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









DUBNA Gas Filled Recoil Separator



 H_2 1.3 mBar

Magnetic

dipole 22.5°

Target

wheel

In operation since 1989

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DUBNA Gas Filled Recoil Separator





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Лантаноиды Lanthanoides

Церий	58 ₄₀₅₀	Празеодим 59	Неодим (50 ₁₁	Прометий 6	1	Самарий	62 ₄₀	Квропий	63 ₁₁	Гадолиний (i4 areat	Тербий	65 _{ar}	Диспрозий 6	6.	Гольмий	67 🦉	Эрбий	68 _{4f}	Тулий	69 42	Иттербий	70	Лютеций	71	
Ce	5.5387 6773	Pr 5.47	Nd	5,525 2009	Pm	1.55 726-	Sm	5,5407 7520	Eu	3.6791 5244	Gd	6.159 [50]	Tb	5,8679 \$230	Dy	3.9389 8551	Но	5.02 S 30-25	Er	6,1035 9066	Tm	6.18/31 9321	Yb	6.254-6 6965	Lu	5,42585 984	
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Гh	6.05 11500	Pa	3.59 15370	U	6.19402 18930	Np	6.2657 20258	Pu	6.05 \$\$10	Am	5,962 13670	Cm	6,82	Bk	6.23 14780	Cf	6.30	Es 5,02	F	n	Md	6.73	No «	Lr		
32,04 borium	1253	231,04 Protactinium	1672	238,03 Uranium	1126	[237] Nentunium	544 2930	[244] Plutonium	140	[243] Americium	1126	[247] Curium	1315	[247] Berkelium	1050	[251] Californium	950	[252] 860 Finsteinium	[251	1	[258] Mendelevium	\$27	[259] sz	[266]	I	162

Н - символ / symbol 1.00794 - атомная масоса / atomic mass 134 - Элистроная конфиграция / electron configuration 135804 - 1-я потенцион наизация, 80 / Lat ionitacion potential, eV 2583.41 - температура палазение, 80 / malting temperature, °C -252.87 - температура клигения, 9C / boiling temperature, °C

Region of superheavy nuclei



Even-Z nuclei





Elements 115 and 117





Production cross-sections of heavy and super-heavy



9

What is beyond 118 element? Heaviest target: ²⁵¹Cf + Z_{max}= 118 ...↓ → Heavier projectiles (⁵⁰Ti, ⁵⁴Cr, ⁵⁸Fe, ⁶⁴Ni)

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 ⁵⁰Ti, ⁵⁴Cr ...;
- 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

A Contraction of the second se	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	6,2×10 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							
238U	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	lon currents, pμA													
	consumption	Q+	5+	7+	8+	9+	10+	11+	12+	15+	17+	19+	20+	23+	26+
14 GHz	5 kW	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)



Area of the accelerating tube



The DECRIS-PM ion source area

Magnetic system of ДЦ-280

Size of magnet yoke LxWxH
Pole diameter
Gap between central plugs
Valley/hill gap
Magnet weight
Magnet power
Maximal current
Magnetic field level

8.76x4.08x4.84 m³ 4 m 400 mm 500/208 mm/mm 1000 t 300 kW 1000 A 0.6÷1.3 T



DC-280- isochronous cyclotron



Magnet assembling: September-November 2016 Magnetic field measurements: June-September 2017



Magnet assembling (November 2016)`



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



RF system



RF resonator with dee



Flat-top resonator

Beam extraction system



Magnetic channel L=0.9 m, G=4.6÷8.4 T/m



Assembling of the deflector L=1.8 m, E=90 κB/cm



Electrostatic deflector in vacuum chamber



Beam transport channels

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



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: ⁴⁸Ca+²⁴³Am (50 days experiment) and ⁴⁸Ca+²⁴²Pu (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



First experiments at SHE Factory

Synthesis of new elements 119 and 120



First experiments at SHE Factory

Synthesis of new elements 119 and 120



Target	Producer	Isotope
materials		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)%

 $0,35-0,40 \text{ mg/cm2} - \approx 12 \text{ mg}$

Isotope reactors irradiation of targets at HFIR

HFIR, ORNL, Oak Ridge, USA



CM-3, IAR, Dimitrovgrad, RF



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

Target block design

old



Target

310 μg/cm² BkO₂



- ➢ 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

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New FLNR gas-filled separator (contracted)







Technical Design Report No 412923



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





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!

