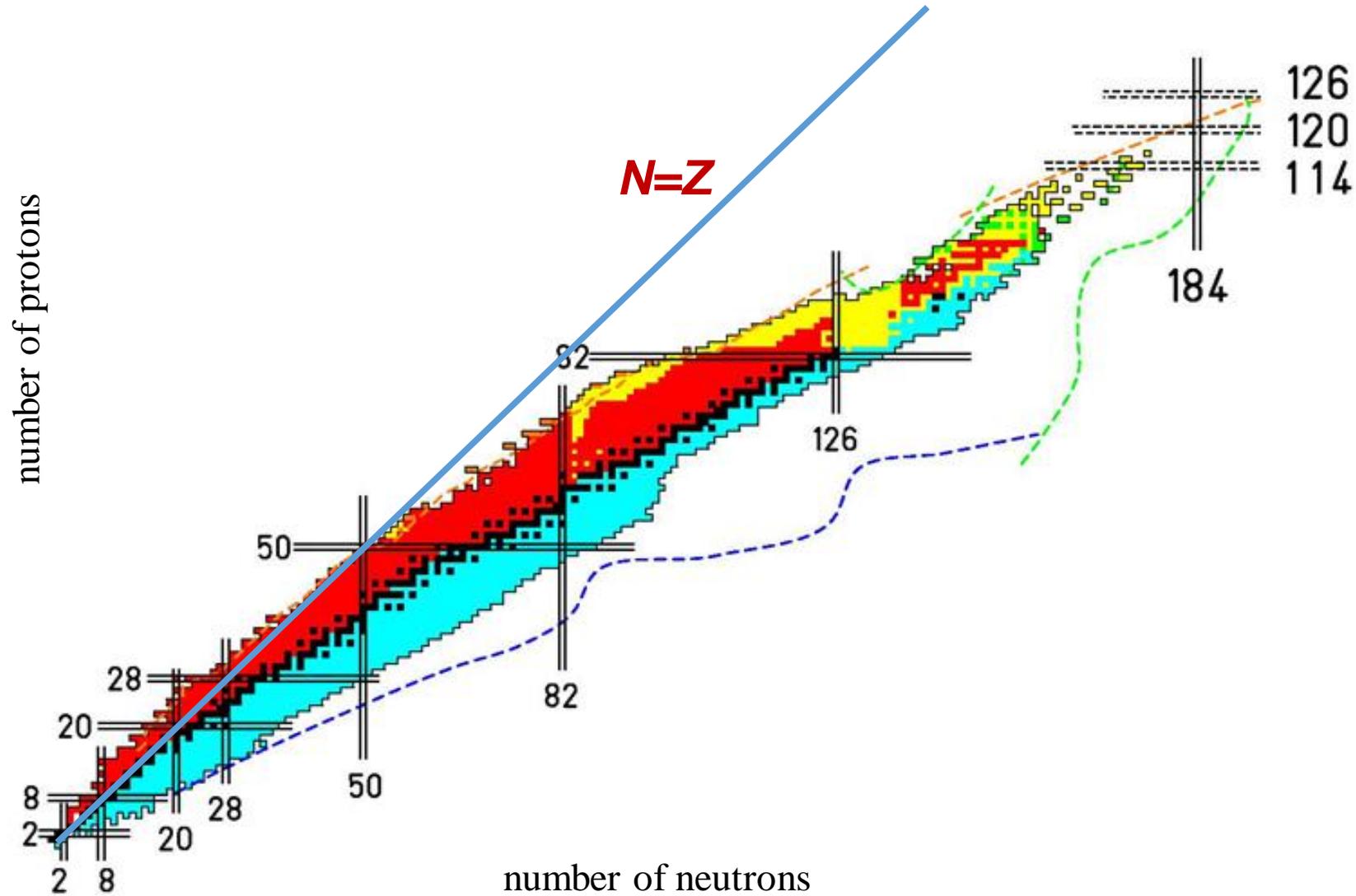


FLNR's basic directions of research:

- Heavy and superheavy nuclei
- Light exotic nuclei
- Radiation effects and physical groundwork of nanotechnology
- Accelerator technologies

Chart of nuclei

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



Mendeleev's Table (1869)

Опыт системы элементов
согласно их химическим свойствам
и атомных весов,
Д. Менделѣевъ.

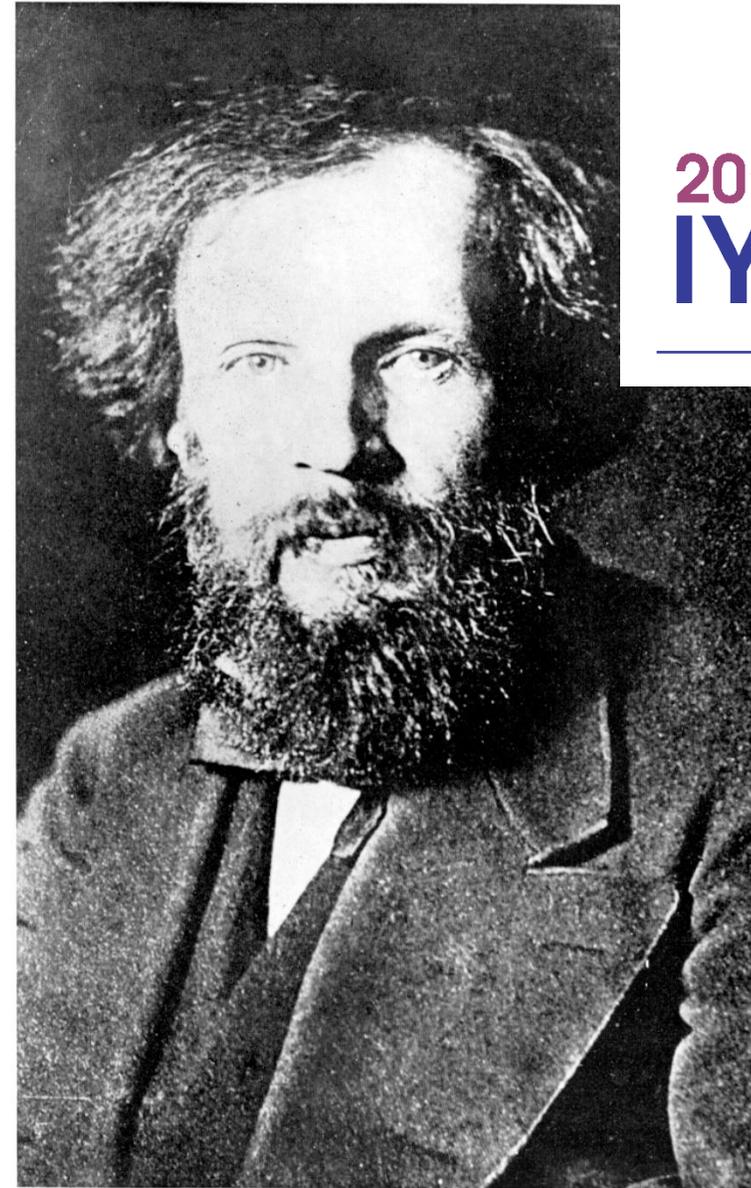
Менделѣевъ
1869. II. 17.

H=1.	?=8	?=22	Cu=63.4	Ag=108.	Hg=200.
H=1.	Li=7.	Be=9.	Mg=24.	Zn=65.2	Cd=112.
	B=11	Al=27.4	?=68	Mn=55	As=75?
	C=12	Si=28	?=70	Fe=56	Sr=88.
	N=14	P=31	As=75	Co=59	Rb=85.
	O=16	S=32	Se=79.4	Ni=58.7	Ca=40.
Li=7.	F=19	Cl=35.5	Br=80	Pt=197.4	Sc=45?
	Na=23	K=39	Rb=85.4	Au=196.6	Ce=140.
					Pr=141.
					La=138.
					Th=232?
					Pa=231?
					U=238?
					Ac=227?

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

18 II 69.

Менделѣевъ



Mendeleev's Table Today



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

1																		2		18																			
Водород ¹ ₁ H 1.00794 Hydrogen																		Гелий ² ₂ He 4.0026 Helium																					
Литий ³ ₃ Li 6.941 Lithium			Бериллий ⁴ ₄ Be 9.01218 Beryllium																					Неон ¹⁰ ₁₀ Ne 20.1797 Neon															
Натрий ¹¹ ₁₁ Na 22.989768 Sodium			Магний ¹² ₁₂ Mg 24.3050 Magnesium																					Аргон ¹⁸ ₁₈ Ar 39.948 Argon															
Калий ¹⁹ ₁₉ K 39.0983 Potassium																		Кальций ²⁰ ₂₀ Ca 40.078 Calcium																				Криптон ³⁶ ₃₆ Kr 83.80 Krypton	
Рубидий ³⁷ ₃₇ Rb 85.4678 Rubidium			Стронций ³⁸ ₃₈ Sr 87.62 Strontium																					Ксенон ⁵⁴ ₅₄ Xe 131.29 Xenon															
Цезий ⁵⁵ ₅₅ Cs 132.90543 Cesium			Барий ⁵⁶ ₅₆ Ba 137.327 Barium																					Радон ⁸⁶ ₈₆ Rn 222 Radon															
Франций ⁸⁷ ₈₇ Fr 223 Francium			Радий ⁸⁸ ₈₈ Ra 226.025 Radium																					Оганесон ¹¹⁸ ₁₁₈ Og 284 Oganesson															

