Yu.Ts. Oganessian, S.N. Dmitriev, G.G. Gulbekian , I.V. Kalagin,

SHE-Factory:
new cyclotron facility for super heavy element research

Igor Kalagin

FLEROV LABORATORY of NUCLEAR REACTIONS
JOINT INSTITUTE FOR NUCLEAR RESEARCH

HIAT 2018


DC-280
SHE factory
U-400
Heavy and superheavy nuclei
U-400M
Light exotic nuclei
IC-100
Applied research
NanoLab
DRIBs gallery
MT-25
Microtron


DUBNA Gas Filled Recoil Separator

Target		Beam		Isotopes
^{238}U, ^{242,244}Pu, ^{243}Am, ^{246,248}Cm, ^{249}Cf	+	^{48}Ca	→	112 – 118

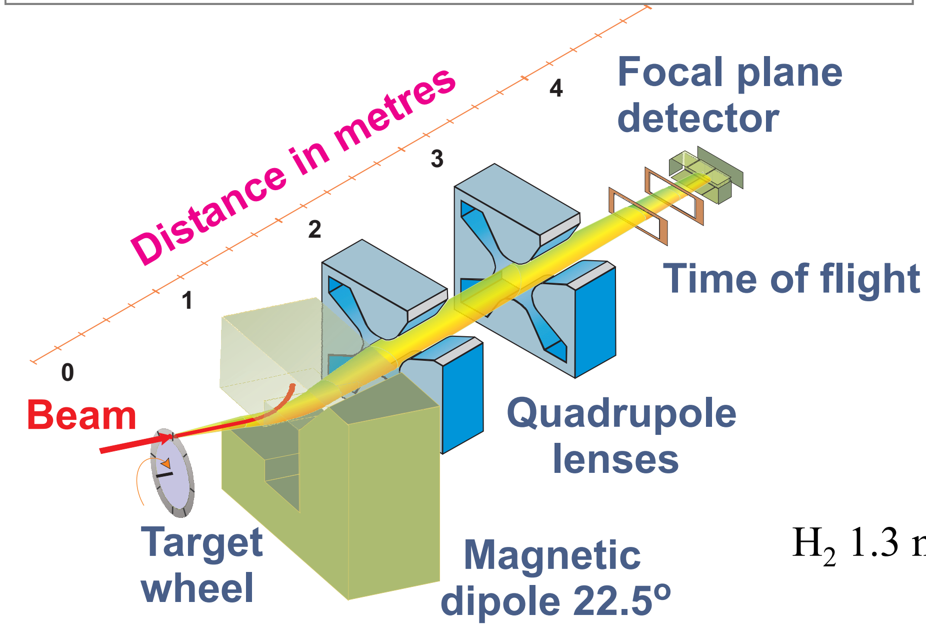
U-400 cyclotron (1978):

Ion beam energy: 5.00 – 5.75 MeV/A

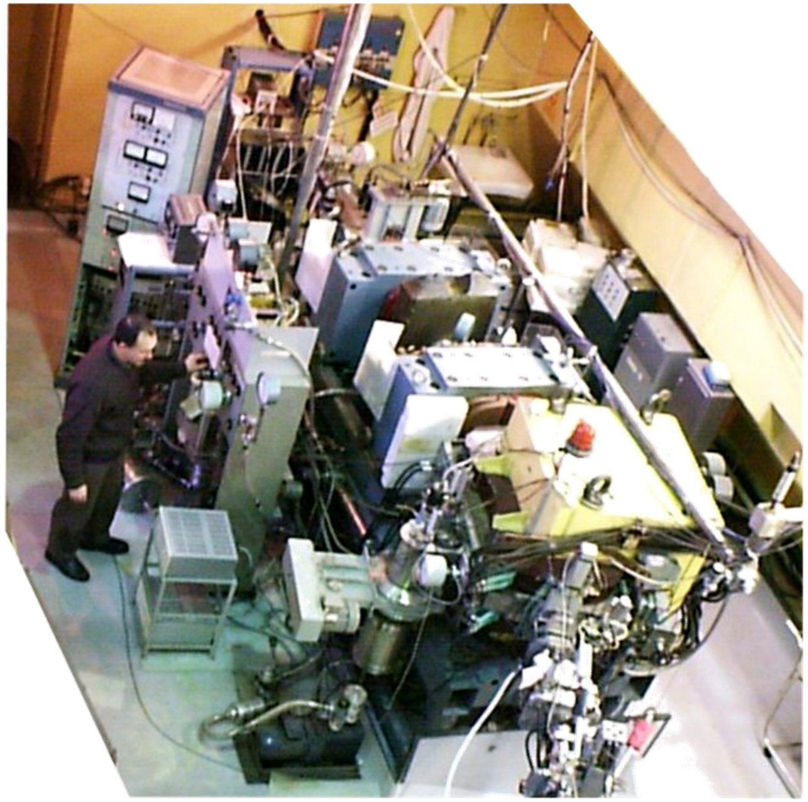
Beam intensity: 6 - 8·10^{12} pps

Consumption of ^{48} Ca = 0.5-0.8 mg/h

Beam time: 2000 – 4000 hours per year



H_2 1.3 mBar



In operation since 1989

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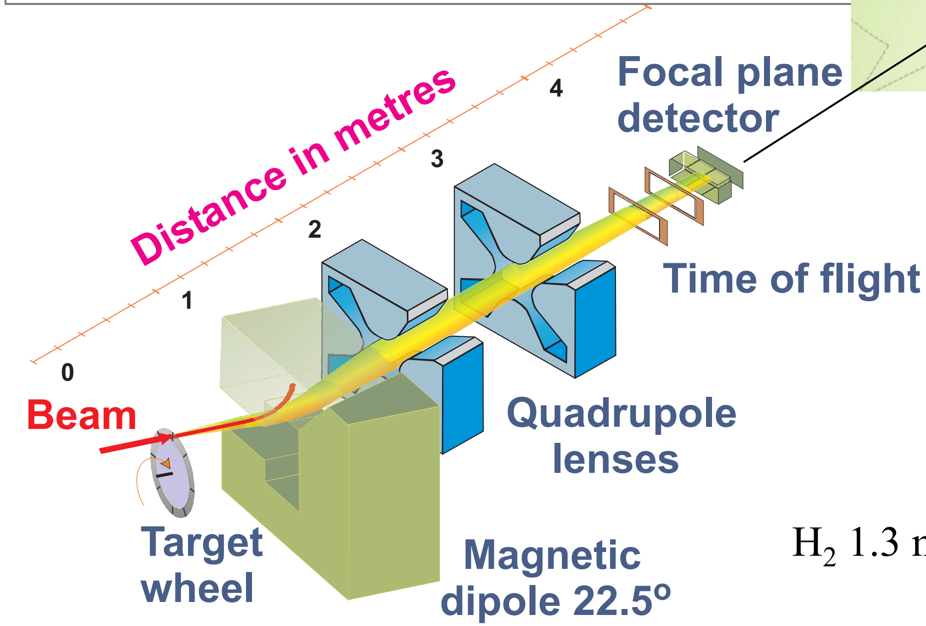

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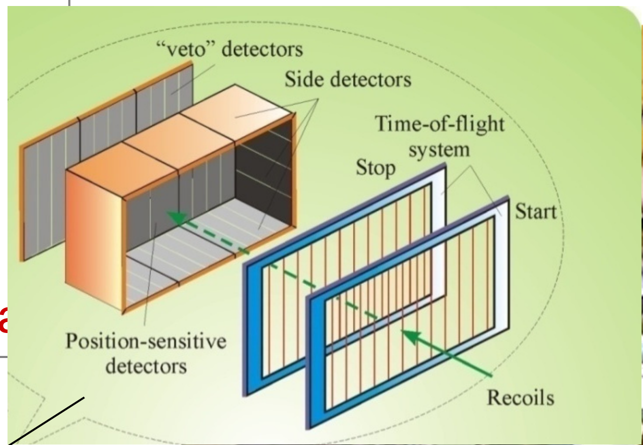
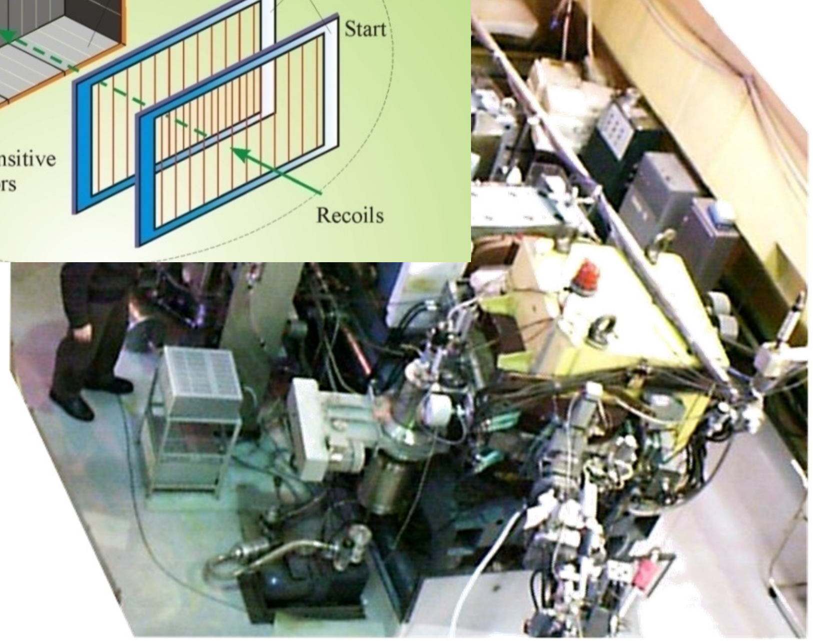
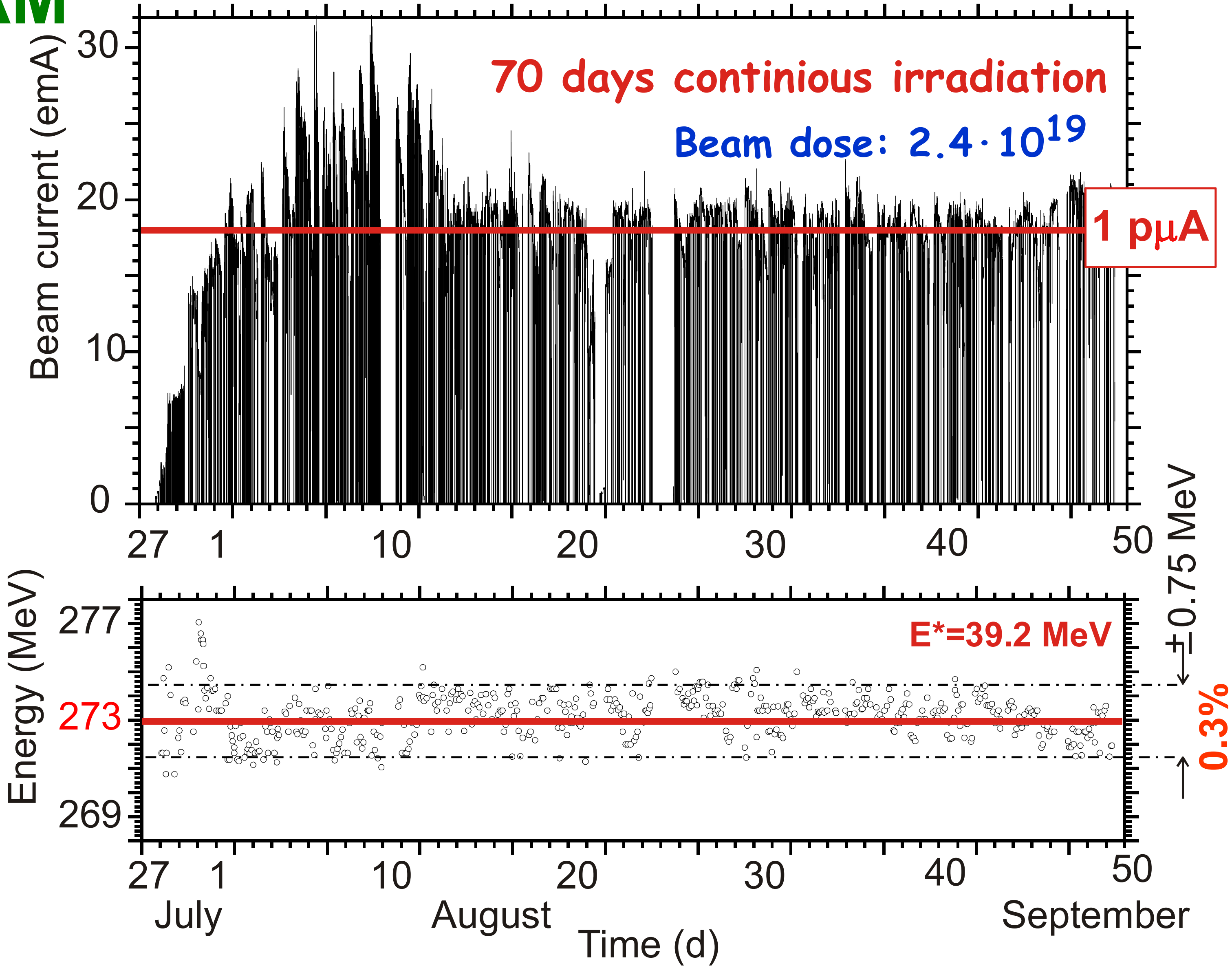




In operation since 1989

BEAM



70 days continious irradiation
Beam dose: 2.4·10^19
1 pμA
Beam current (emA)
30
20
10
0
27
1
10
20
30
40
50
E*=39.2 MeV
±0.75 MeV
0.3%
Energy (MeV)
277
273
269
July
August
September
Time (d)