Лантаноиды Lanthanoides

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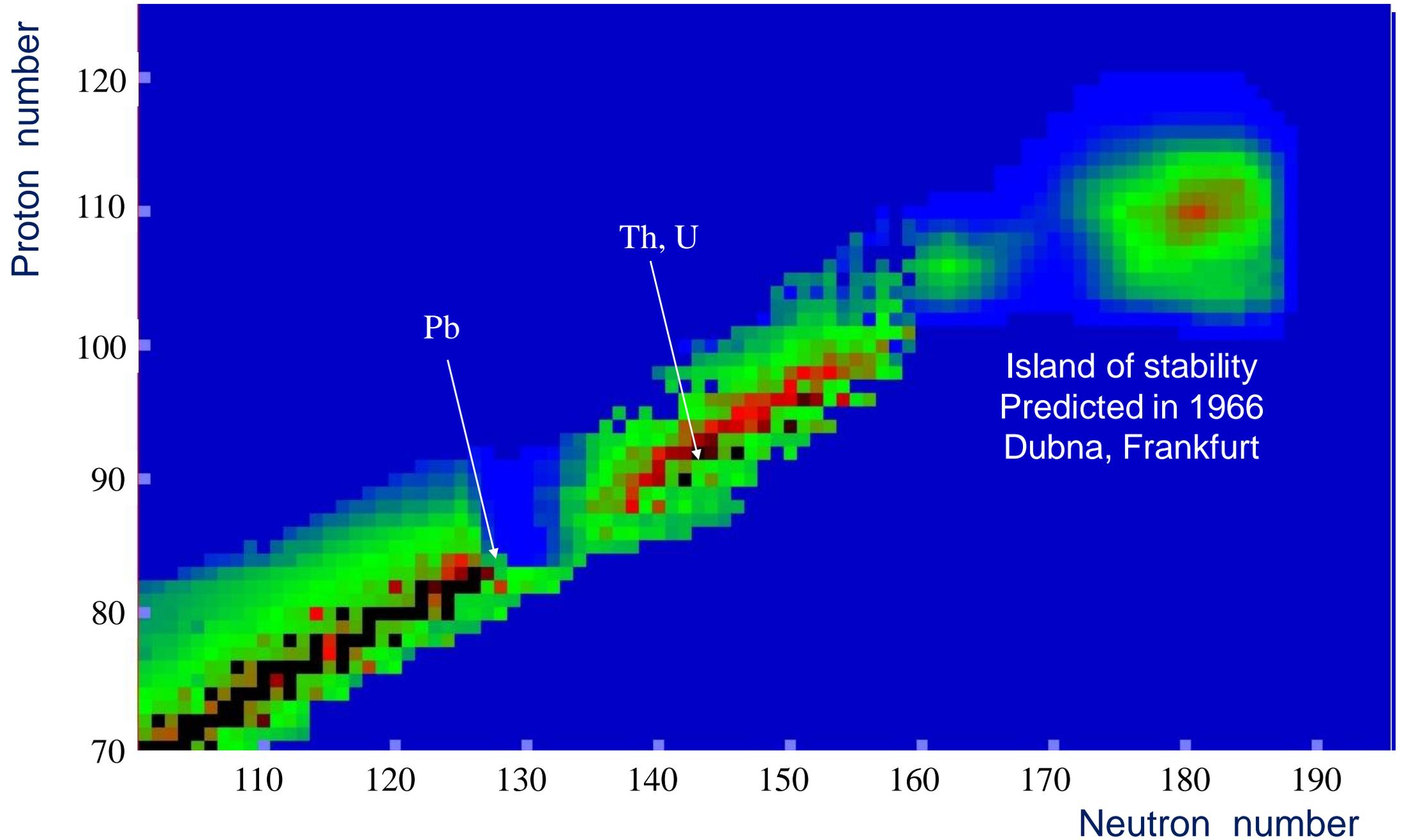
Актиноиды Actinoides

Торий ⁹⁰ ₉₀ Th 232.0381 Thorium		Протактиний ⁹¹ ₉₁ Pa 231.03609 Protactinium		Уран ⁹² ₉₂ U 238.02891 Uranium		Нептуний ⁹³ ₉₃ Np 237.04817 Neptunium		Плутоний ⁹⁴ ₉₄ Pu 244.06422 Plutonium		Америций ⁹⁵ ₉₅ Am 243.06138 Americium		Кюрий ⁹⁶ ₉₆ Cm 247.07724 Curium		Берклий ⁹⁷ ₉₇ Bk 247.07724 Berkelium		Калифорний ⁹⁸ ₉₈ Cf 251.0832 Californium		Эйнштейний ⁹⁹ ₉₉ Es [252] Einsteinium		Фермий ¹⁰⁰ ₁₀₀ Fm [253] Fermium		Менделевий ¹⁰¹ ₁₀₁ Md [258] Mendelevium		Нобелий ¹⁰² ₁₀₂ No [259] Nobelium		Лоуренсий ¹⁰³ ₁₀₃ Lr [262] Lawrencium	
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Водород ¹ ₁ H 1.00794 Hydrogen	
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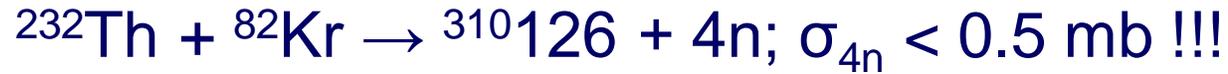
H - символ / symbol
1.00794 - атомная масса / atomic mass
1s¹ - электронная конфигурация / electron configuration
13,59844 - 1-й потенциал ионизации, эВ / 1st ionization potential, eV
0,0899 - плотность, кг/м³ / density, kg/m³
-252,84 - температура плавления, °C / melting temperature, °C
-252,87 - температура 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: $^{48}\text{Ca} + \text{Actinides}$:

Los Alamos (USA)

Berkeley (USA)

Dubna (JINR)

Oak Ridge (USA)

Mainz (Germany)

Darmstadt (Germany)

Orsay (France)

Würenlingen (Switzerland)

Tokyo (Japan) some later



U-400 ACCELERATOR COMPLEX

NUCLEAR SPECTROSCOPY AND REACTION MECHANISMS

Commissioned: 1978
 Modernized: 1996
 Reconstruction: 2020-2023 (plan)

Tasks:

Stand-alone mode:

- Synthesis of superheavy elements (SHE)
- Chemistry of SHE
- Nuclear & laser spectroscopy
- Nuclear reactions: fusion, fusion-fission & quasi-fission, multi-nucleon transfer reactions
- Applied research

Post-accelerator mode:

- Reactions with exotic nuclei
- Structure of light exotic nuclei

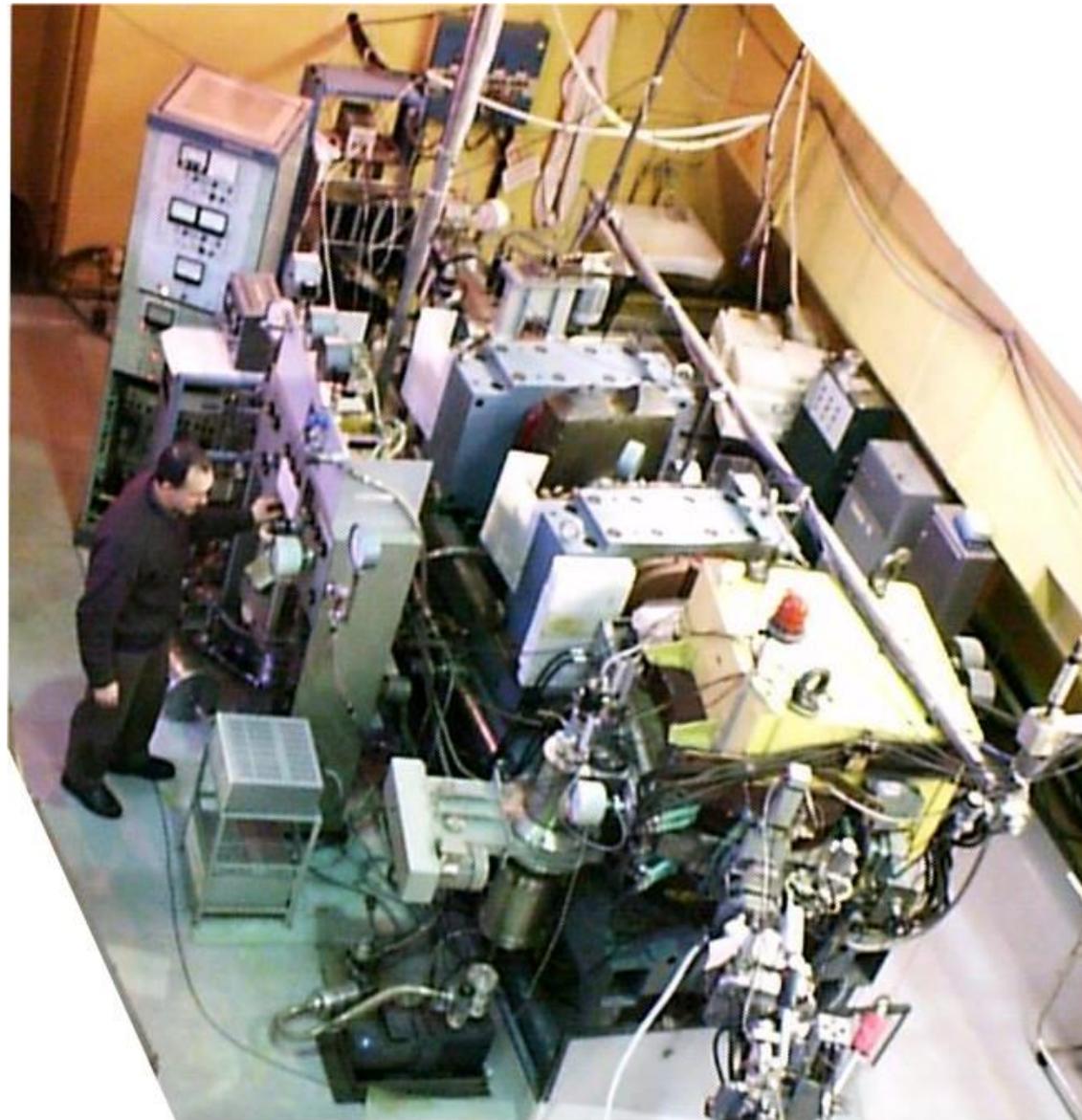
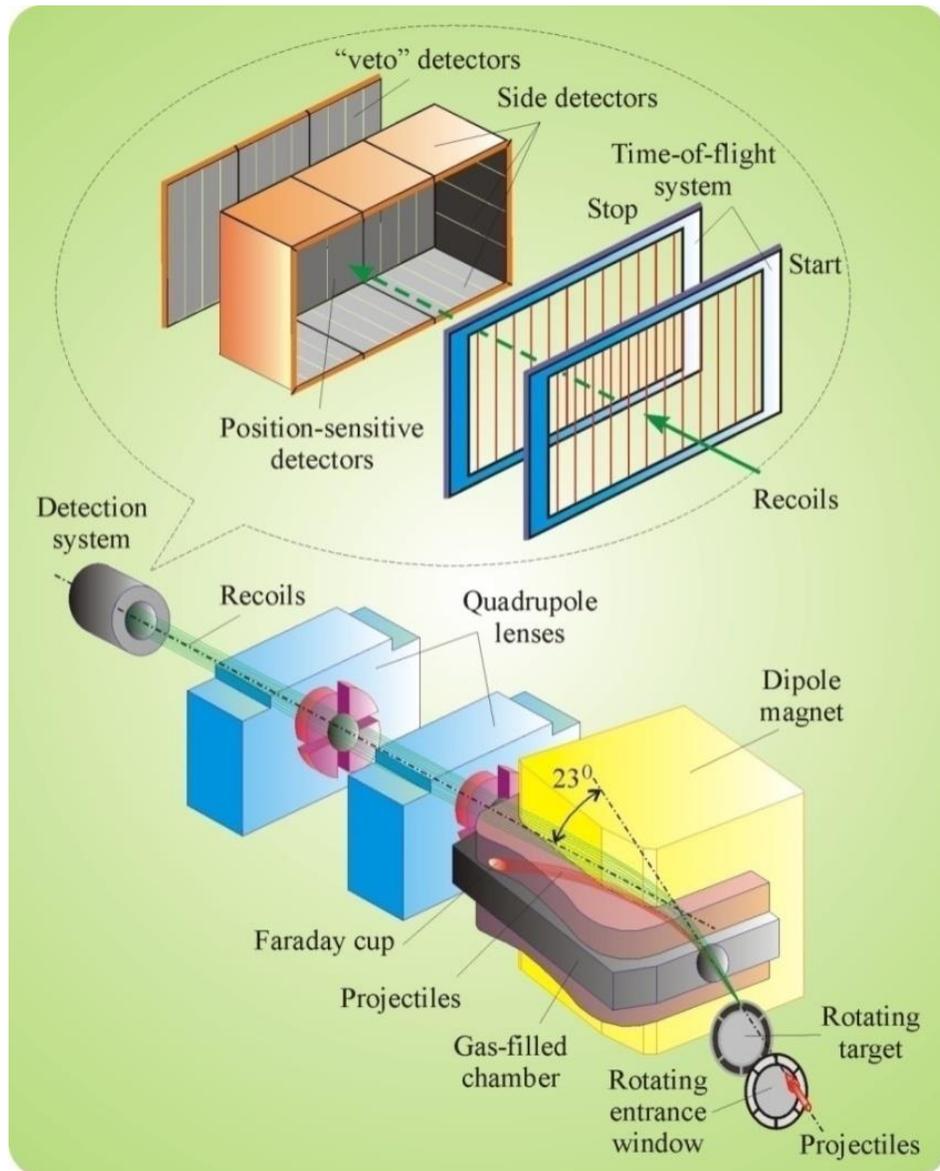
Ion	Ion energies [MeV/A]	Output intensity [pps]
$^{16}\text{O}^{2+}$	5.7; 7.9	3×10^{13}
$^{18}\text{O}^{3+}$	7.8; 10.5; 15.8	2.6×10^{13}
$^{40}\text{Ar}^{4+}$	3.8; 5.1	1×10^{13}
$^{48}\text{Ca}^{5+}$	3.7; 5.3	7.2×10^{12}
$^{48}\text{Ca}^{9+}$	8.9; 11; 17.7	6×10^{12}
$^{50}\text{Ti}^{5+}$	3.6; 5.1	2.4×10^{12}
$^{58}\text{Fe}^{6+}$	3.8; 5.4	4.2×10^{12}
$^{84}\text{Kr}^{8+}$	3.1; 4.4	1.8×10^{12}
$^{136}\text{Xe}^{14+}$	3.3; 4.6; 6.9	4.8×10^{11}
$^{160}\text{Gd}^{19+}$	5.5	6×10^{10}
$^{209}\text{Bi}^{19+}$	3.4	6×10^{10}

Main parameters	
Energy range	3÷21 MeV/A
K factor max.	650
Pole diameter	4 m
Magnet weight	2100 t
Magnet power	850 kW
Vacuum	10^{-7} Torr

Experimental setups:

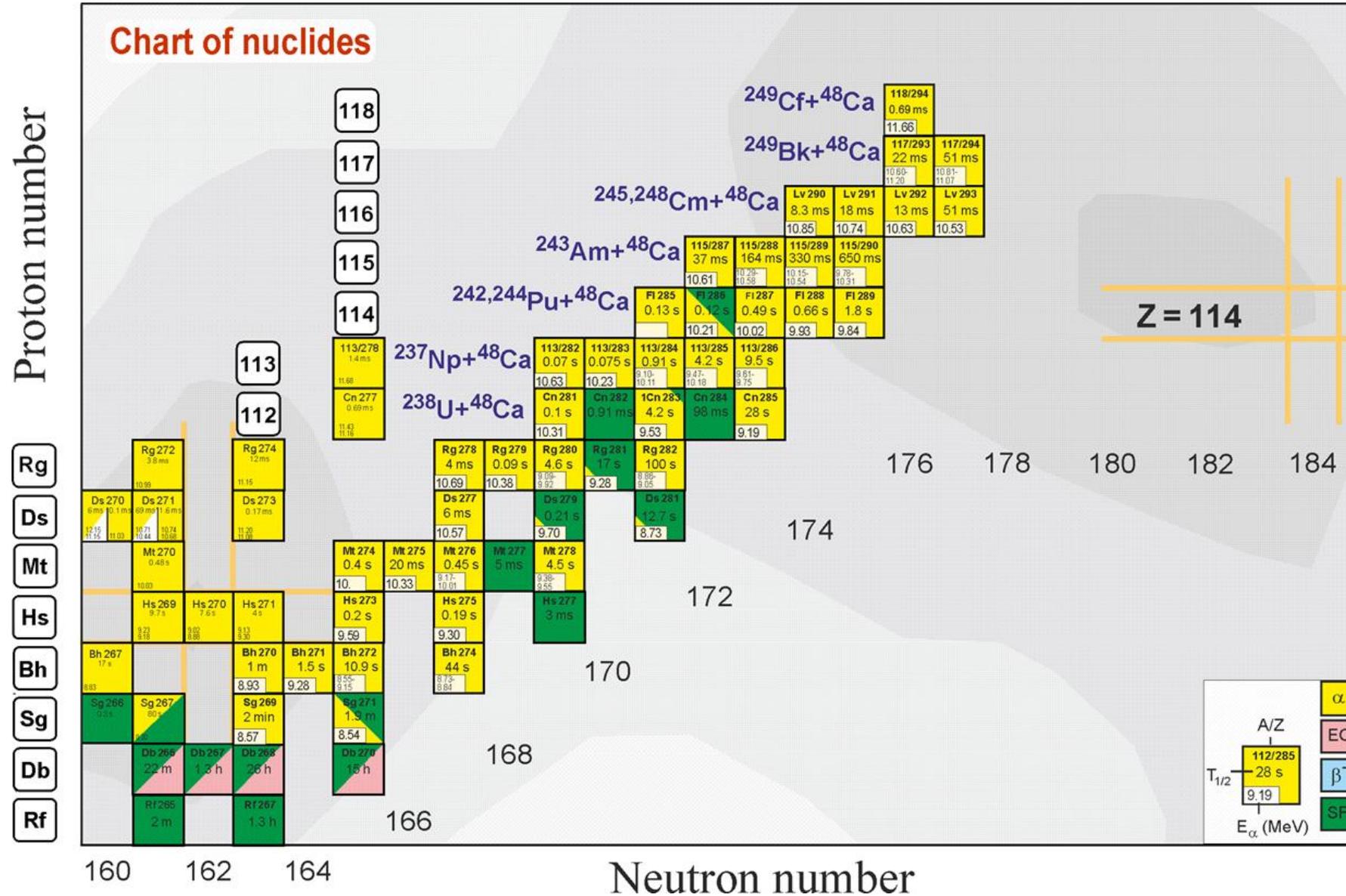
- Gas-Filled Recoil Separator (DGFRS-I)
- Separator for Heavy Elements Spectroscopy (SHELS)
- Radio-chemical setups
- Double-arm time-of-flight spectrometer (CORSET)
- Magnetic Analyzer of High Resolution (MAVR)

Dubna gas-filled recoil separator



Region of superheavy nuclei.