JINR
114 Flerovium
FLNR
Dubna

Периодическая таблица элементов Д.И. Менделеева

D.I. Mendeleev's Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Водород 1 H 1,008 Hydrogen																	Гелий 2 He 4,0026 Helium
Литий 3 Li 6,94 Lithium	Бериллий 4 Be 9,0122 Beryllium											Бор 5 B 10,81 Boron	Углерод 6 C 12,011 Carbon	Азот 7 N 14,007 Nitrogen	Кислород 8 O 15,999 Oxygen	Фтор 9 F 18,998 Fluorine	Неон 10 Ne 20,18 Neon
Натрий 11 Na 22,99 Sodium	Магний 12 Mg 24,305 Magnesium											Алюминий 13 Al 26,982 Aluminum	Кремний 14 Si 28,085 Silicon	Фосфор 15 P 30,974 Phosphorus	Сера 16 S 32,06 Sulfur	Хлор 17 Cl 35,45 Chlorine	Аргон 18 Ar 39,948 Argon
Калий 19 K 39,098 Potassium	Кальций 20 Ca 40,078(4) Calcium	Скандий 21 Sc 44,956 Scandium	Титан 22 Ti 47,867 Titanium	Ванадий 23 V 50,942 Vanadium	Хром 24 Cr 51,996 Chromium	Марганец 25 Mn 54,938 Manganese	Железо 26 Fe 55,845(2) Iron	Кобальт 27 Co 58,933 Cobalt	Никель 28 Ni 58,693 Nickel	Медь 29 Cu 63,546(3) Copper	Цинк 30 Zn 65,38(2) Zinc	Галлий 31 Ga 69,723 Gallium	Германий 32 Ge 72,630(8) Germanium	Мышьяк 33 As 74,922 Arsenic	Селен 34 Se 78,971(8) Selenium	Бром 35 Br 79,904 Bromine	Криптон 36 Kr 83,798(2) Krypton
Рубидий 37 Rb 85,468 Rubidium	Стронций 38 Sr 87,62 Strontium	Иттрий 39 Y 88,906 Yttrium	Цирконий 40 Zr 91,224(2) Zirkonium	Ниобий 41 Nb 92,906 Niobium	Молибден 42 Mo 95,95 Molybdenum	Технеций 43 Tc [98] Technetium	Рутений 44 Ru 101,07(2) Ruthenium	Родий 45 Rh 102,91 Rhodium	Палладий 46 Pd 106,42 Palladium	Серебро 47 Ag 107,87 Silver	Кадмий 48 Cd 112,41 Cadmium	Индий 49 In 114,82 Indium	Олово 50 Sn 118,71 Tin	Сурьма 51 Sb 121,76 Antimony	Теллур 52 Te 127,60(3) Tellurium	Иод 53 I 126,90 Iodine	Ксенон 54 Xe 131,29 Xenon
Цезий 55 Cs 132,91 Cesium	Барий 56 Ba 137,33 Barium	Лантан 57 La 138,91 Lanthanum	Гафний 72 Hf 178,49(2) Hafnium	Тантал 73 Ta 180,95 Tantalum	Вольфрам 74 W 183,84 Tungsten	Рений 75 Re 186,21 Rhenium	Осмий 76 Os 190,23(3) Osmium	Иридий 77 Ir 192,22 Iridium	Платина 78 Pt 195,08 Platinum	Золото 79 Au 196,97 Gold	Ртуть 80 Hg 200,59 Mercury	Таллий 81 Tl 204,38 Thallium	Свинец 82 Pb 207,2 Lead	Висмут 83 Bi 208,98 Bismuth	Полоний 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 [267] Rutherfordium	Дубний 105 Db [268] Dubnium	Сиборгий 106 Sg [271] Seaborgium	Борий 107 Bh [270] Bohrium	Хассий 108 Hs [269] Hassium	Мейтнерий 109 Mt [278] Meitnerium	Дармштадтий 110 Ds [281] Darmstadtium	Рентгений 111 Rg [282] Roentgenium	Коперникий 112 Cn [285] Copernicium	Нихоний 113 Nh [286] Nihonium	Флеровий 114 Fl [289] Flerovium	Московий 115 Mc [290] Moscovium	Ливерморий 116 Lv [293] Livermorium	Теннессин 117 Ts [294] Tennessine	Оганесон 118 Og [294] Oganesson

Лантаноиды Lanthanoides

Церий 58 Ce 140,12 Cerium	Празеодим 59 Pr 140,91 Praseodymium	Неодим 60 Nd 144,24 Neodymium	Прометий 61 Pm [145] Promethium	Самарий 62 Sm 150,36(2) Samarium	Европий 63 Eu 151,96 Europium	Гадолиний 64 Gd 157,25(3) Gadolinium	Тербий 65 Tb 158,93 Terbium	Диспрозий 66 Dy 162,50 Dysprosium	Гольмий 67 Ho 164,93 Holmium	Эрбий 68 Er 167,26 Erbium	Тулий 69 Tm 168,93 Thulium	Иттербий 70 Yb 173,05 Ytterbium	Лютеций 71 Lu 174,97 Lutetium

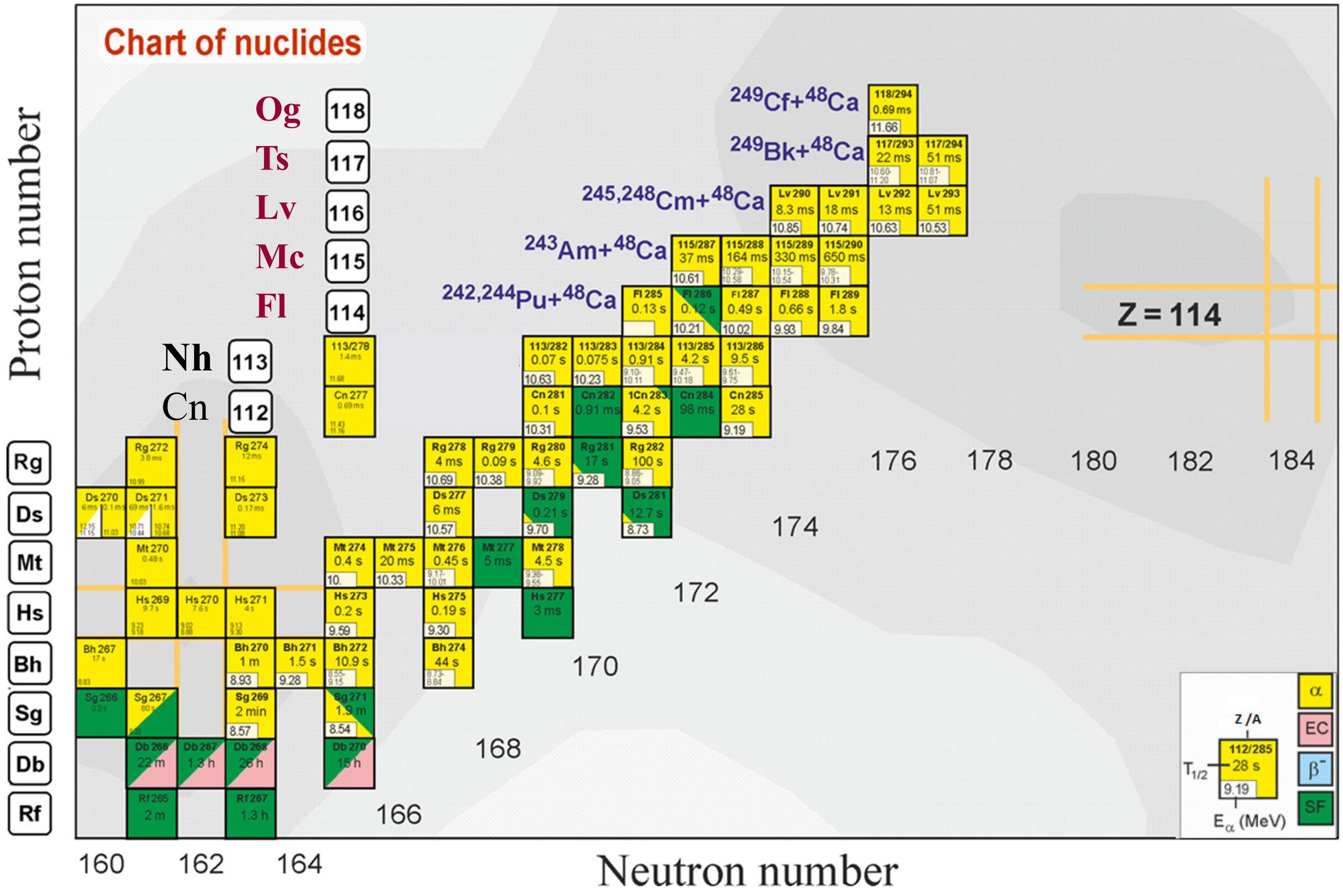
Актиноиды Actinoides

Торий 90 Th 232,04 Thorium	Протактиний 91 Pa 231,04 Protactinium	Уран 92 U 238,03 Uranium	Нептуний 93 Np [237] Neptunium	Плутоний 94 Pu [244] Plutonium	Америций 95 Am [243] Americium	Кюрий 96 Cm [247] Curium	Берклий 97 Bk [247] Berkelium	Калифорний 98 Cf [251] Californium	Эйнштейний 99 Es [252] Einsteinium	Фермий 100 Fm [257] Fermium	Менделевий 101 Md [258] Mendelevium	Нобелий 102 No [259] Nobelium	Лоуренсий 103 Lr [266] Lawrencium

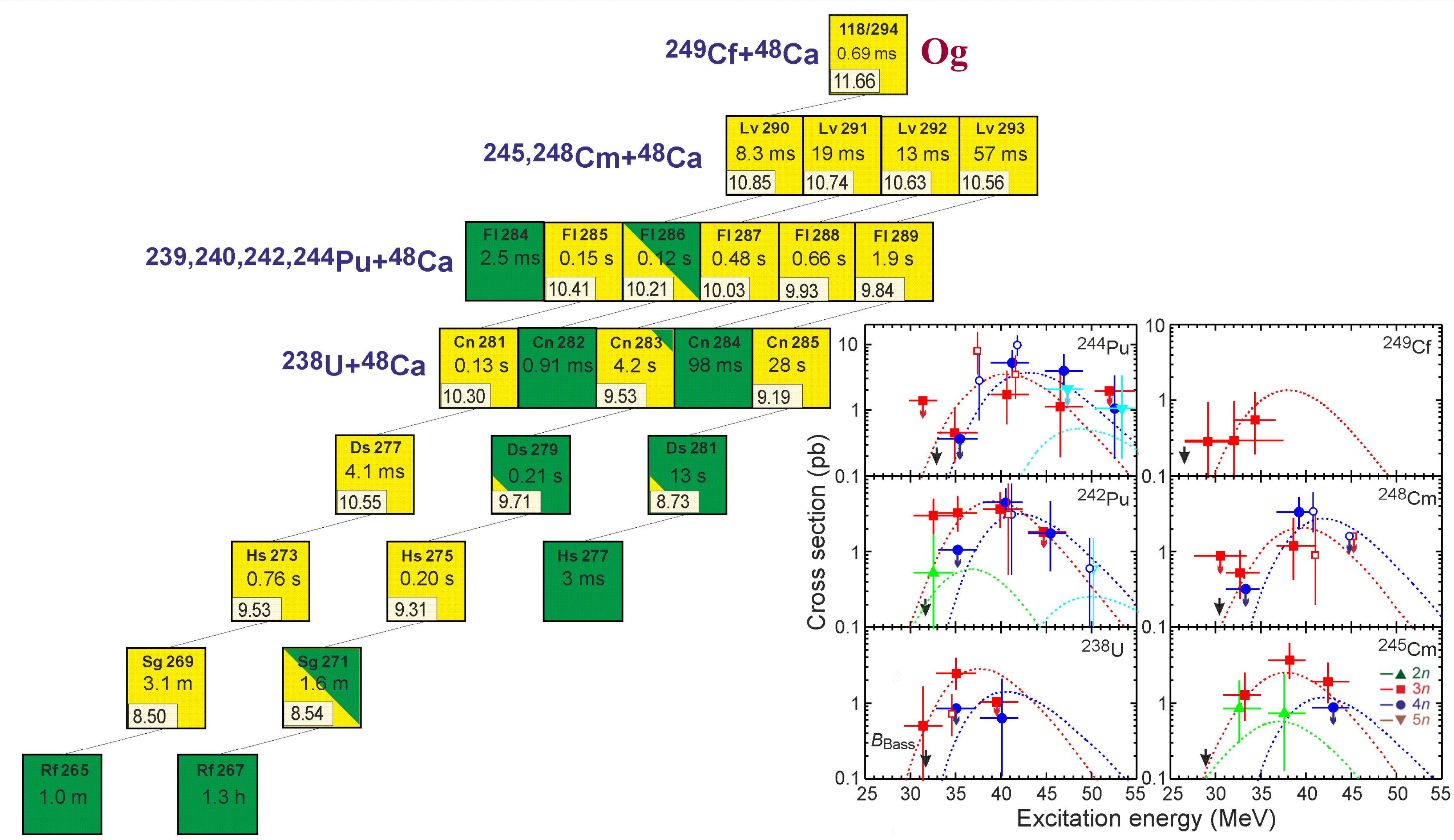
Водород 1 1s
H
1,00794 Hydrogen
13,59844 0,0899 -259,34 -252,87

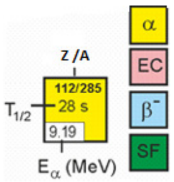
H - символ / symbol
1,00794 - атомная масса / atomic mass
1s¹ - электронная конфигурация / electron configuration
13,59844 - 1-й потенциал ионизации, эВ / 1st ionization potential, eV
0,0899 - плотность, кг/м³ / density, kg/m³
-259,34 - температура плавления, °C / melting temperature, °C
-252,87 - температура кипения, °C / boiling temperature, °C

Region of superheavy nuclei



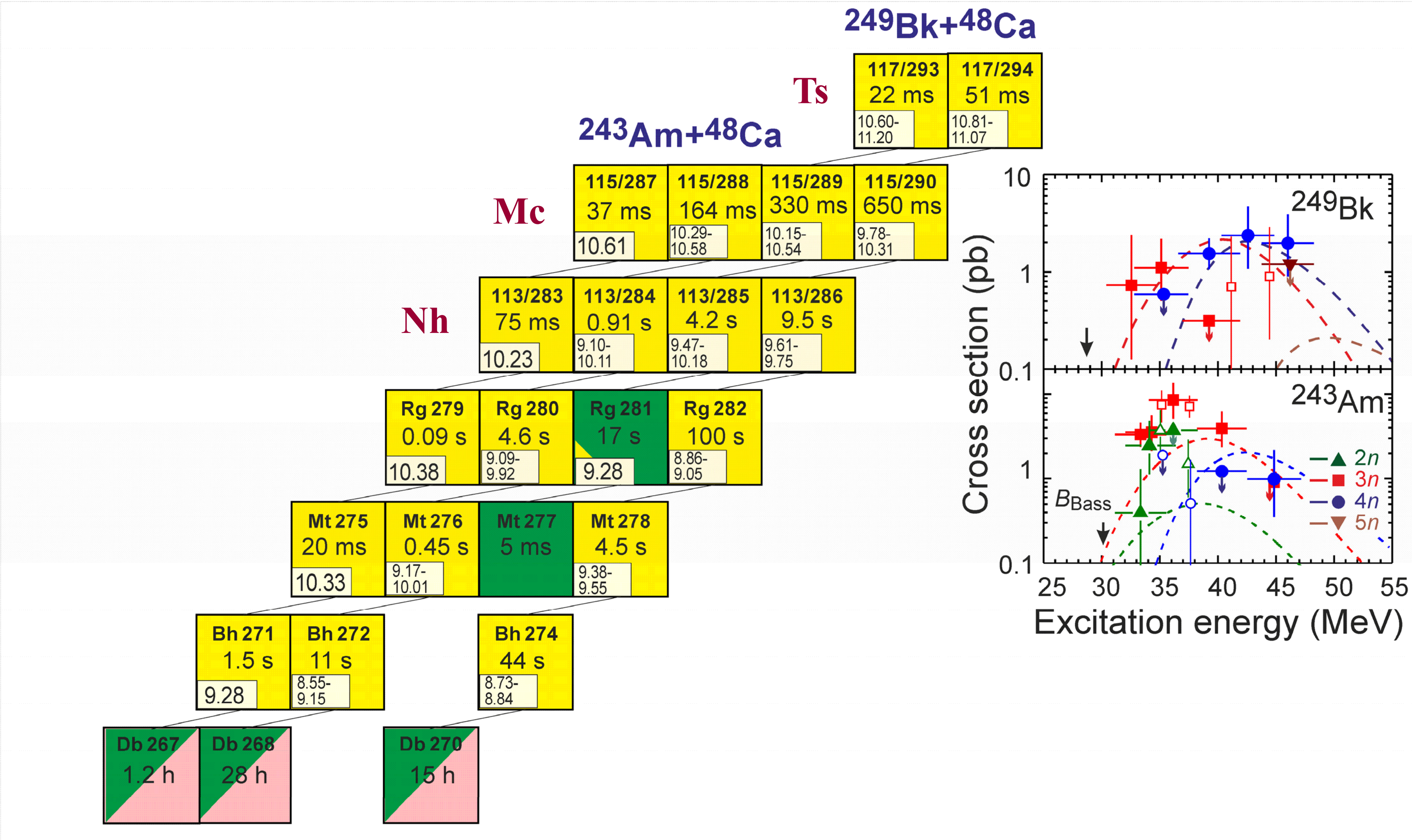
Even-Z nuclei

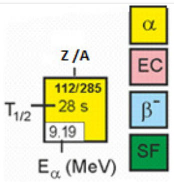




V.K. Utyonkov, Yu.Ts. Oganessian, S.N. Dmitriev el al., Eurasian Journal of Physics and Functional Materials, 2017, 1(1), p.5-11