Recent achievements: 6 new elements and > 50 new isotopes of SHE

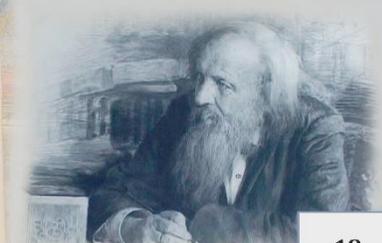


Confirmations

(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)

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 ₁ H 1.00794 Hydrogen																		Гелий ² ₂ He 4.0026 Helium																																			
Литий ³ ₃ Li 6.941 Lithium			Бериллий ⁴ ₄ Be 9.01218 Beryllium			Бор ⁵ ₅ B 10.811 Boron			Углерод ⁶ ₆ C 12.011 Carbon			Азот ⁷ ₇ N 14.0067 Nitrogen			Кислород ⁸ ₈ O 15.9994 Oxygen			Фтор ⁹ ₉ F 18.9984 Fluorine			Неон ¹⁰ ₁₀ Ne 20.1797 Neon																																
Натрий ¹¹ ₁₁ Na 22.989768 Sodium			Магний ¹² ₁₂ Mg 24.3050 Magnesium			Алюминий ¹³ ₁₃ Al 26.981539 Aluminum			Кремний ¹⁴ ₁₄ Si 28.0855 Silicon			Фосфор ¹⁵ ₁₅ P 30.97376 Phosphorus			Сера ¹⁶ ₁₆ S 32.066 Sulfur			Хлор ¹⁷ ₁₇ Cl 35.4527 Chlorine			Аргон ¹⁸ ₁₈ Ar 39.948 Argon																																
Калий ¹⁹ ₁₉ K 39.0983 Potassium			Кальций ²⁰ ₂₀ Ca 40.078 Calcium			Скандий ²¹ ₂₁ Sc 44.95591 Scandium			Титан ²² ₂₂ Ti 47.88 Titanium			Ванадий ²³ ₂₃ V 50.9415 Vanadium			Хром ²⁴ ₂₄ Cr 51.9961 Chromium			Марганец ²⁵ ₂₅ Mn 54.93805 Manganese			Железо ²⁶ ₂₆ Fe 55.847 Iron			Кобальт ²⁷ ₂₇ Co 58.93320 Cobalt			Никель ²⁸ ₂₈ Ni 58.6934 Nickel			Медь ²⁹ ₂₉ Cu 63.546 Copper			Цинк ³⁰ ₃₀ Zn 65.39 Zinc			Галлий ³¹ ₃₁ Ga 69.723 Gallium			Германий ³² ₃₂ Ge 72.61 Germanium			Арсен ³³ ₃₃ As 74.92159 Arsenic			Селен ³⁴ ₃₄ Se 78.96 Selenium			Бром ³⁵ ₃₅ Br 79.904 Bromine			Криpton ³⁶ ₃₆ Kr 83.80 Krypton		
Рубидий ³⁷ ₃₇ Rb 85.4678 Rubidium			Стронций ³⁸ ₃₈ Sr 87.62 Strontium			Иттрий ³⁹ ₃₉ Y 88.90585 Yttrium			Цирконий ⁴⁰ ₄₀ Zr 91.224 Zirconium			Ниобий ⁴¹ ₄₁ Nb 92.90638 Niobium			Молибден ⁴² ₄₂ Mo 95.94 Molybdenum			Технеций ⁴³ ₄₃ Tc [98] Technetium			Рутений ⁴⁴ ₄₄ Ru 101.07 Ruthenium			Родий ⁴⁵ ₄₅ Rh 101.07 Rhodium			Палладий ⁴⁶ ₄₆ Pd 106.42 Palladium			Серебро ⁴⁷ ₄₇ Ag 107.8682 Silver			Кадмий ⁴⁸ ₄₈ Cd 112.411 Cadmium			Индий ⁴⁹ ₄₉ In 114.818 Indium			Олово ⁵⁰ ₅₀ Sn 118.710 Tin			Свинец ⁵¹ ₅₁ Pb 127.60 Lead			Теллур ⁵² ₅₂ Te 127.60 Tellurium			Йод ⁵³ ₅₃ I 126.90447 Iodine			Ксенон ⁵⁴ ₅₄ Xe 131.29 Xenon		
Цезий ⁵⁵ ₅₅ Cs 132.90543 Cesium			Барий ⁵⁶ ₅₆ Ba 137.327 Barium			Лантан ⁵⁷ ₅₇ La 138.9055 Lanthanum			Гафний ⁷² ₇₂ Hf 178.49 Hafnium			Тантал ⁷³ ₇₃ Ta 180.9479 Tantalum			Вольфрам ⁷⁴ ₇₄ W 183.84 Tungsten			Рений ⁷⁵ ₇₅ Re 186.207 Rhenium			Осний ⁷⁶ ₇₆ Os 190.23 Osmium			Иридий ⁷⁷ ₇₇ Ir 192.22 Iridium			Платина ⁷⁸ ₇₈ Pt 195.08 Platinum			Золото ⁷⁹ ₇₉ Au 196.96654 Gold			Ртуть ⁸⁰ ₈₀ Hg 200.59 Mercury			Таллий ⁸¹ ₈₁ Tl 204.3833 Thallium			Свинец ⁸² ₈₂ Pb 207.2 Lead			Висмут ⁸³ ₈₃ Bi 208.98037 Bismuth			Полюний ⁸⁴ ₈₄ Po [209] Polonium			Астат ⁸⁵ ₈₅ At [210] Astatine			Радон ⁸⁶ ₈₆ Rn [222] Radon		
Франций ⁸⁷ ₈₇ Fr [223] Francium			Радий ⁸⁸ ₈₈ Ra [226] Radium			Актиний ⁸⁹ ₈₉ Ac [227] Actinium			Резерфордий ¹⁰⁴ Rf [261] Rutherfordium			Дубний ¹⁰⁵ Db [263] Dubnium			Сборгбий ¹⁰⁶ Sg [266] Seaborgium			Борий ¹⁰⁷ Bh [269] Bohrium			Хассий ¹⁰⁸ Hs [271] Hassium			Мейтнерий ¹⁰⁹ Mt [272] Meitnerium			Дармштадтий ¹¹⁰ Ds [281] Darmstadtium			Рентгений ¹¹¹ Rg [285] Roentgenium			Коперниций ¹¹² Cn [289] Copernicium			Нихоний ¹¹³ Nh [291] Nihonium			Флеровий ¹¹⁴ Fl [294] Flerovium			Московский ¹¹⁵ Mc [298] Moscovium			Ливерморий ¹¹⁶ Lv [302] Livermorium			Теннесси ¹¹⁷ Ts [304] Tennessine			Оганesson ¹¹⁸ Og [304] Oganesson		

Лантаноиды Lanthanoides

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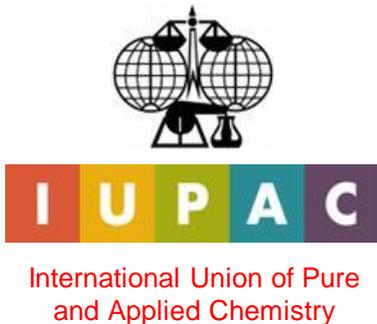
Актиноиды Actinoides

Торий ⁹⁰ ₉₀ Th 232.0381 Thorium		Протактиний ⁹¹ ₉₁ Pa 231.03689 Protactinium		Уран ⁹² ₉₂ U 238.02891 Uranium		Нептуний ⁹³ ₉₃ Np 237.04817 Neptunium		Плутоний ⁹⁴ ₉₄ Pu 244.06422 Plutonium		Америций ⁹⁵ ₉₅ Am 243.06138 Americium		Кюрий ⁹⁶ ₉₆ Cm 247.07724 Curium		Берклий ⁹⁷ ₉₇ Bk 247.07724 Berkelium		Калифорний ⁹⁸ ₉₈ Cf 251.10888 Californium		Эйнштейний ⁹⁹ ₉₉ Es [252] Einsteinium		Фермий ¹⁰⁰ ₁₀₀ Fm [257] Fermium		Менделевий ¹⁰¹ ₁₀₁ Md [258] Mendelevium		Нобелий ¹⁰² ₁₀₂ No [259] Nobelium		Лоуренсий ¹⁰³ ₁₀₃ Lr [262] Lawrencium	
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Водород ¹ 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-й потенциал ионизации, 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



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.

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 – the Goals

- **Experiments at the extremely low ($\sigma < 100$ fb) cross sections:**
 - Synthesis of new SHE in reactions with ^{50}Ti , ^{54}Cr ... (119, 120);
 - Shaping of the region of SHE (synthesis of new isotopes of SHE);
 - Study of decay properties of SHE;
 - Study of excitation functions.

- **Experiments requiring high statistics:**
 - Nuclear spectroscopy of SHE;
 - Precise mass measurements;
 - Study of chemical properties of SHE.

Superheavy Elements Factory

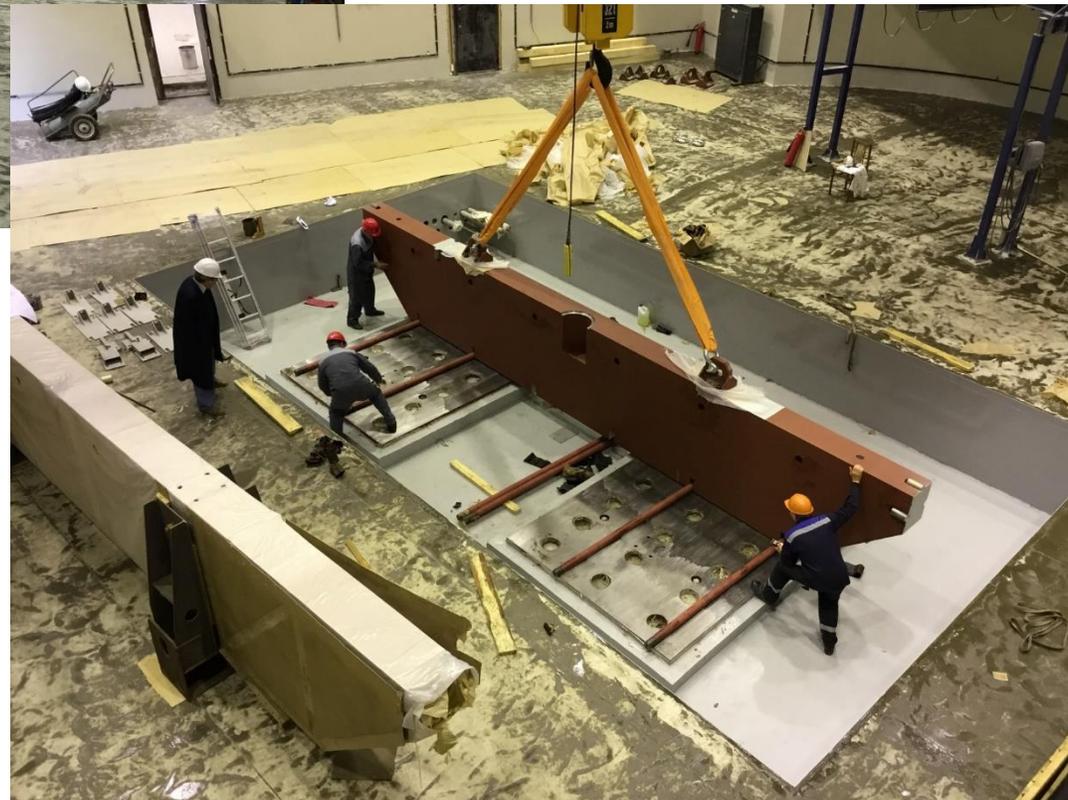


Assembling of the DC-280 main magnet



← 15/09/2016, 9:00

Same day, 14:35 →



Assembling of DC-280 magnet

28 Sep 2016, 08:53



Assembling of DC-280 magnet

18 Oct 2016, 11:02



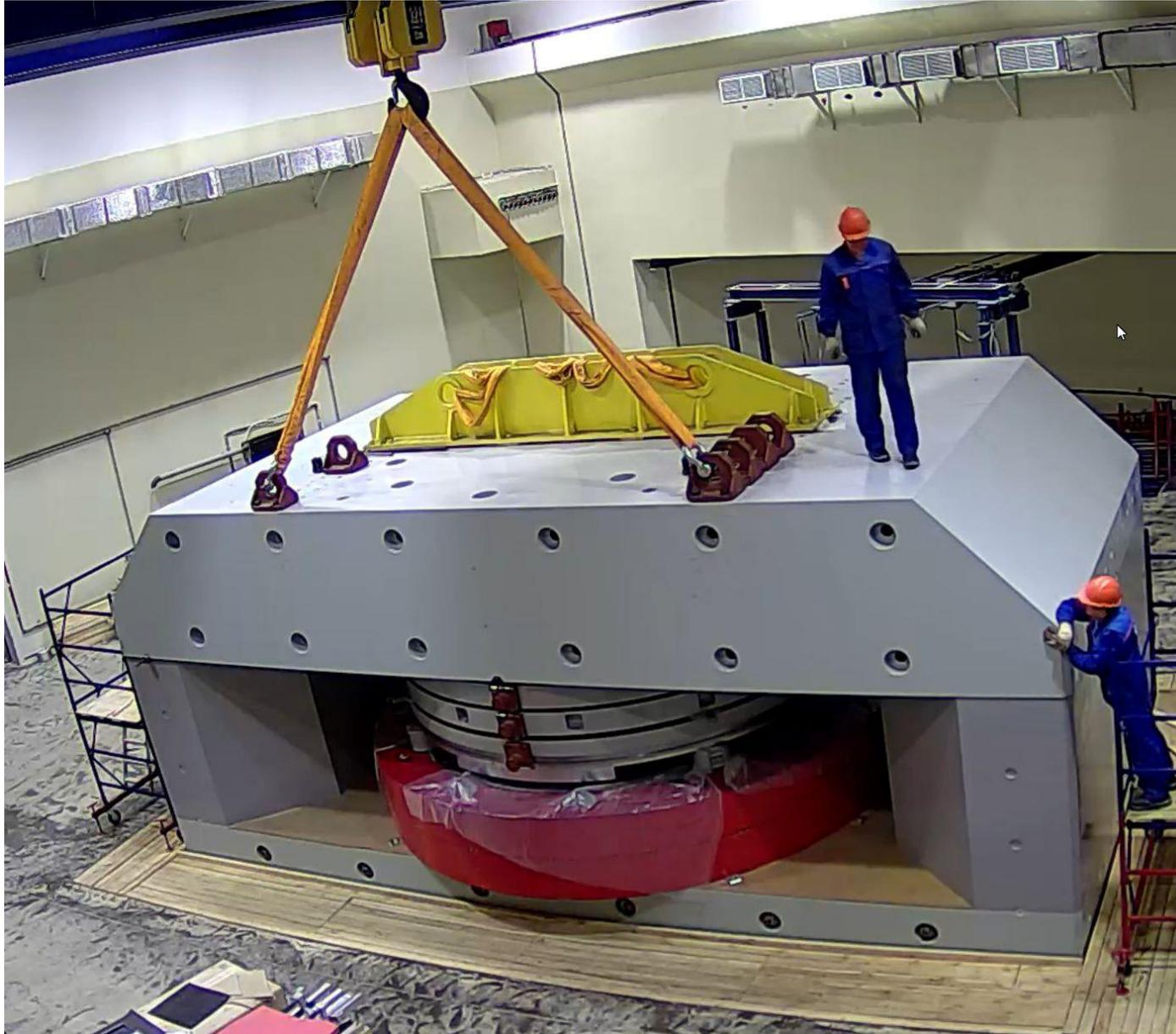
Assembling of DC-280 magnet

31 Oct 2016, 15:52



Assembling of DC-280 magnet

03 Nov 2016, 10:00

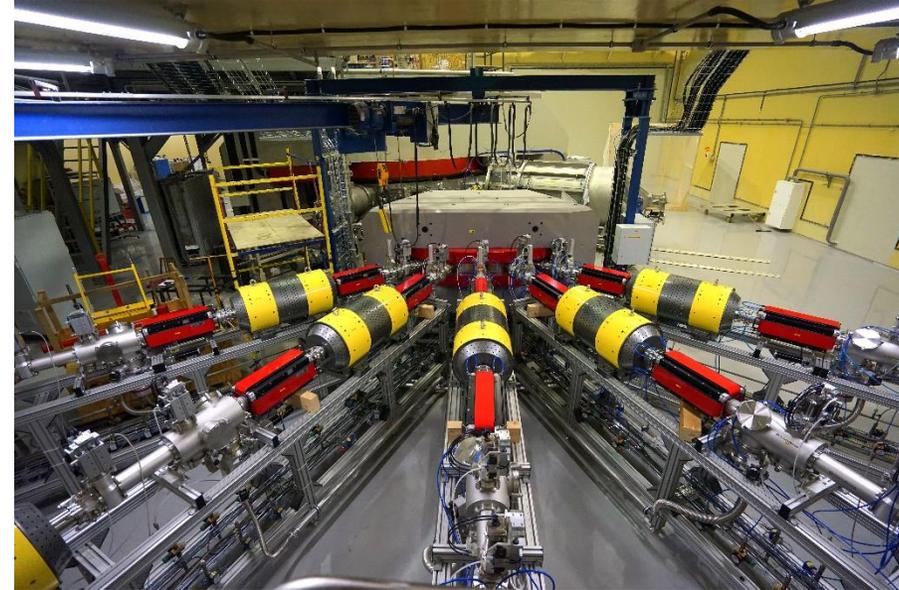


Magnet of DC-280 cyclotron – ready for testing



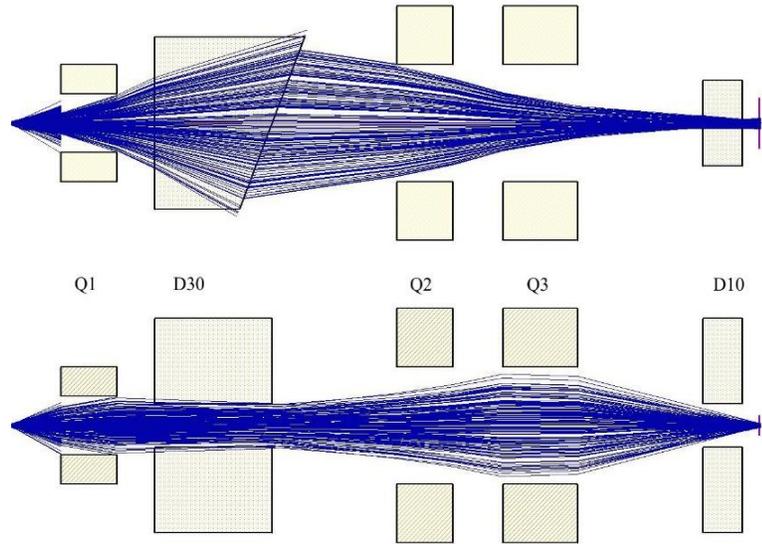
18.01.2017 <http://lideo.ru/embed/4655>

Specialized high-current cyclotron DC-280



DC-280 (expected) E=4÷8 MeV/A		
${}^7\text{Li}$	4	1×10^{14}
${}^{18}\text{O}$	8	1×10^{14}
${}^{40}\text{Ar}$	5	6×10^{13}
${}^{48}\text{Ca}$	5	1×10^{14}
${}^{54}\text{Cr}$	5	2×10^{13}
${}^{136}\text{Xe}$	5	1×10^{14}
${}^{238}\text{U}$	7	5×10^{10}