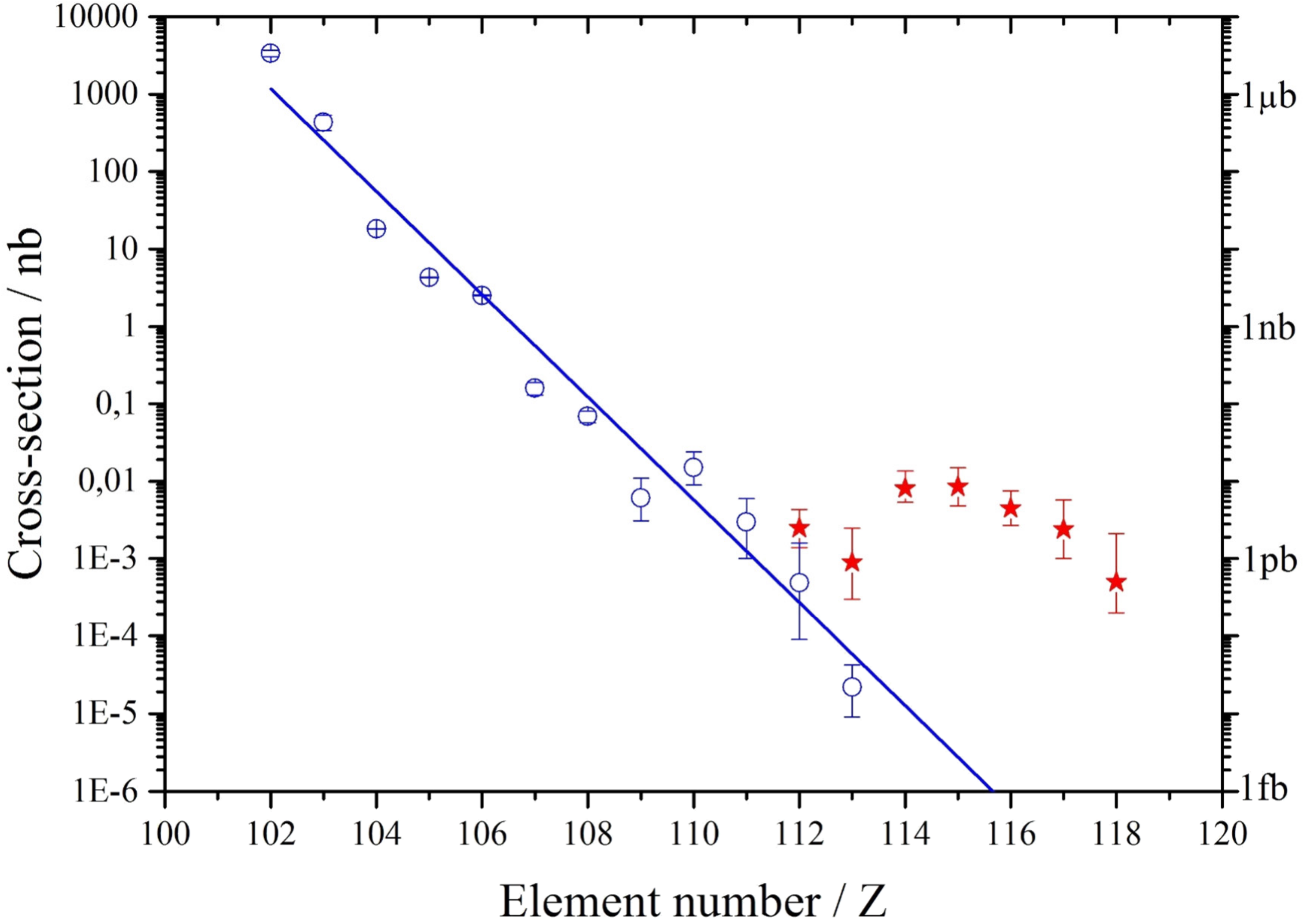
Elements 115 and 117





V.K. Utyonkov, Yu.Ts. Oganessian, S.N. Dmitriev el al., Eurasian Journal of Physics and Functional Materials, 2017, 1(1), p.5-11

Production cross-sections of heavy and super-heavy



At 1 pµA of ^{48}Ca

100 / h

1 / week

1 / 20 y

What is beyond 118 element?

Heaviest target: $^{251}Cf + Z_{max} = 118$ …

↓

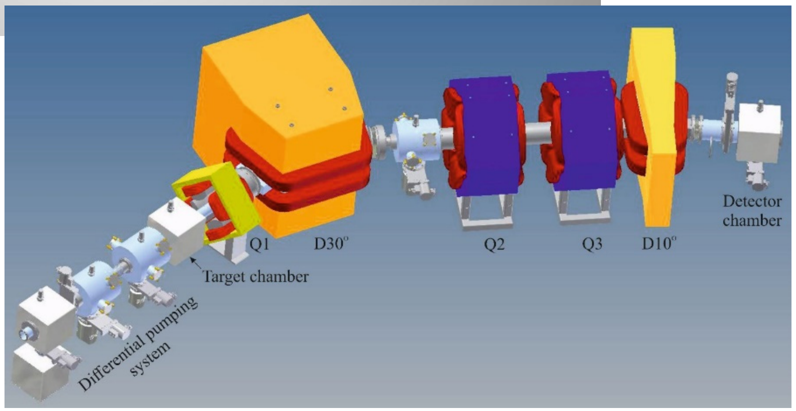
- **Heavier projectiles (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni)**

Sufficient increasing of overall experiment efficiency is needed!

Superheavy Elements (SHE) Factory

SHE Factory Building

High-current cyclotron DC-280



New facilities:

- New gas-filled separator
- Preseparator
- SHELS
- Etc.

SHE Factory – the Goals

- Experiments at the extremely low (σ<100 fb) cross sections:
  - Synthesis of new SHE in reactions with ^{50}Ti, ^{54}Cr ...;
  - Synthesis of new isotopes of SHE;
  - Study of decay properties of SHE;

- Experiments requiring high statistics:
  - Nuclear spectroscopy of SHE;
  - Study of chemical properties of SHE.

DC-280 CYCLOTRON- THE NEW FLNR ACCELERATOR

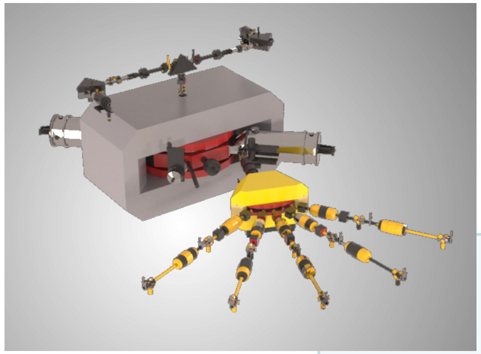
To satisfy the Goals, the DC-280 has to provide the following parameters of ion beams:

Ion energy	4÷8 MeV/n
Ion masses	10÷238
Intensities (A~50)	>10 pμA
Beam emittance	less than 30 π mm·mrad
Efficiency of beam transfer	>50%

Ion energies correspond to total accelerating potential up to 40 MV

Stand-alone SHE factory with DC-280 cyclotron

SHE factory building 2012



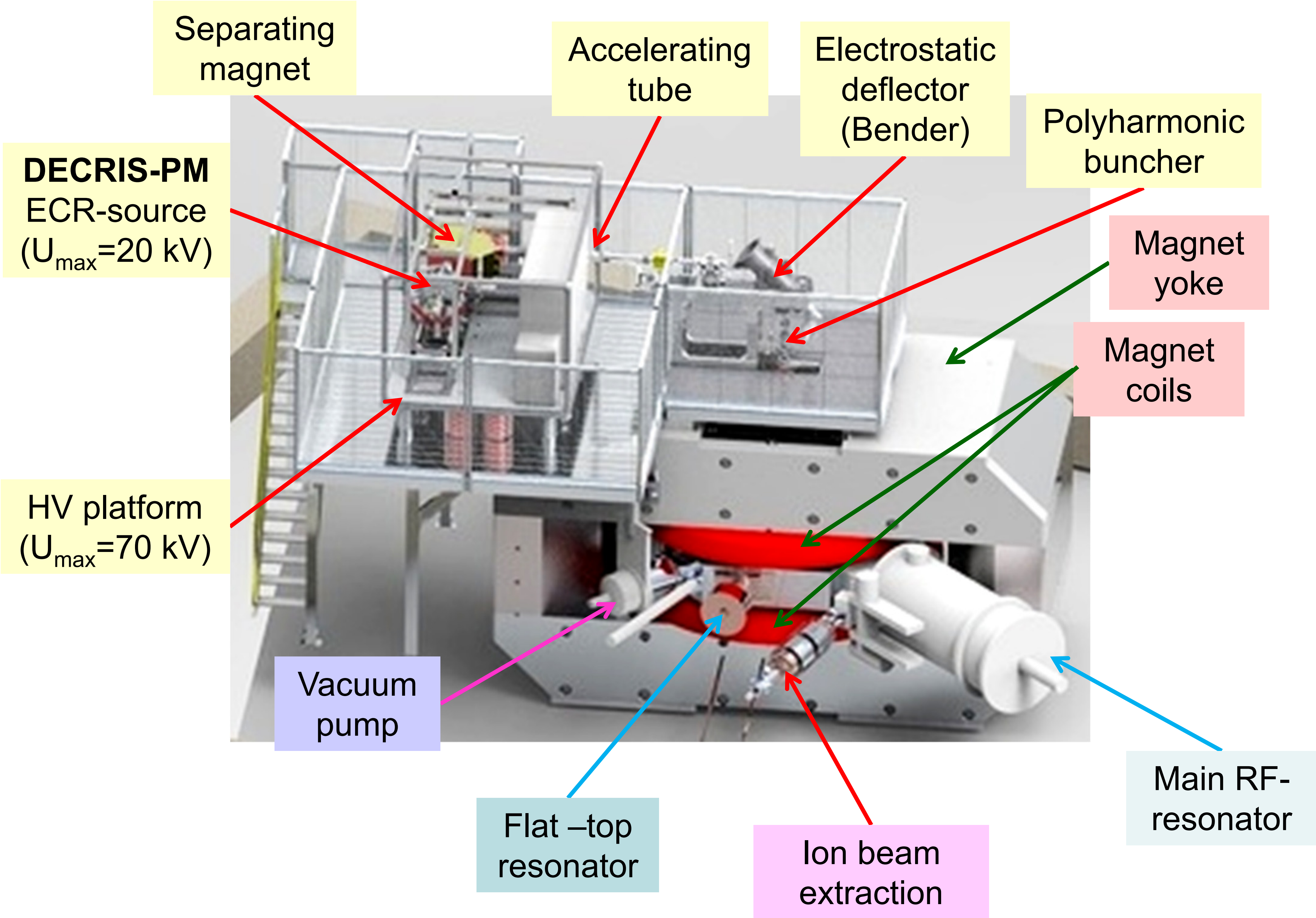
SHE factory building 2018

DC280 (expected) E=4÷8 MeV/A		
Ion	Ion energy [MeV/A]	Output intensity
^{7}Li	4	1×10^{14}
^{18}O	8	1×10^{14}
^{40}Ar	5	6×10^{13}
^{48}Ca	5	$6,2\times10^{13}$
^{54}Cr	5	2×10^{13}
^{58}Fe	5	1×10^{13}
^{124}Sn	5	2×10^{12}
^{136}Xe	5	1×10^{14}
^{238}U	7	5×10^{10}

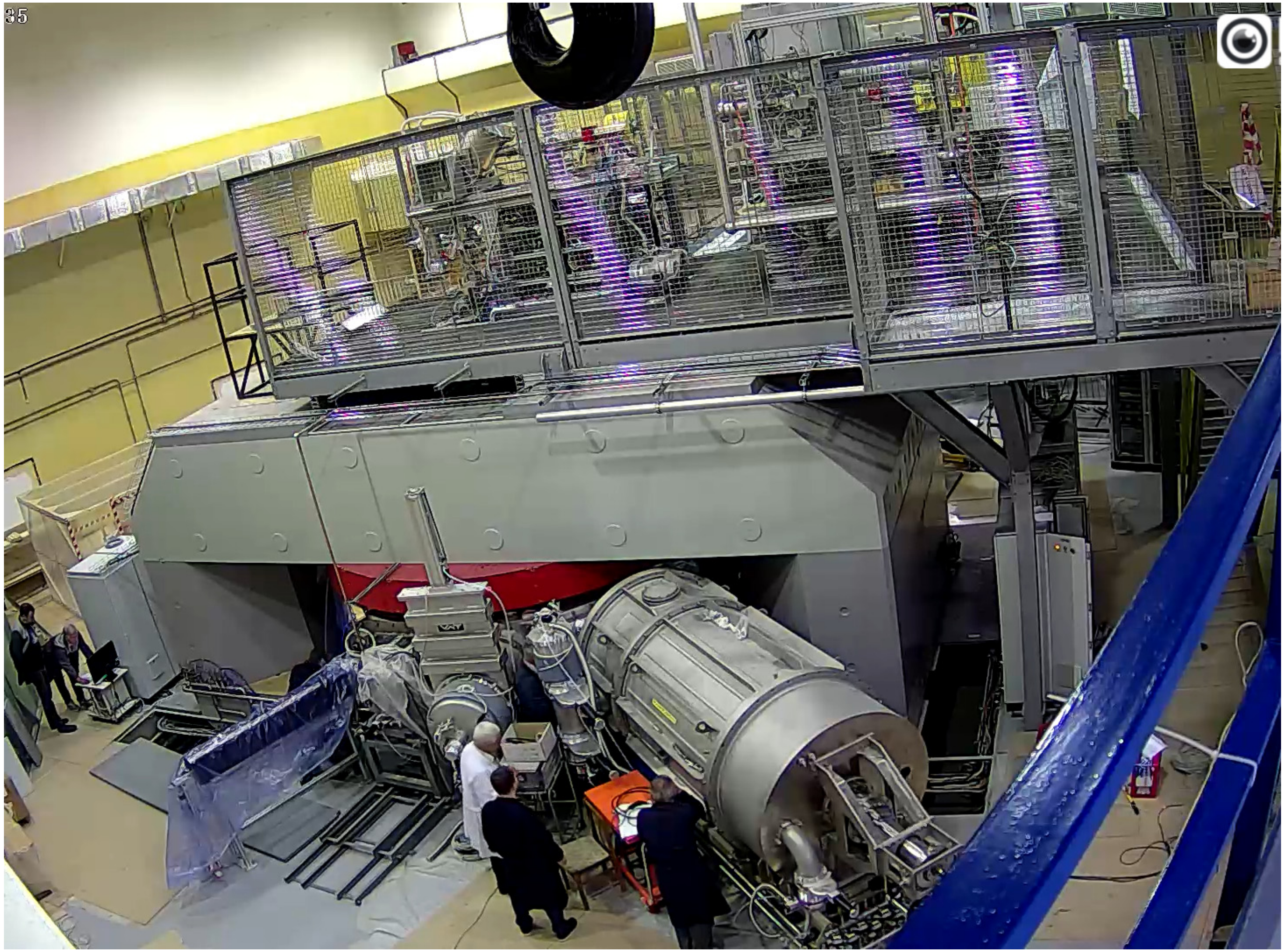
DC-280
Main Parameters

Ion sources	DECRIS-PM - 14 GHz Superconducting ECR (developing stage)
Injection energy	Up to 80 keV/Z
A/Z range	4÷7.5
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.3 T
K factor	280
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Deflector voltage	90 kV