New gas-filled separator



Reaction	Transmission
$^{244}\text{Pu}(^{48}\text{Ca},3n)^{289}\text{114}$	60 %
$^{244}\text{Pu}(^{58}\text{Fe},4n)^{298}\text{120}$	75 %

Reactions of Synthesis



Projectiles ${}^{48}\text{Ca}$ produced by
Heavy Ion Accelerator U-400;

Energy: 235-250 MeV
($v \approx 0.1 c$);

Intensity: 1.0-1.5 pμA
($n \times 10^{12} \div 10^{13}$ 1/s);

Consumption: 0.5-0.8 mg/h

Beam dose: $(0.3-3.0) \cdot 10^{19}$

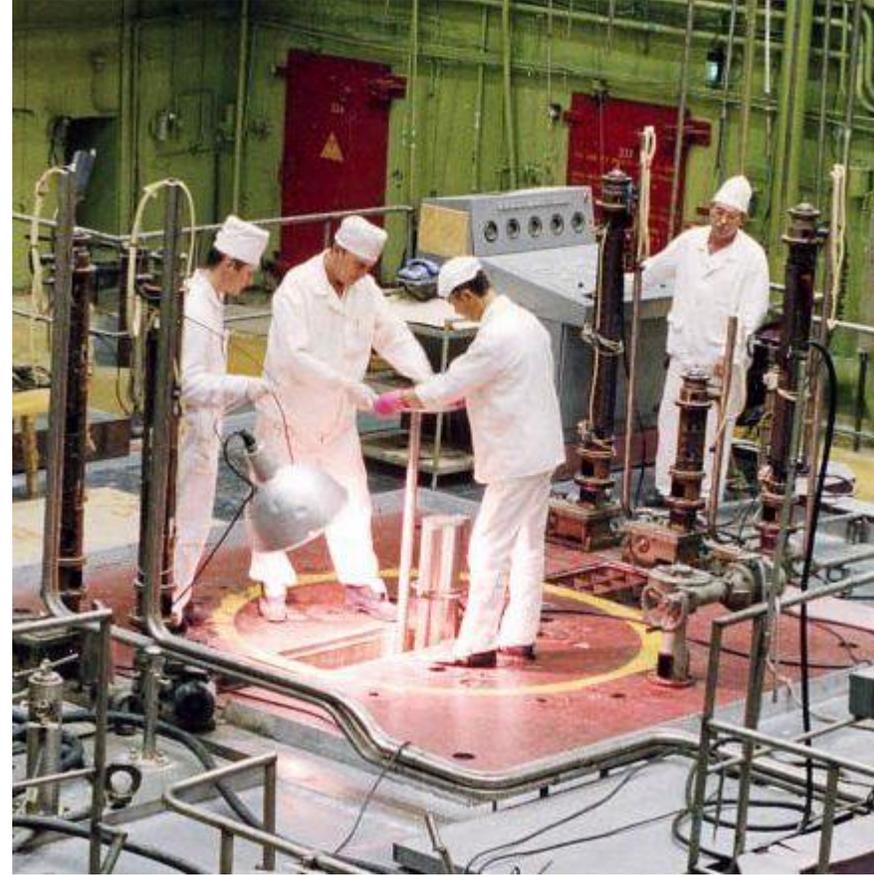
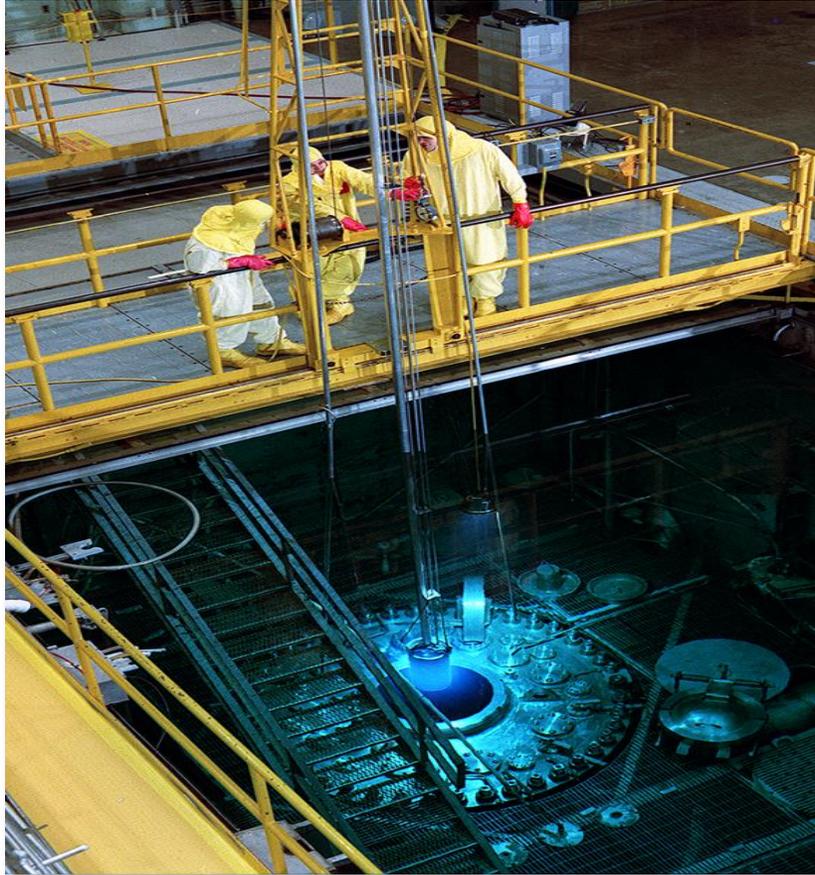
Target materials	Producer	Isotope enrichment (%)
${}^{237}\text{Np}$	IAR	99.3
${}^{239}\text{Pu}$	RFNC	---
${}^{240}\text{Pu}$	IAR/ORNL	99.98
${}^{242}\text{Pu}$	RFNC/ORNL	99.98
${}^{244}\text{Pu}$	ORNL	98.6
${}^{243}\text{Am}$	IAR / ORNL	99.9
${}^{245}\text{Cm}$	IAR	98.7
${}^{248}\text{Cm}$	IAR / ORNL	97.4
${}^{249}\text{Bk}$	ORNL	≥ 95
${}^{249}\text{Cf}$	IAR/ORNL	97.3
${}^{249,250,251}\text{Cf}$	ORNL	(50+14+36)%

0,35-0,40 mg /cm² - ≈ 12 mg

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\$

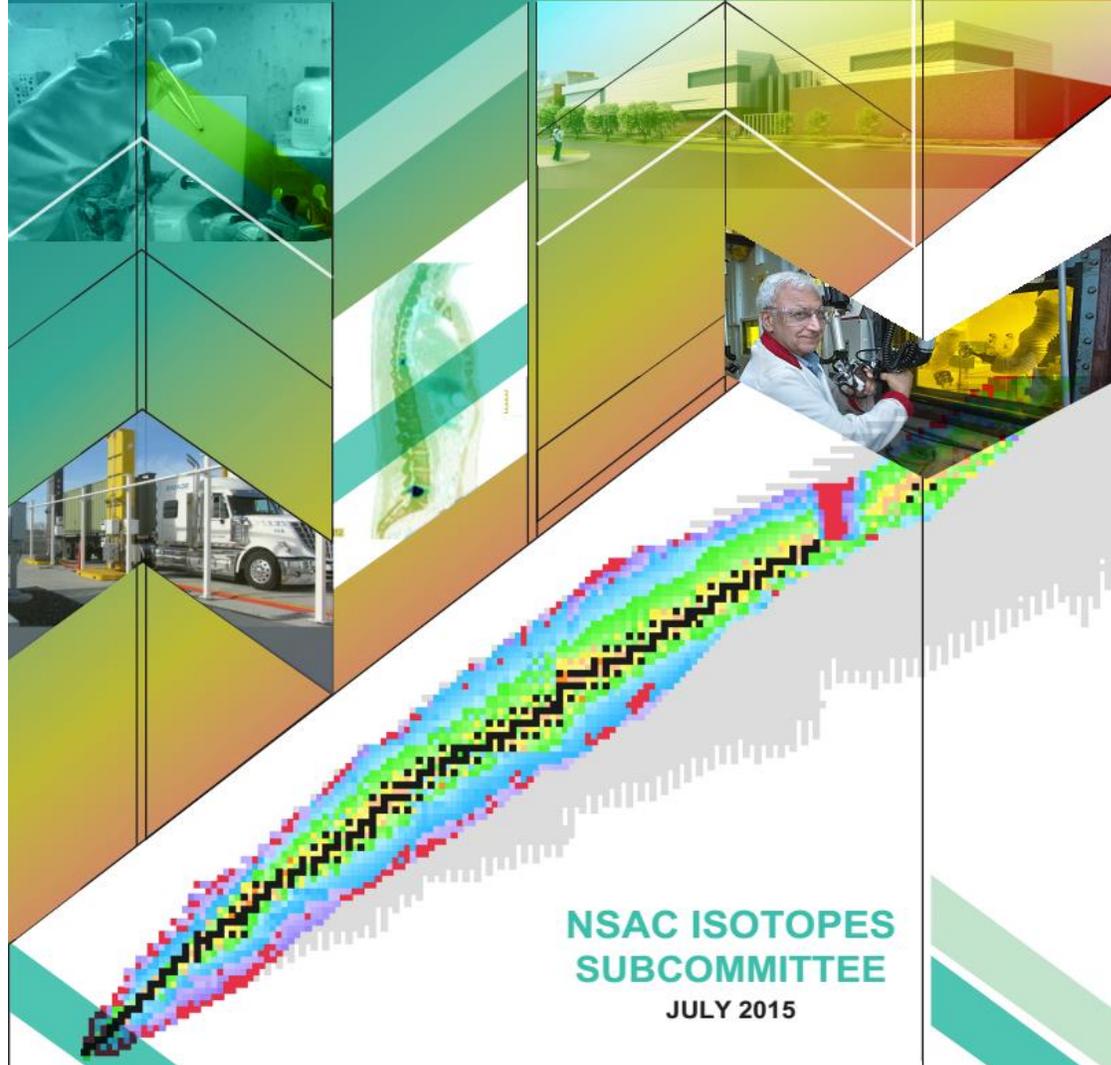
$^{249}\text{Cf} \approx 60\,000$ US\$

Target wheel



MEETING ISOTOPE NEEDS AND CAPTURING OPPORTUNITIES FOR THE FUTURE:

THE 2015 LONG RANGE PLAN FOR
THE DOE-NP ISOTOPE PROGRAM



NSAC ISOTOPES
SUBCOMMITTEE

JULY 2015

Future Isotopes for Use in Physics and Chemistry

- Isotopes with high isotopic purity required for continued production of superheavy elements and exploration of the island of stability include: $^{233,235}\text{U}$, ^{237}Np , $^{239,240,242,244}\text{Pu}$, ^{243}Am , $^{245,248}\text{Cm}$, ^{249}Bk , and $^{249,251}\text{Cf}$. Note that with new accelerator facilities with higher beam intensities coming on-line (such as the **Super Heavy Element Factory in Dubna, Russia**), demand for these isotopes will increase because thicker and larger targets will be required; current targets require ~20 mg whereas future targets are envisioned to require > 100 mg. Note also that high isotopic purity may necessitate usage of an isotope separator capable of separating radioactive material. Isotopes with high isotopic purity required for chemical study include: ^{248}Cm , ^{249}Bk , $^{249,251}\text{Cf}$, $^{252,254}\text{Es}$, and ^{257}Fm . The Isotope Program is working with this community to develop a strategic plan for the materials needed for further studies in this area and then to implement it.
- Mixed and mass separated actinides for chemical and physical studies of transuranium and trans-neptunium isotopes namely ^{237}Np ; ^{242}Pu , ^{244}Pu , ^{243}Am , ^{248}Cm , ^{249}Cf , ^{249}Bk , ^{251}Cf , $^{253/254}\text{Es}$, and ^{257}Fm . ^{248}Cm is the only readily available isotope of curium that can be used in standard radiochemical facility. The world-wide supply of ^{248}Cm is constrained, and the available ^{249}Bk is currently primarily used as target for synthesis of superheavy elements. ^{249}Bk decays to ^{249}Cf and, similar to Cm, ^{249}Cf is the only Cf isotope readily available that can be used in radiochemical laboratory. Specific metallic and/or chemical forms of these isotopes would be most interesting.

Superconducting 18 GHz ECR ion sources

~2 grams of ^{48}Ca

Ion source DECRIS-SC2



Consumption: 0.5-0.8 mg/h

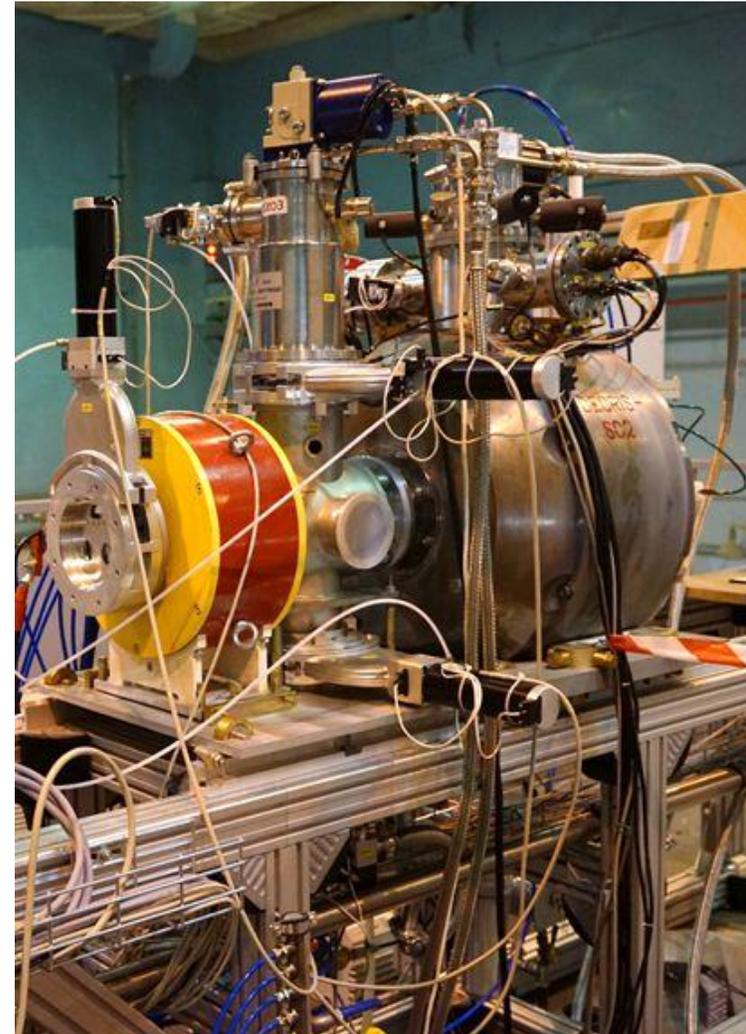
Prices per 1 mg

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

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

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

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



Development of ^{50}Ti beam using MIVOC method

Synthesis of (trimethyl)pentamethyl-cyclopentadienyl titanium



where Cp^* - $(\text{CH}_3)_5\text{C}_5$

Starting material: $^{50}\text{TiCl}_4$ enrichment > 90% - available from Trace Sciences International Inc.

The first step of synthesis was performed at IPHC, the final step at FLNR.
The efficiency of synthesis is more than 90%.



Chemistry laboratory

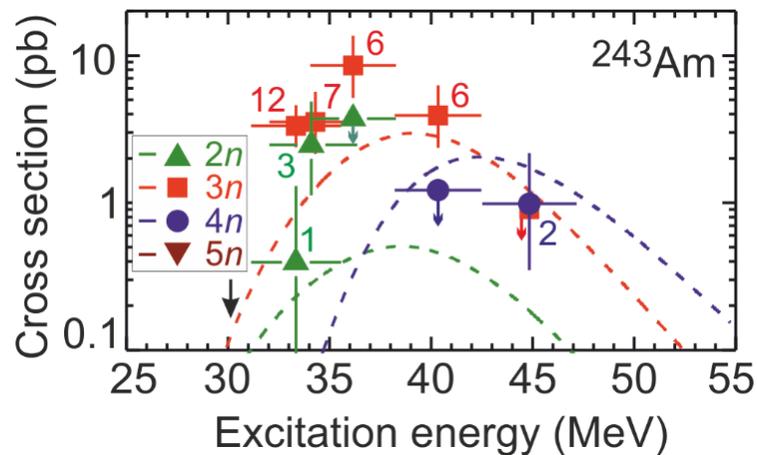
Superheavy Elements Factory



DC-280 cyclotron:
autonomous launching and
tuning works

gas-filled recoil separator (GFRS-2):
assembled

existing data for $^{48}\text{Ca}+^{243}\text{Am}$



**the most critical tasks for
the end of 2018 – beginning of 2019:**

- certifying;
- full commissioning;
- preparing and conducting day-first test experiments ($^{48}\text{Ca}+^{243}\text{Am}$);

2nd half of 2019:

- preparing and conducting experiment on synthesis of element 119 in the $^{50}\text{Ti}+^{249}\text{Bk}$ reaction;

Day-one experiments at SHE Factory

Test experiments I:

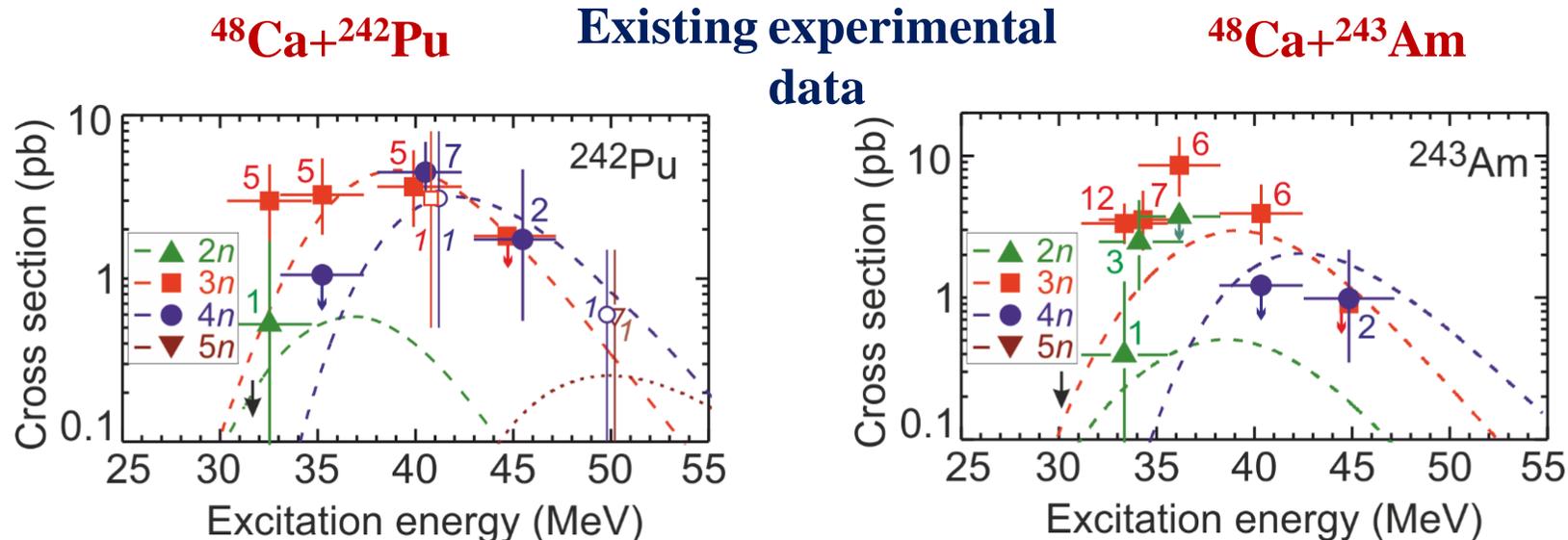
Test of functionalities of all the systems of the accelerator and gas-filled separator