Configuration of the DC-280

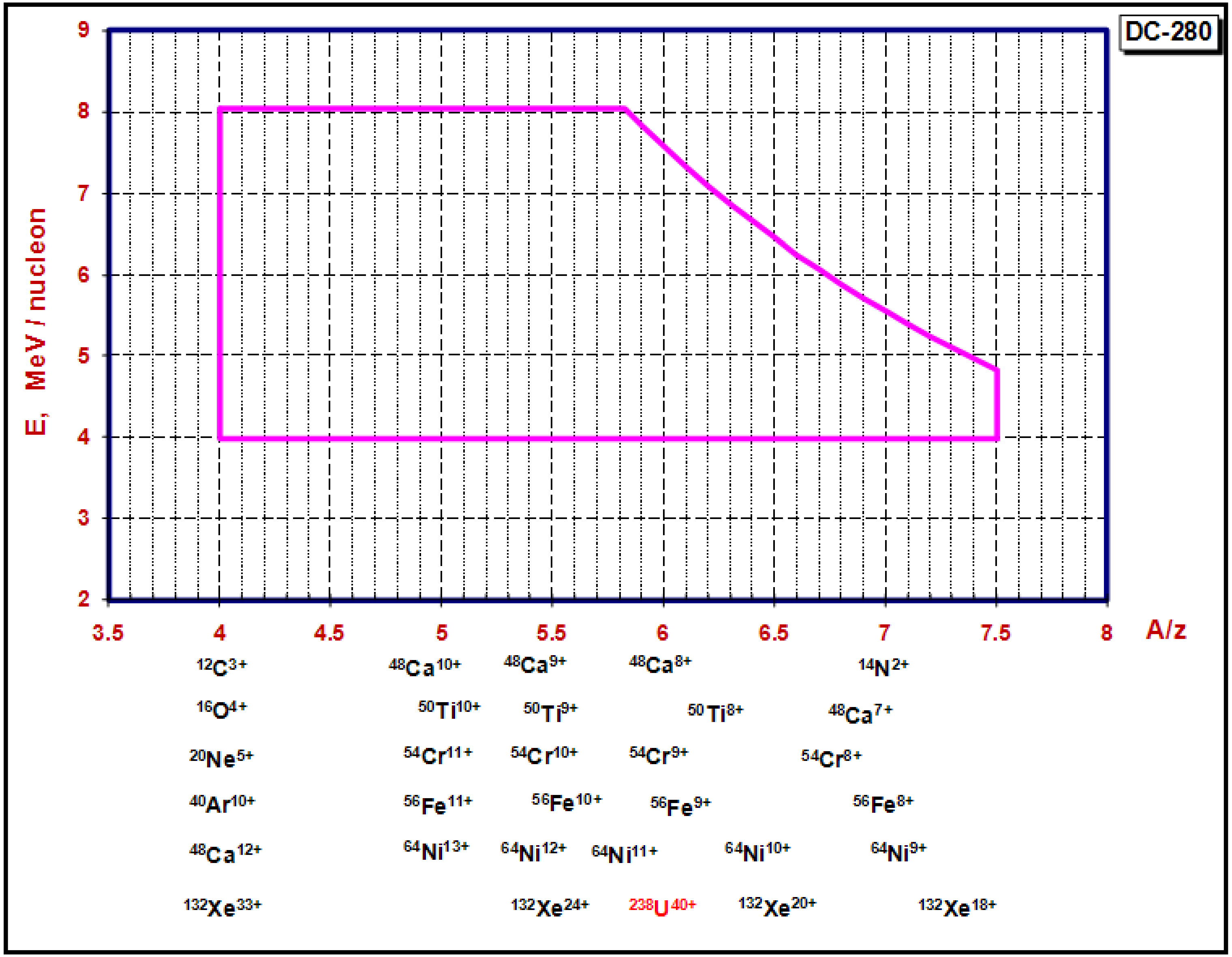


DC-280 cyclotron

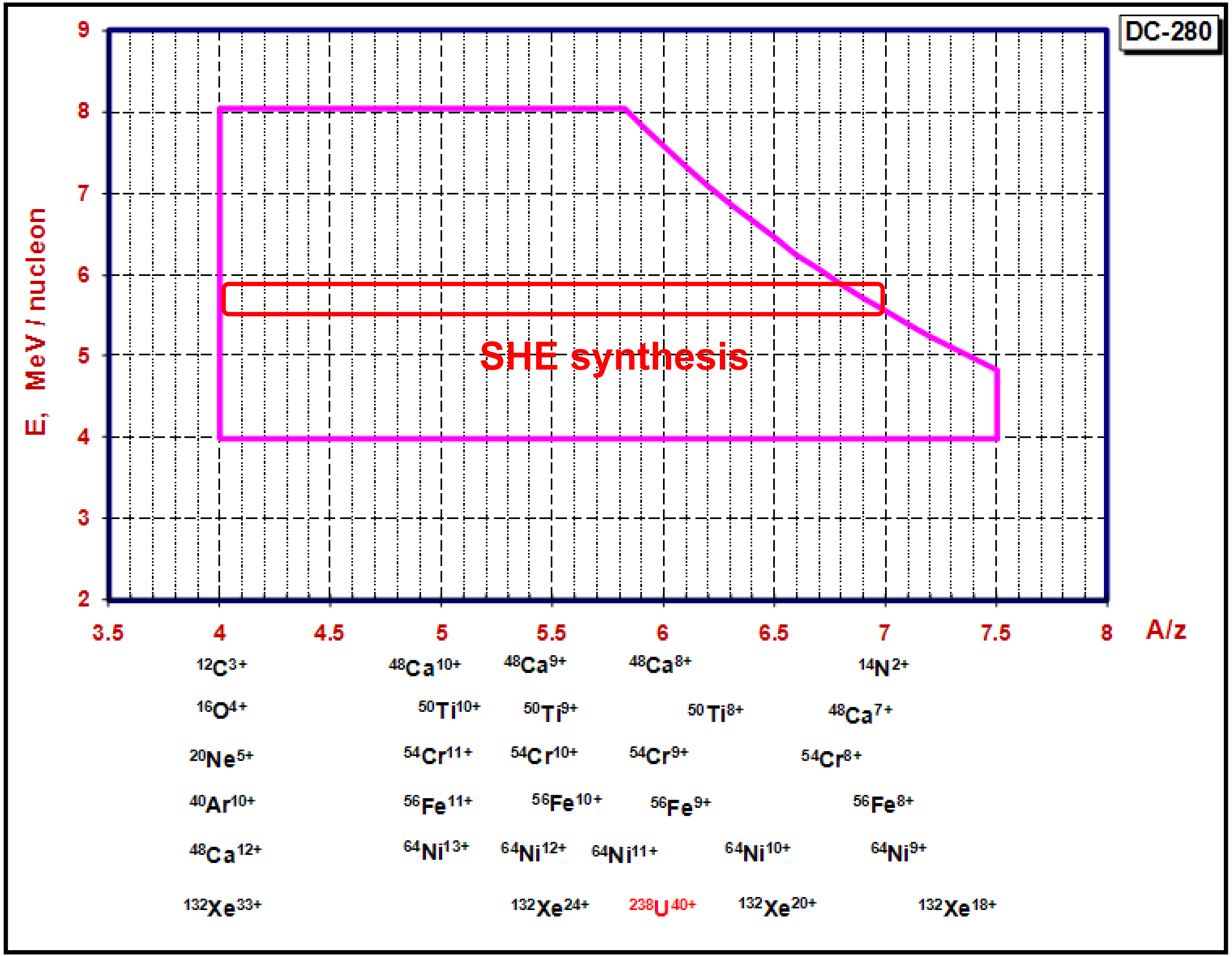


Launching and Tuning Works on the DC-280 systems without ion beam

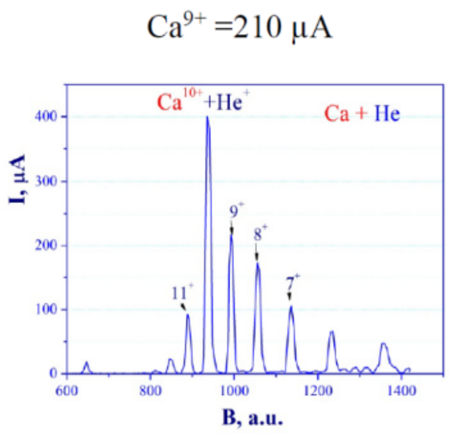
Working diagram of the DC-280

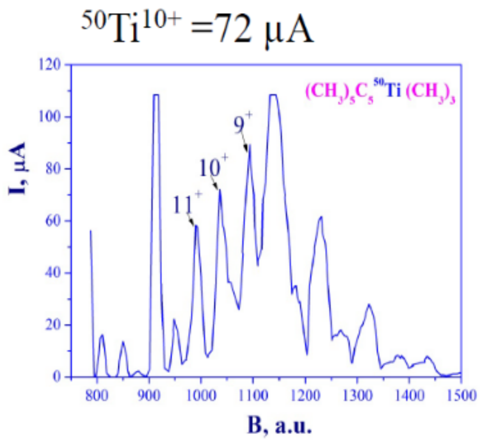


Working diagram of the DC-280



DECRIS-PM ion source



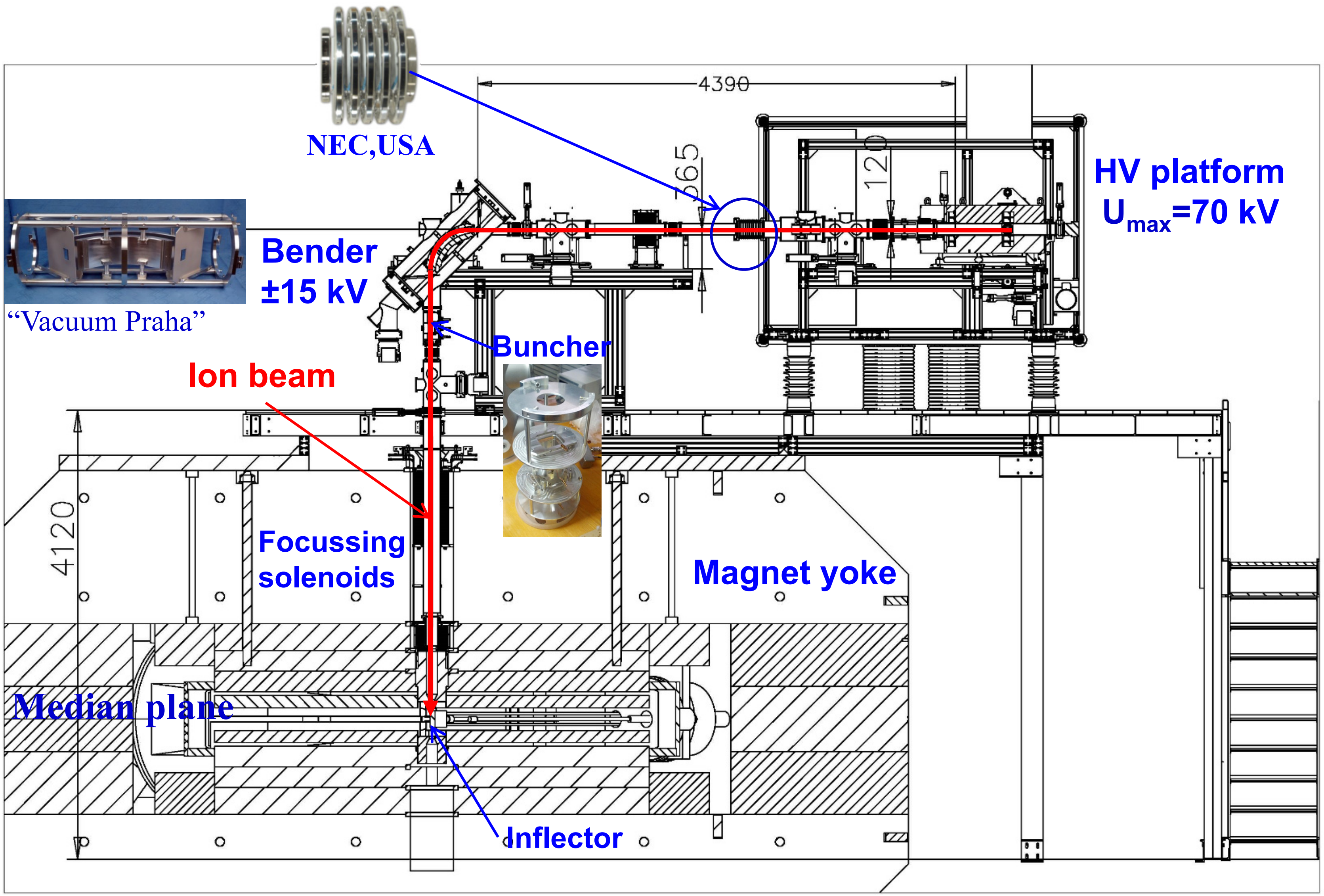


Results of bench test of DECRIS-PM

Frequency	Power consumption
14 GHz	5 kW

Ion currents, pμA												
Q+	5+	7+	8+	9+	10+	11+	12+	15+	17+	19+	20+	23+	26+
Ar			116	56		19	13						
Kr							13	12	7,3	2,6			
Xe											3,9	3	2
^{24}Mg	90	20	5	1,7									
^{40}Ca		16	22	24		14	4,8						
^{50}Ti				10	7,2	5,5	1,9						
^{56}Fe				9,4	8	5							