$^{40}\text{Ar} + \text{natDy}$ and $^{18}\text{O} + ^{208}\text{Pb}$

Test experiments II:

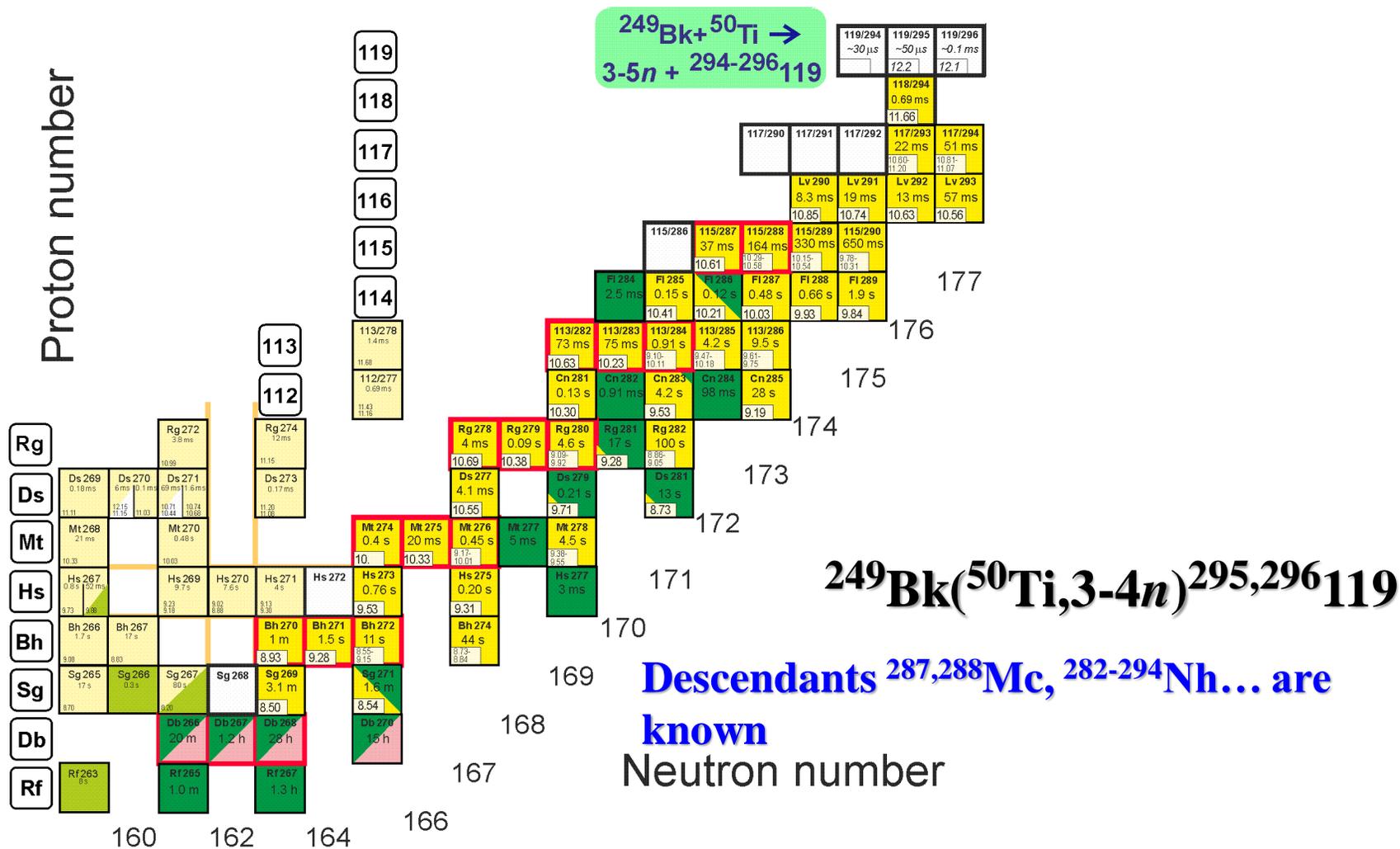
$^{48}\text{Ca} + ^{242}\text{Pu}$ and $^{48}\text{Ca} + ^{243}\text{Am}$

1. Enough material to prepare “big” targets
2. Well-studied in previous experiments
3. Relatively large cross sections



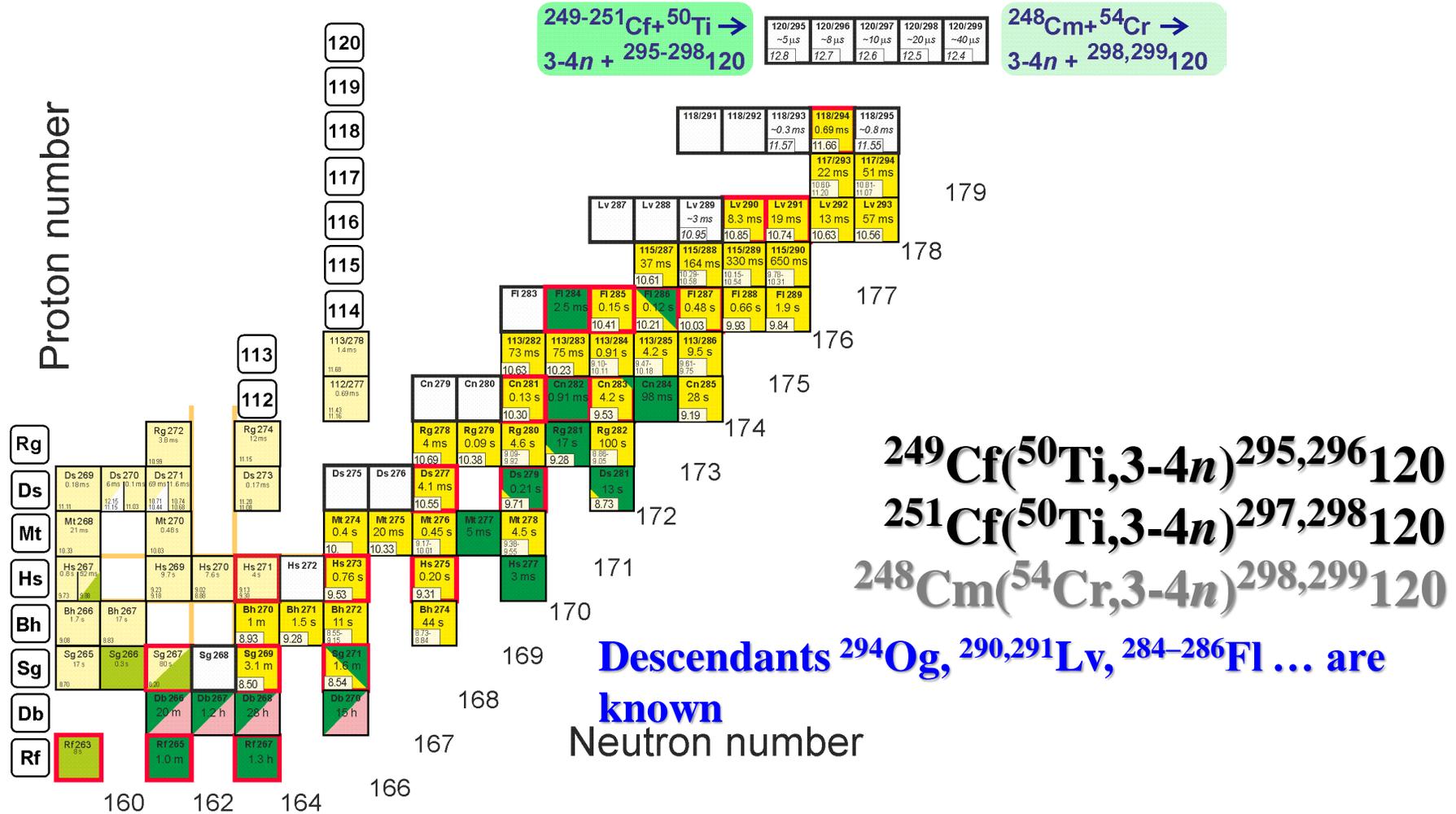
First experiments at SHE Factory

Synthesis of new element 119



First experiments at SHE Factory

Synthesis of new element 120



$s=50 \text{ fb}$, $h_t=0.3 \text{ mg/cm}^2$, $\epsilon_{\text{coll}}=0.6$, $I_{\text{beam}}=3 \text{ pA} \rightarrow \approx 1 \text{ event per month}$

Thank you for your attention!