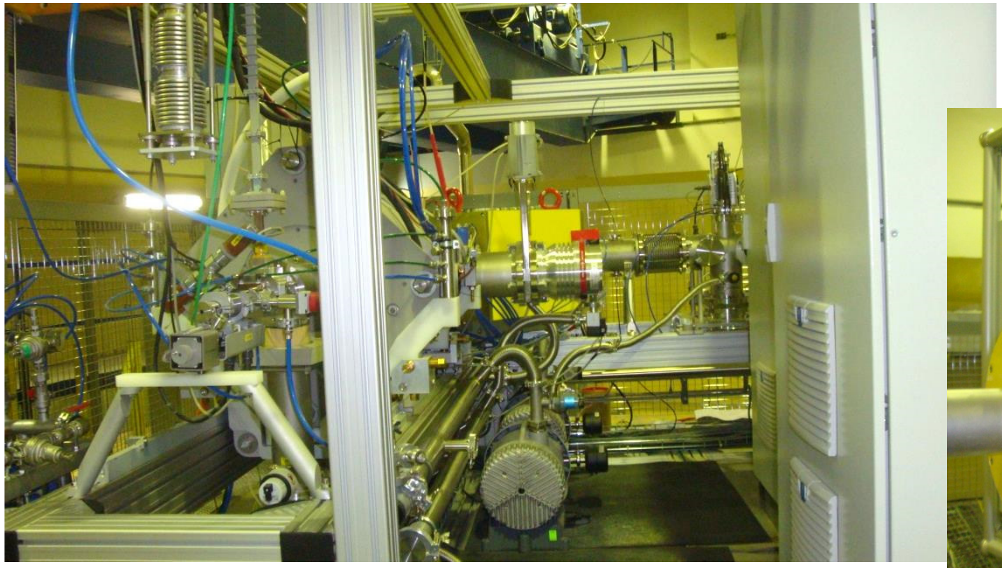
Beam injection system



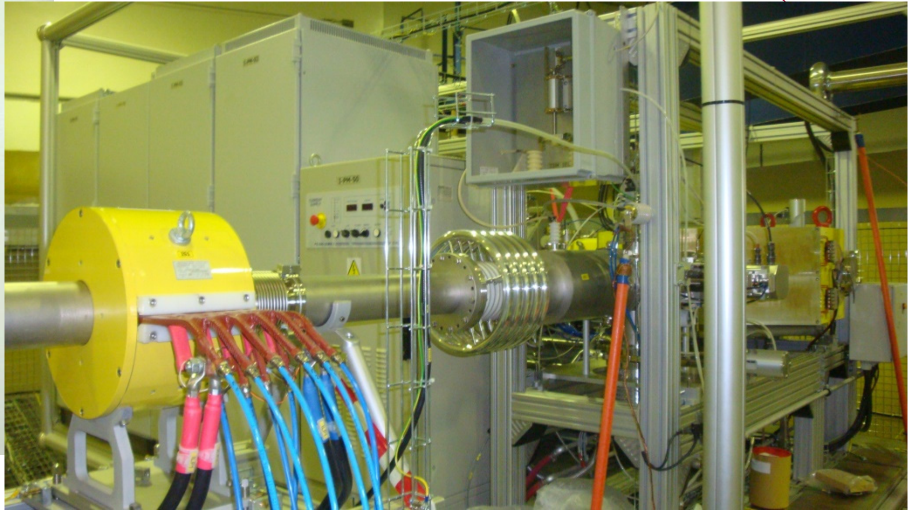
Beam injection system

The HV platform

Area of the electrostatic deflector (Bender)



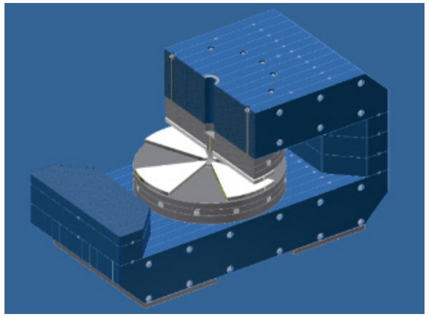
The DECRIS-PM ion source area



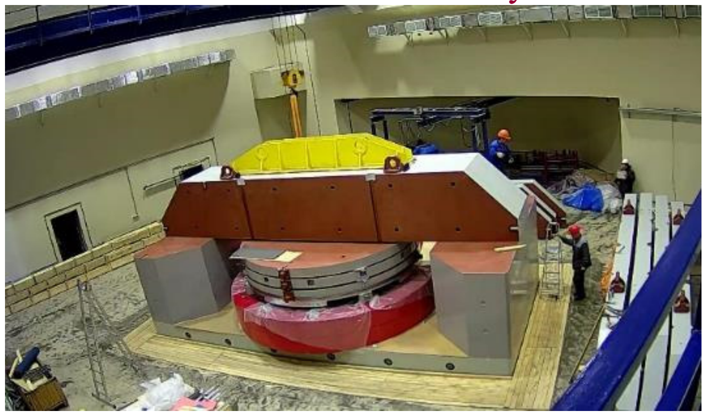
Area of the accelerating tube

Magnetic system of ДЦ-280

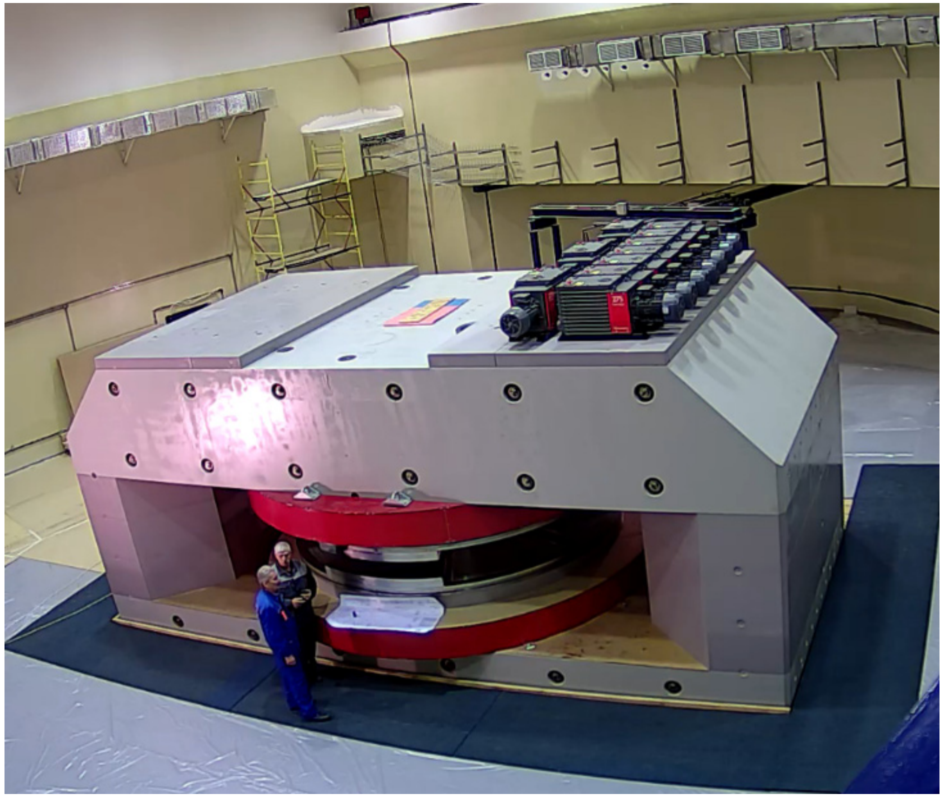
Size of magnet yoke LxWxH	8.76x4.08x4.84 m^3
Pole diameter	4 m
Gap between central plugs	400 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Maximal current	1000 A
Magnetic field level	0.6÷1.3 T



DC-280- isochronous cyclotron

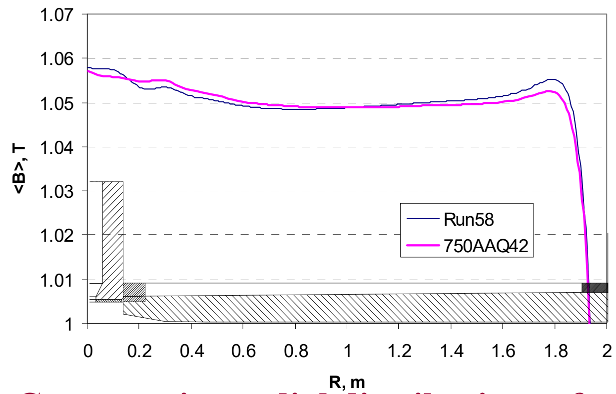


Magnet assembling (November 2016)`



Magnet assembling: September-November 2016

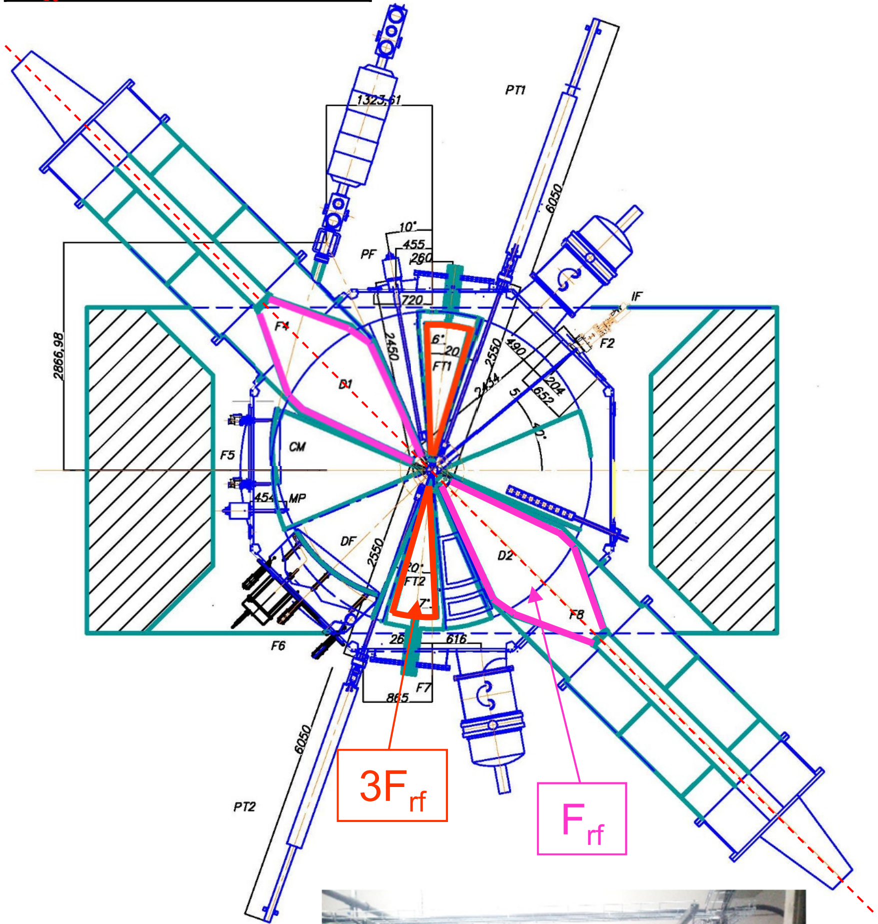
Magnetic field measurements: June-September 2017

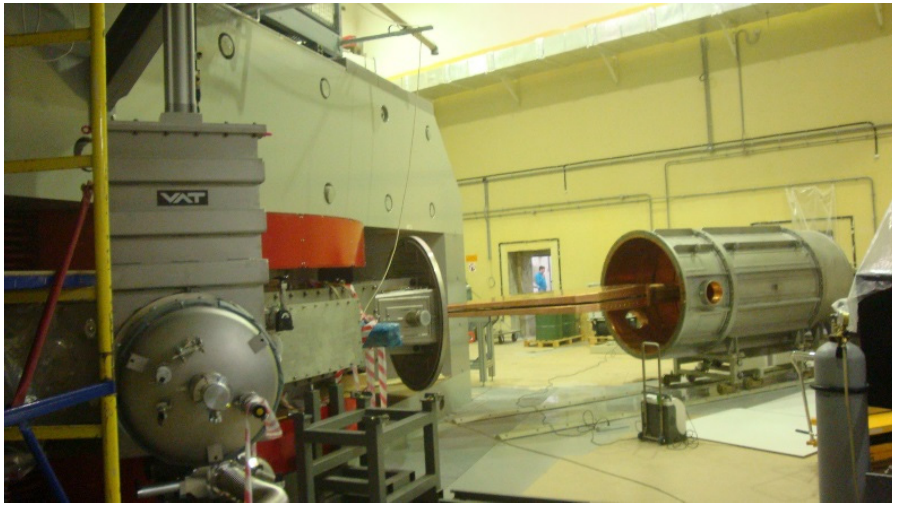


Comparative radial distributions of calculated and measured average magnetic field at the main coil current of 750A

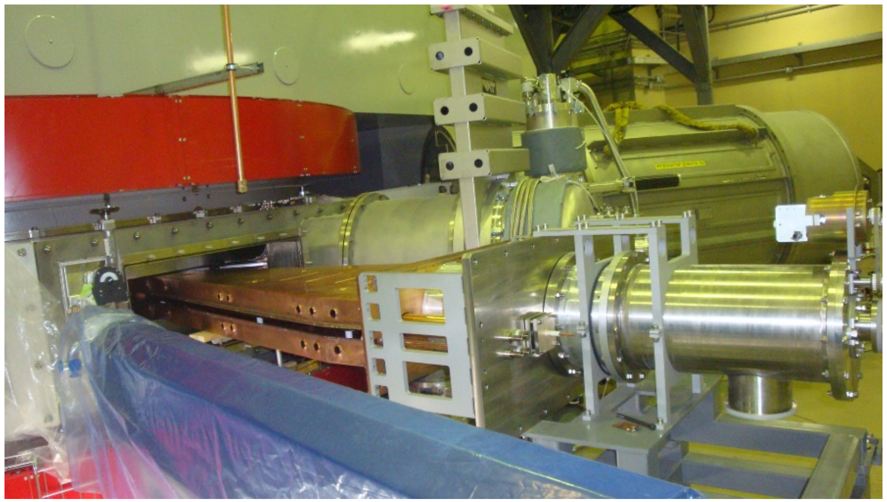
RF system

F_{rf}=7.32÷10.38 MHz
F_{ft}=21.96÷31.14 MHz





RF resonator with dee

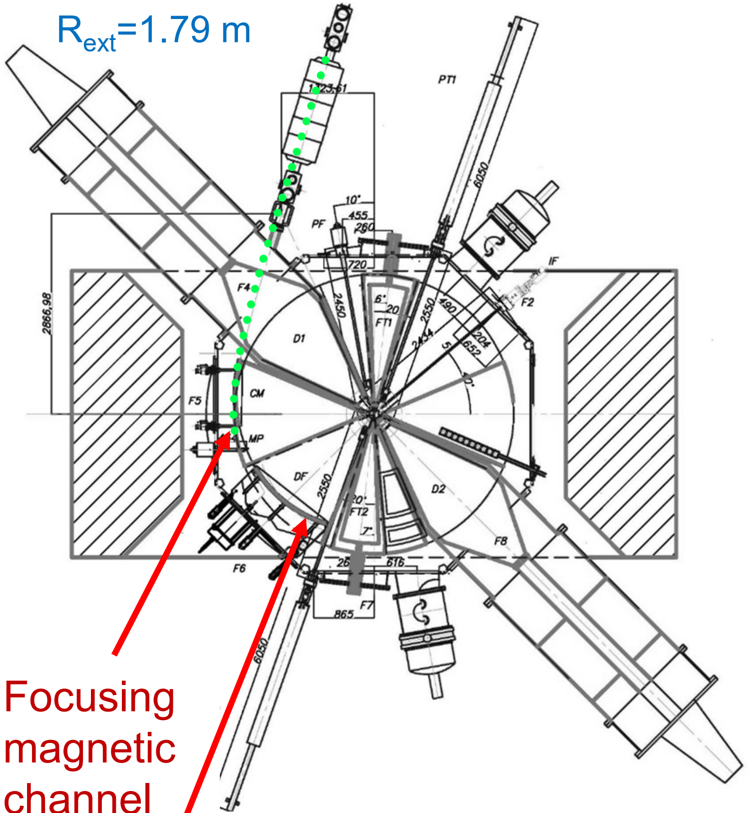


Flat-top resonator

RF generators

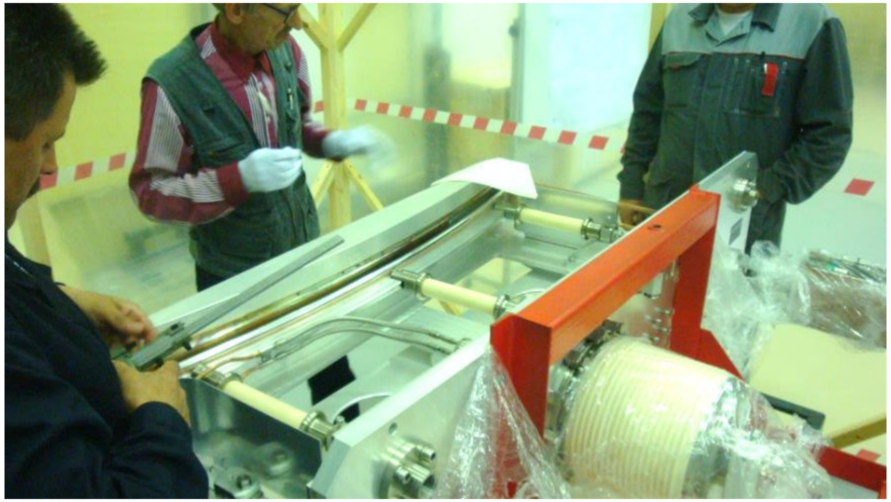
Beam extraction system

Extraction radius of R_{ext}=1.79 m



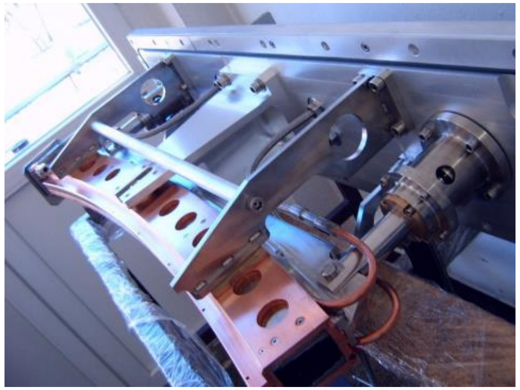
Focusing magnetic channel

Electrostatic deflector



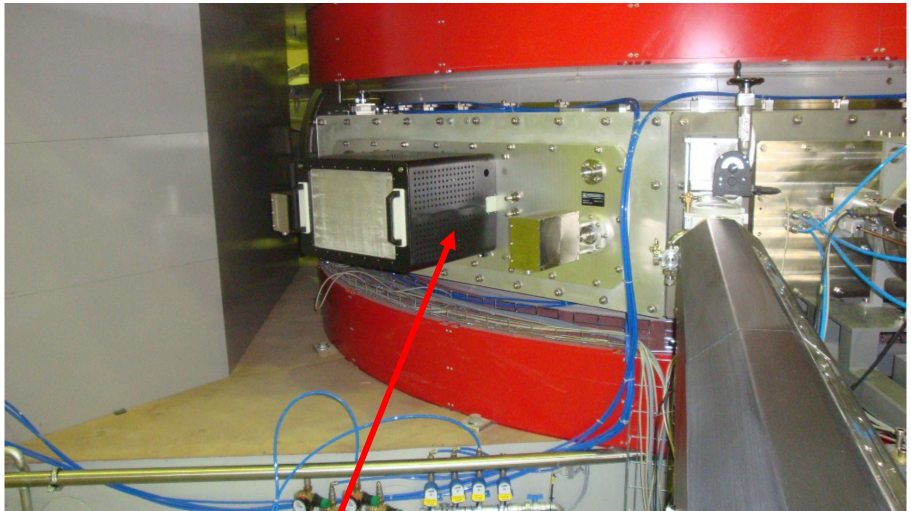
Assembling of the deflector

L=1.8 m, E=90 кВ/cm



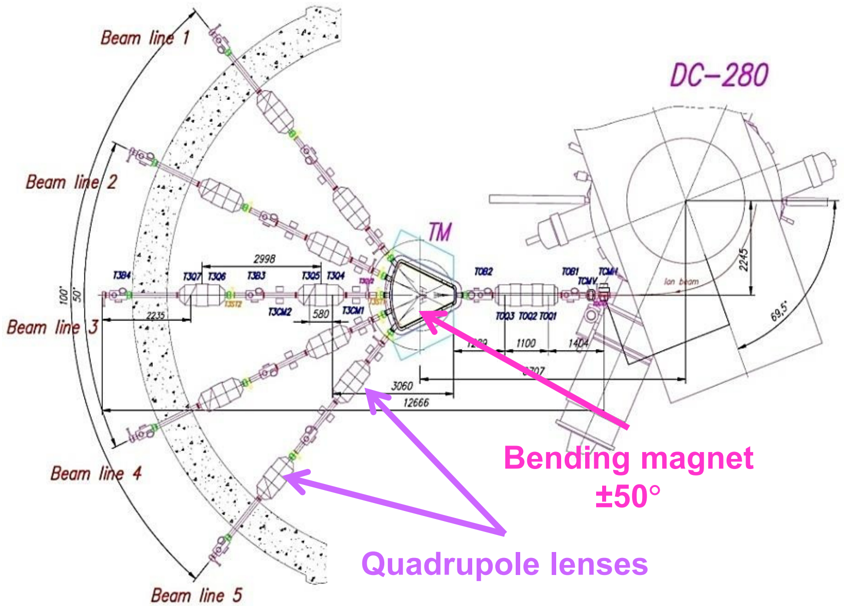
Magnetic channel

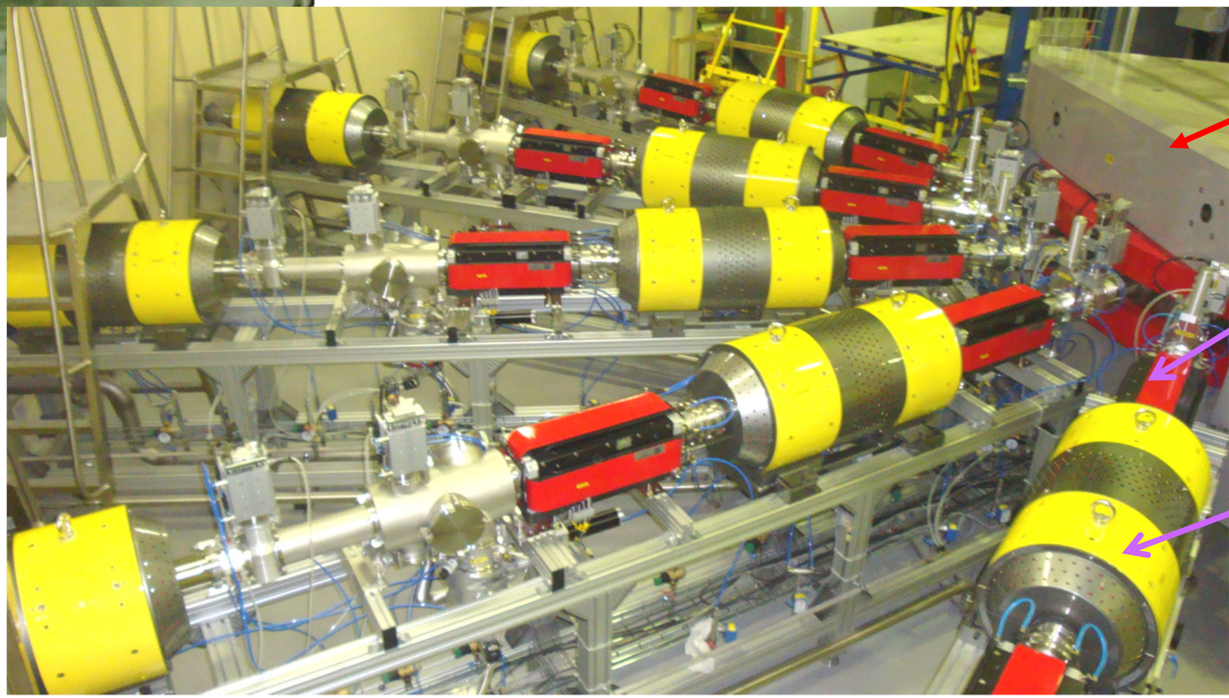
L=0.9 m, G=4.6÷8.4 T/m



Electrostatic deflector in vacuum chamber

Beam transport channels





Bending magnet ±50°

Steering magnet

Quadrupole doublet

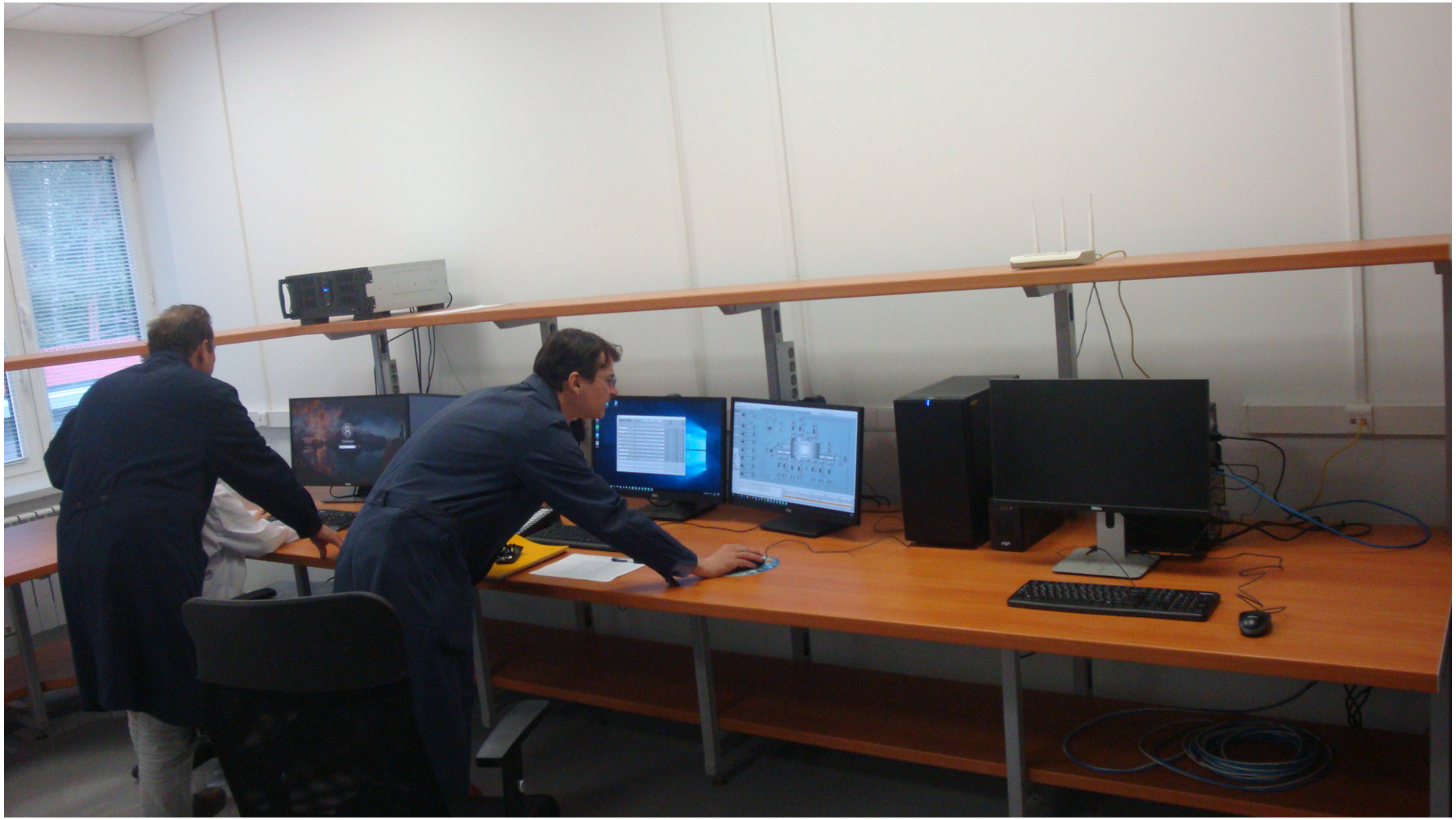
Control and power supply systems

Power supplies of cyclotron

Power supplies of injection

Water cooling system

DC-280 control room

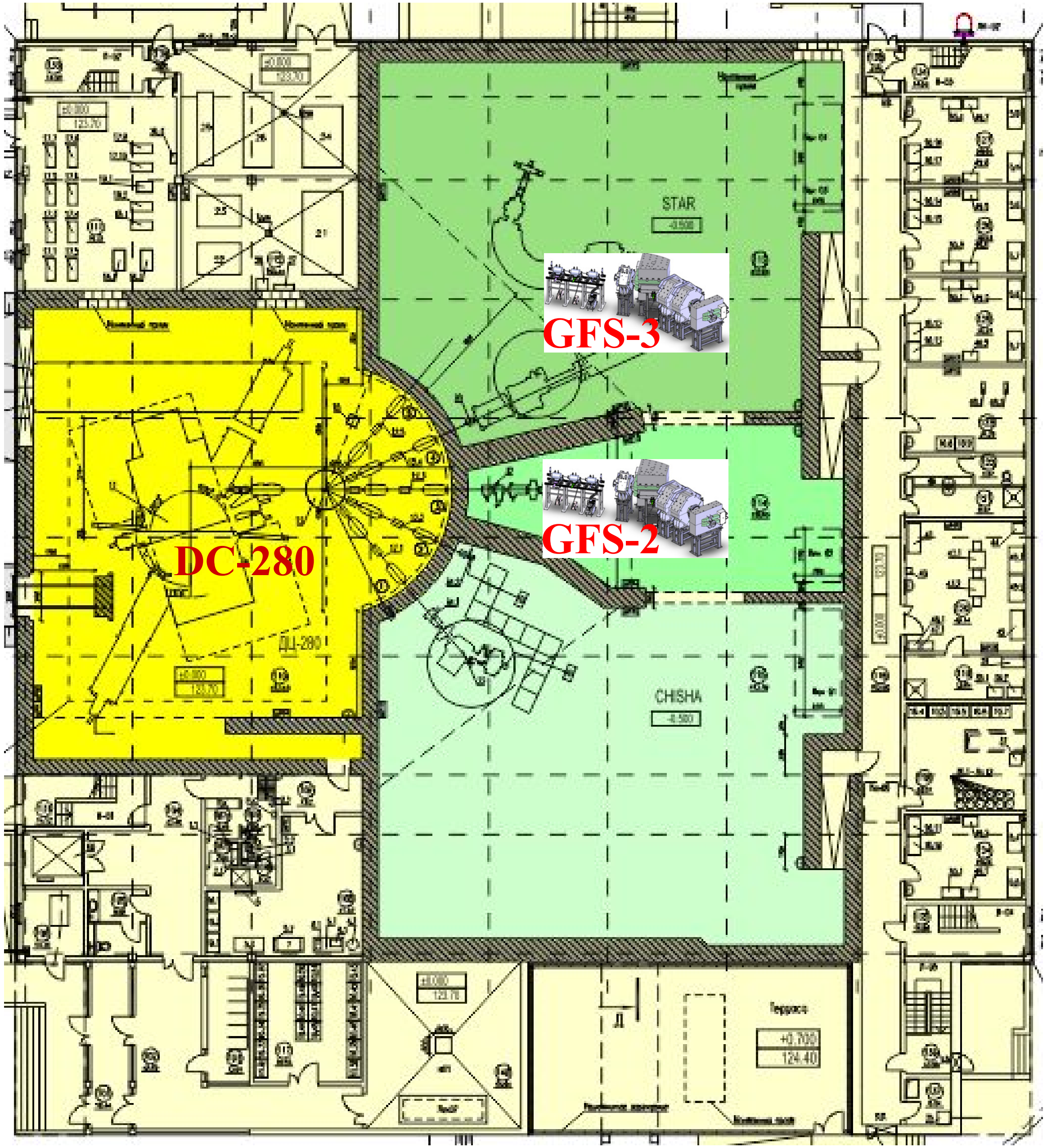


Launching and Tuning Works on the DC-280 systems without beam: June – Oct. 2018

Obtaining licenses and permits : Nov. 2018

Commissioning: Nov. – Dec. 2018

Plan of the 1-st floor of the SHE Factory



Experimental area ~1000 m^2 (3 halls)

First-day experiments at SHE Factory

Aims of the experiments:

1. Test of functionalities of all the systems of new accelerator and new gas-filled recoil separator
2. Accumulate additional statistics for the chosen reactions

Chosen reactions:

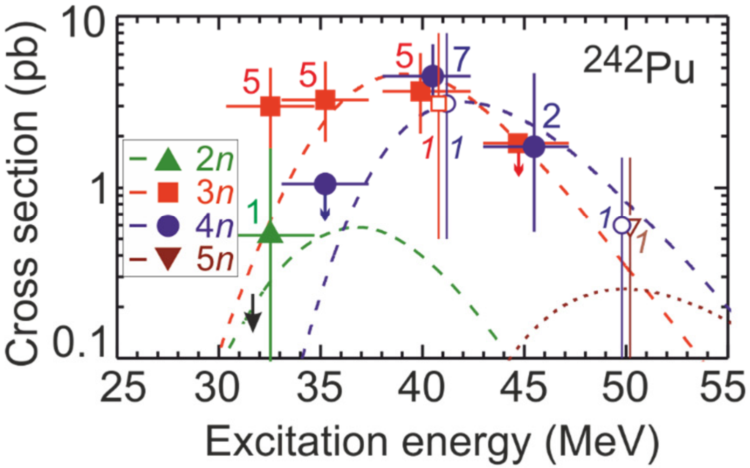
$^{48}Ca+^{243}Am$ (50 days experiment)

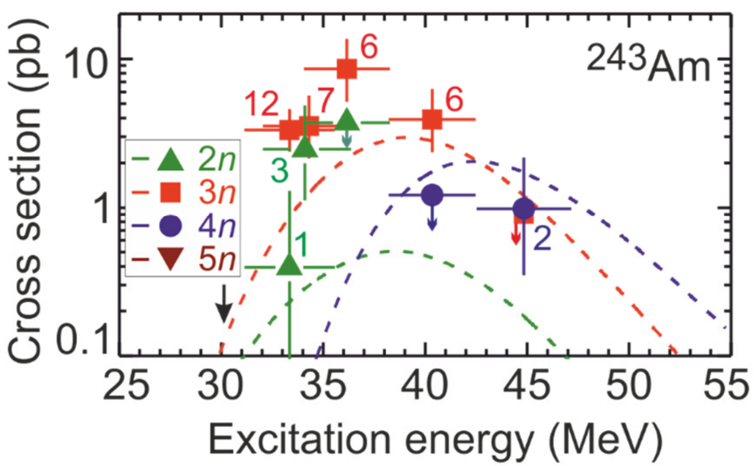
and

$^{48}Ca+^{242}Pu$ (50 days experiment)

1. Enough material to prepare “big” targets (60 mg)
2. Relatively large cross sections (~ 8 pb)
3. Well-studied in previous experiments. Good for testing of the accelerator complex

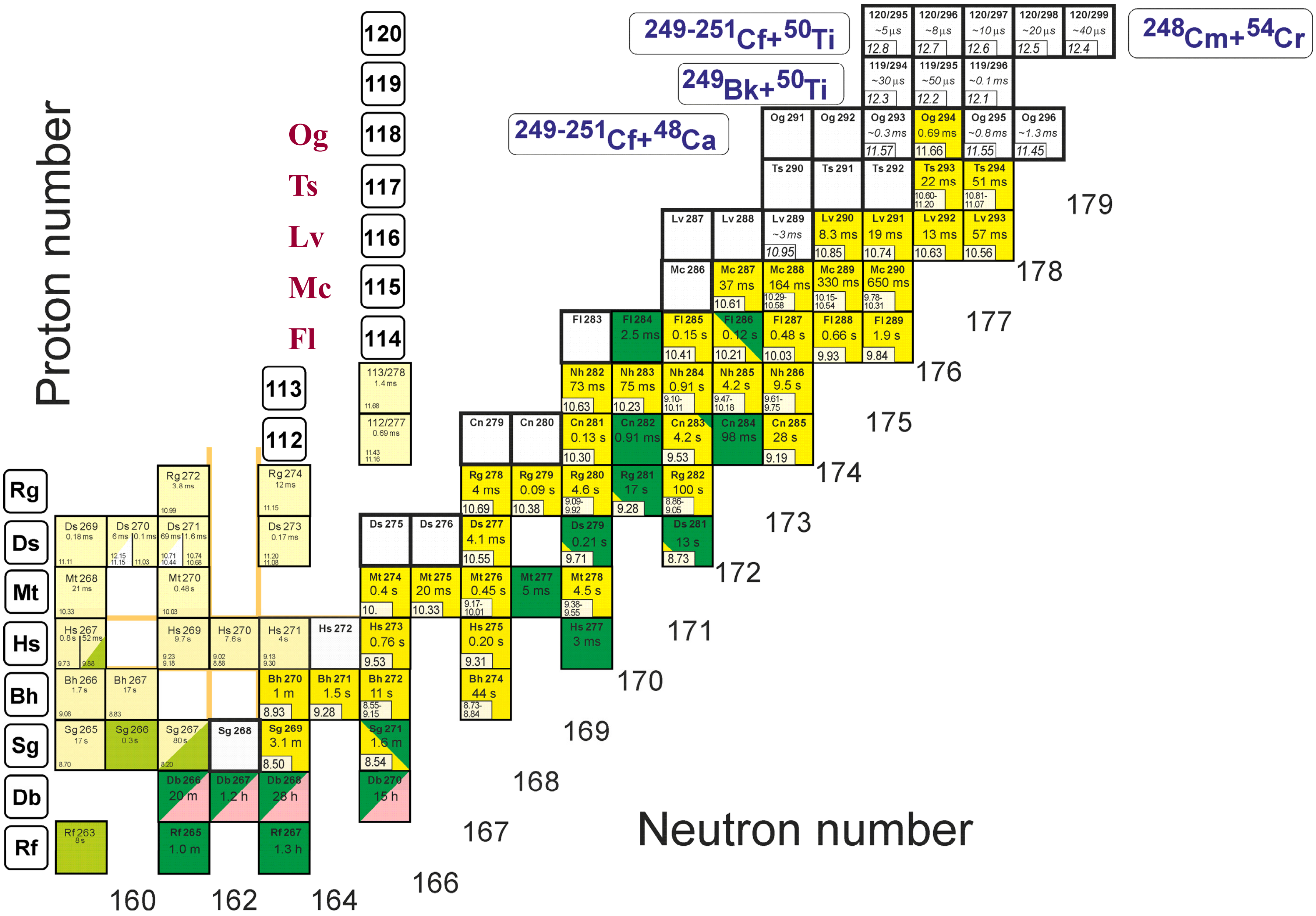
Fl **$^{48}Ca+^{242}Pu$** **Existing experimental data** **$^{48}Ca+^{243}Am$** **Mc**





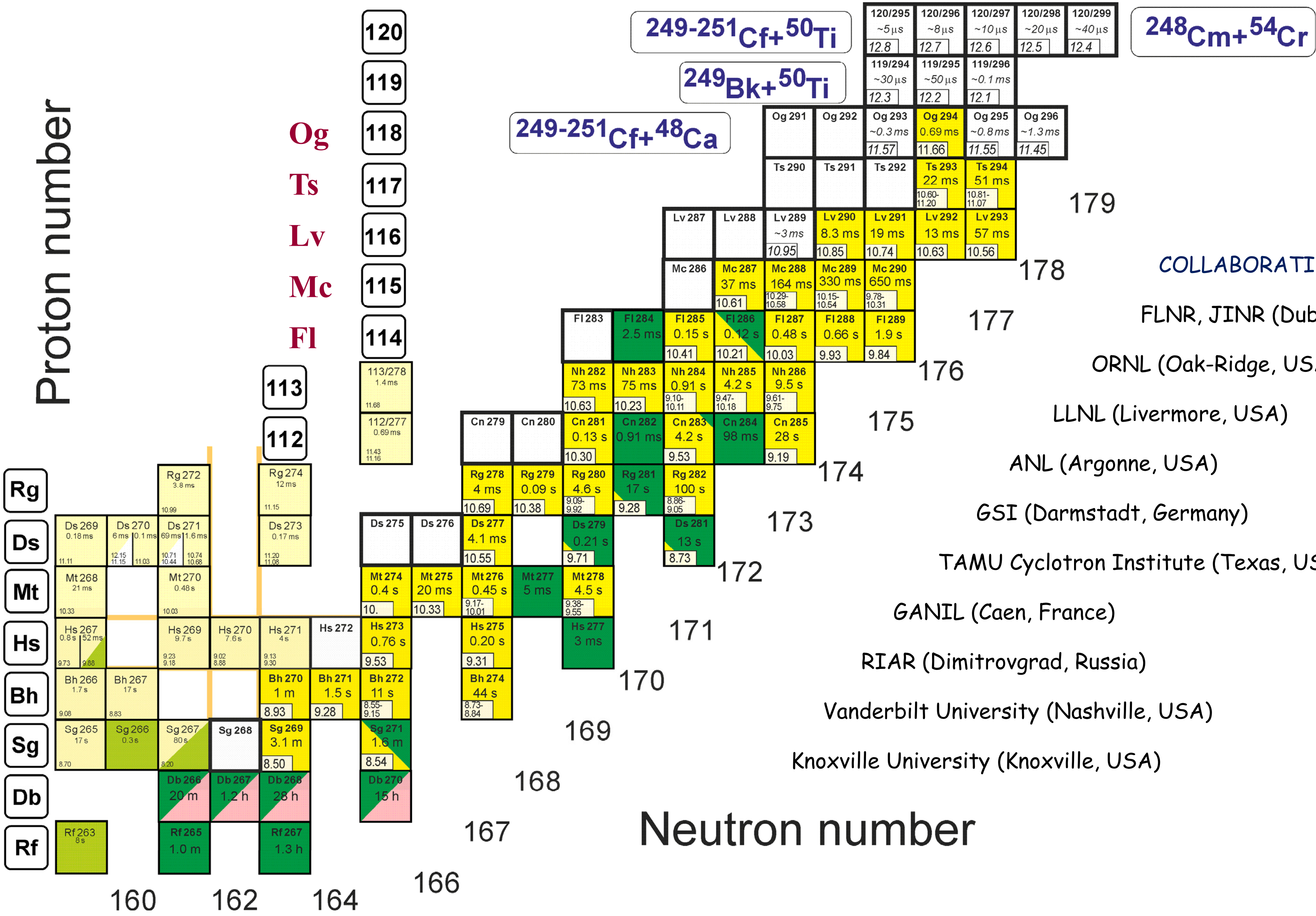
First experiments at SHE Factory

Synthesis of new elements 119 and 120



First experiments at SHE Factory

Synthesis of new elements 119 and 120



COLLABORATION

FLNR, JINR (Dubna)

ORNL (Oak-Ridge, USA)

LLNL (Livermore, USA)

ANL (Argonne, USA)

GSI (Darmstadt, Germany)

TAMU Cyclotron Institute (Texas, USA)

GANIL (Caen, France)

RIAR (Dimitrovgrad, Russia)

Vanderbilt University (Nashville, USA)

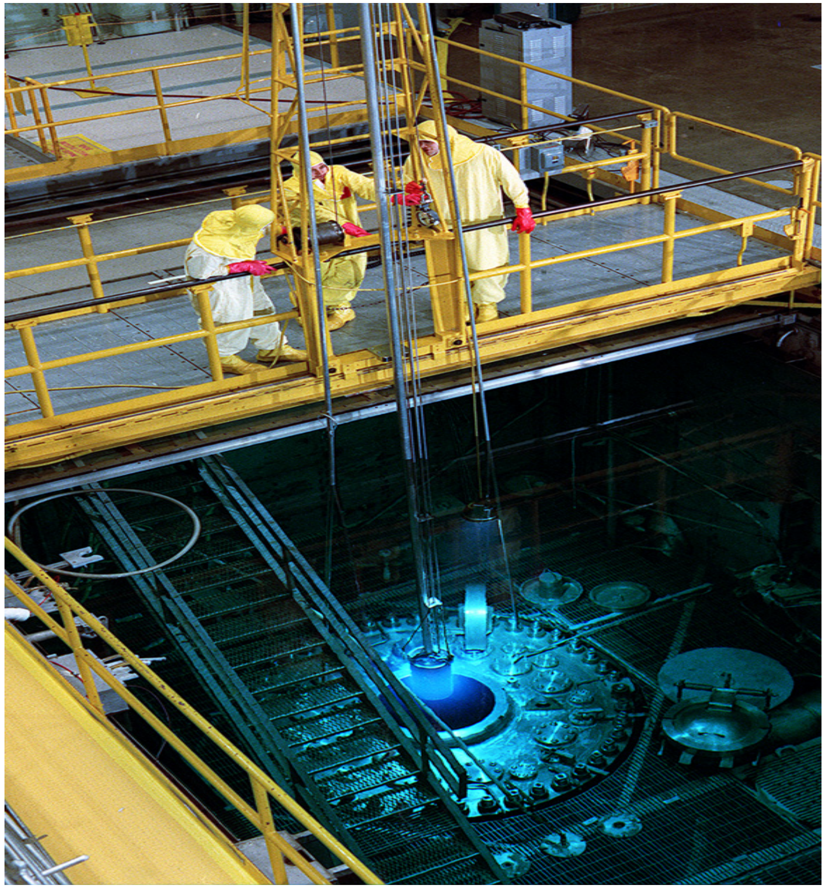
Knoxville University (Knoxville, USA)

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

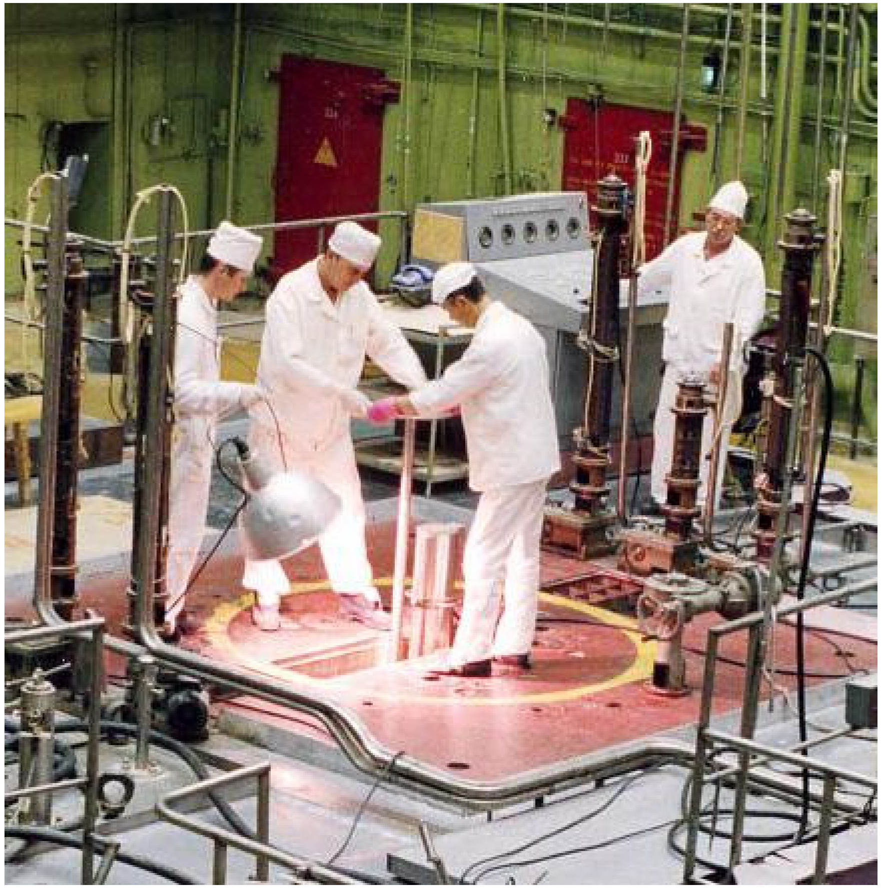
0,35-0,40 mg /cm2 - ≈ 12 mg

Isotope reactors irradiation of targets at HFIR

HFIR, ORNL, Oak Ridge, USA



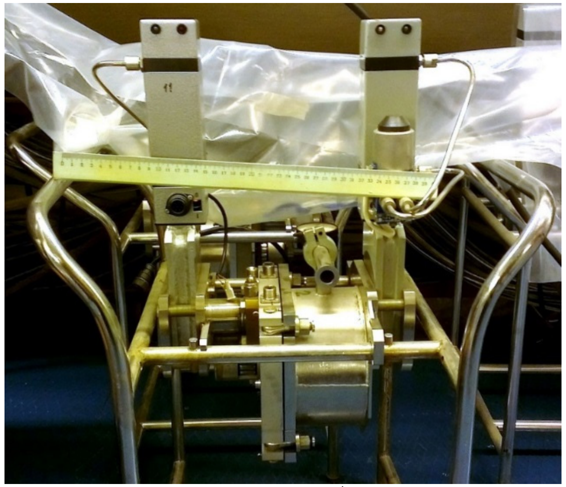
CM-3, IAR, Dimitrovgrad, RF

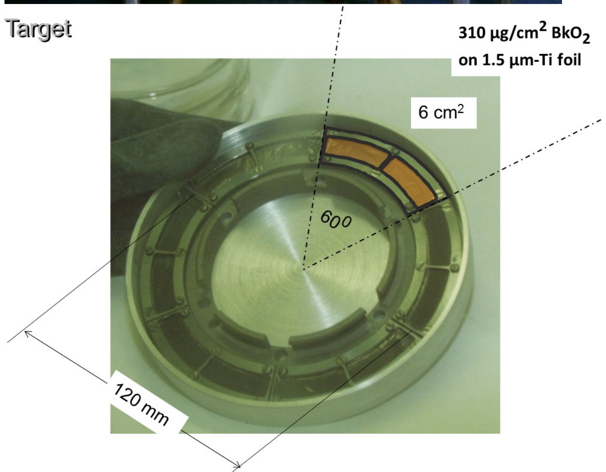


22 mg of ^{249}Bk
have been produced in 250 days
irradiation
at HFIR (ORNL)

Target block design

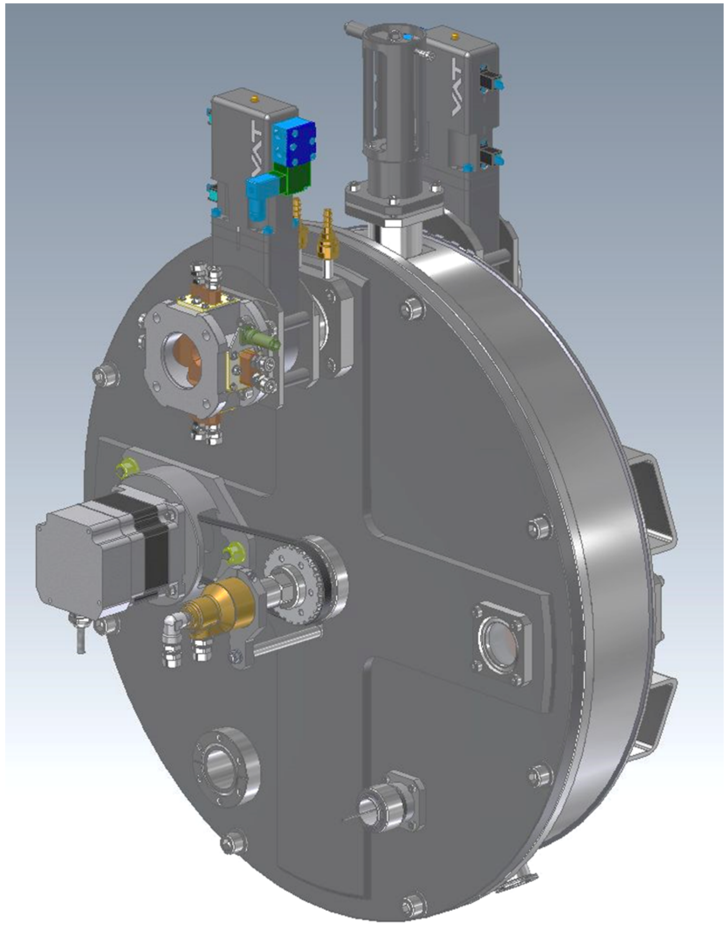
old





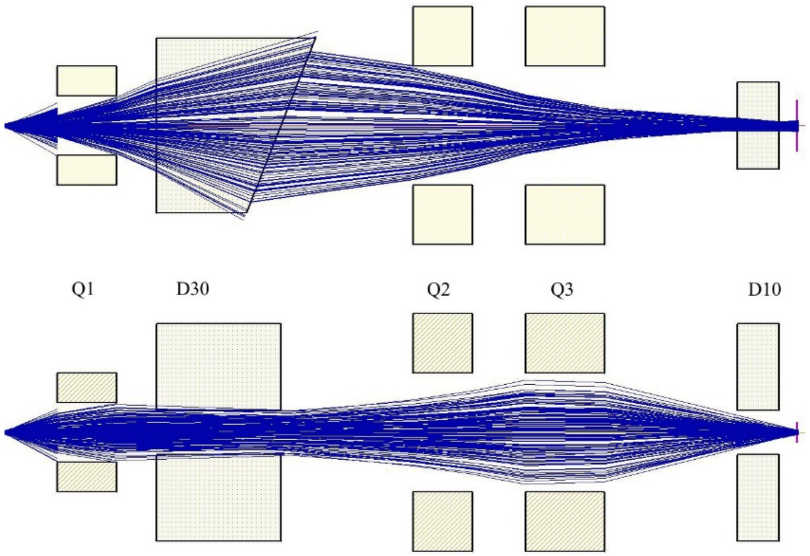
- Ø = 120 mm, 1500 r.p.m. synchronous
- Beam wobbler or scanner,
- Segmented beam diafragm
- Is in use at GFS, SHELS, MASHA

new



- Ø = 240mm, 1500 r.p.m. synchronous,
- e-beam & optical diagnostic,
- water cooling

New FLNR gas-filled separator (contracted)



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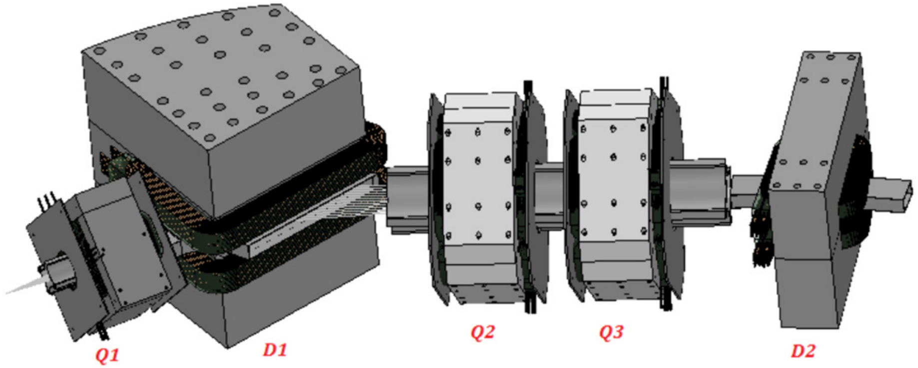
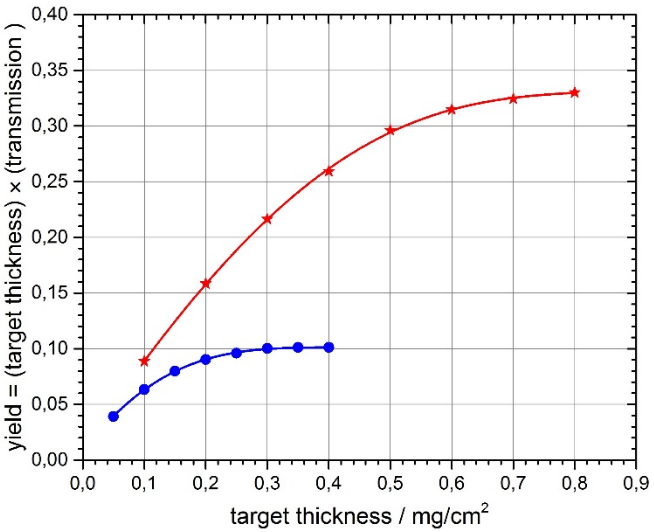
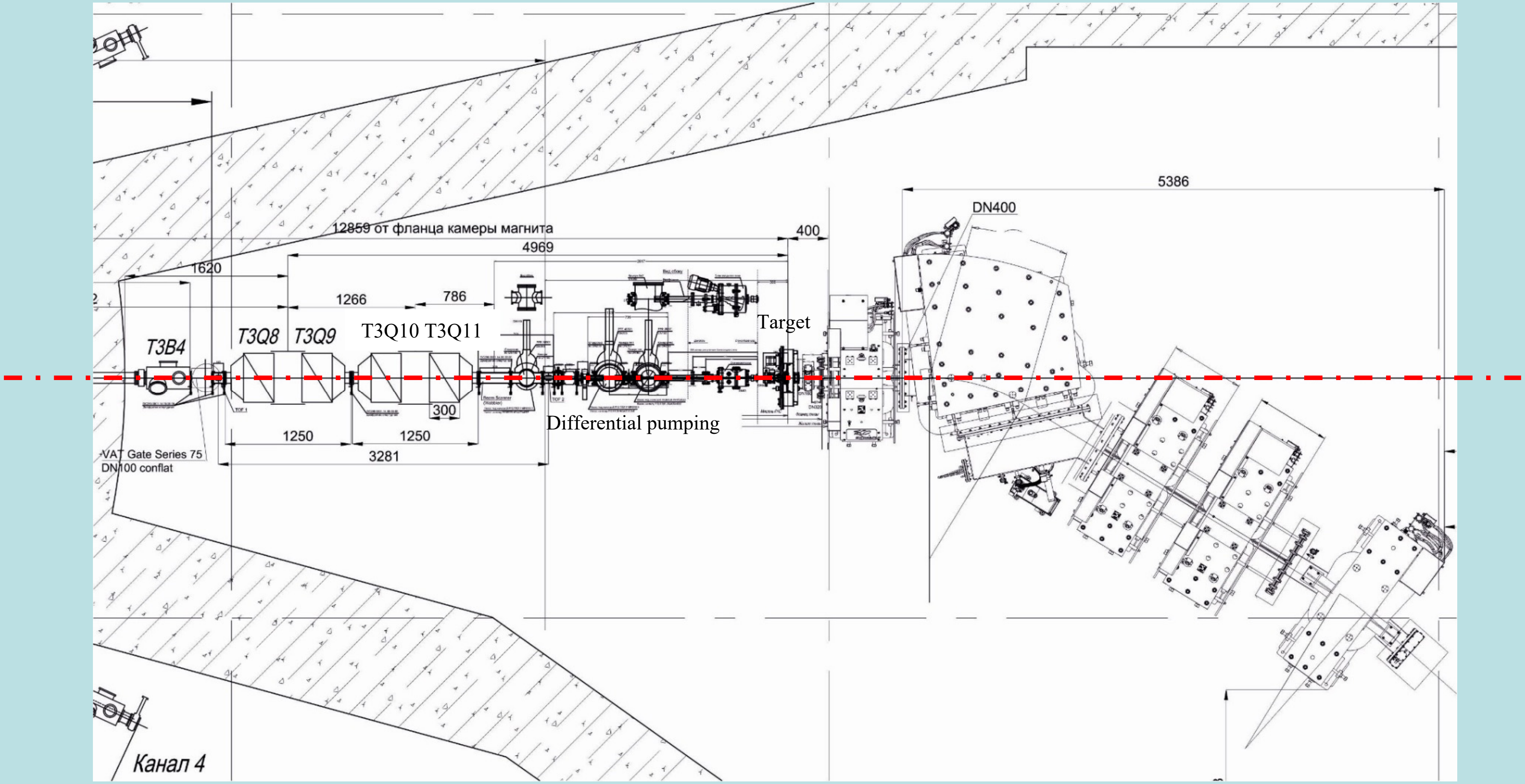


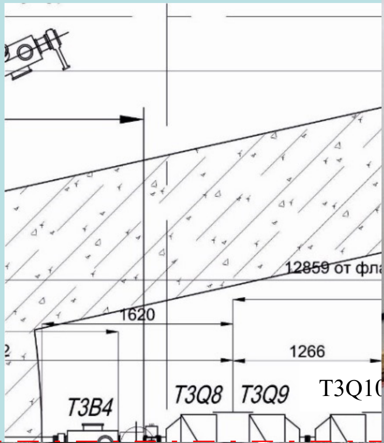


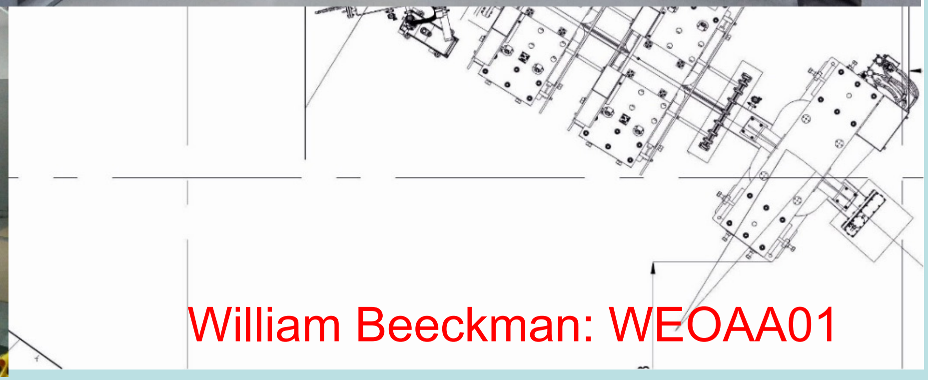
Reaction	Transmission
$^{244}Pu(^{48}Ca,3n)^{289}114$	60 %
$^{244}Pu(^{58}Fe,4n)^{298}120$	75 %

Arrangement of GFS-2 at the beam line No3



Arrangem





William Beeckman: WEOAA01

Installation of magnets: **June 2018**

Expected obtaining licenses and permits : **Nov. 2018**

Planned commissioning: **Dec. 2018**

Conclusion

- Launching and Tuning Works of the DC-280 cyclotron systems are being carried out.
- The GFS-2 separator is being assembled.
- Obtaining licenses and permits: Nov. 2018
- Planned commissioning of the DC-280 and GFS-2 : Nov. – Dec. 2018
- First experiments on SHE Factory: 2019

THANKS FOR YOUR ATTENTION!