Form No. 21

APPROVED BY
JINR Vice Director

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SCIENTIFIC AND TECHNICAL JUSTIFICATION FOR THE EXTENSION OF THEME
JINR TOPICAL PLAN FOR 2022–2023

Theme code 03-5-1130-2017/2023 **Flerov Laboratory of Nuclear Reactions**

Field of Research: Nuclear Physics
Theme title: Synthesis and properties of superheavy elements, structure of nuclei at the limits of nucleon stability.

Leaders: M.G. Itkis, S.I. Sidorchuk
Scientific Leader: Yu.Ts. Oganessian

Brief description:
The commissioning of the Factory of Superheavy Elements whose key element is the DC-280 cyclotron, upgrade of the U-400M cyclotron, and construction of new-generation experimental set-ups considerably expand possibilities at JINR for top level fundamental nuclear and applied research carried out in broad collaboration with scientific centers of JINR member states and other countries that aim to conduct research in Dubna.

- ***Synthesis of superheavy elements and study of their nuclear properties at the SHE Factory***

In 2022/23 experiments on the synthesis of isotopes of elements 114 (Fl) and 115 (Mc) will continue in the reactions of ^{48}Ca ions with the ^{242}Pu and ^{243}Am targets for thoroughly studying the radioactive properties of isotopes from Lr to Mc.

A series of experiments will be conducted for defining the production cross sections of SHE isotopes in reactions of actinides with ^{50}Ti and ^{54}Cr, which will help outlining prospects of the synthesis of new elements 119 and 120 and launching first experiments.

- ***The investigation of multi-nucleon transfer processes in collisions of massive nuclei; synthesis of new neutron-rich heavy nuclei***

The next step in studying the heaviest nuclei will be the investigation of deep inelastic transfer reactions

and quasi-fission as an instrument for the synthesis of heavy and superheavy nuclei with a large neutron excess, study of the influence of the shape of nuclei and shell effects on the yields of synthesized nuclides.

Special attention will be drawn to both the production of neutron-rich nuclei in the vicinity of the neutron closed shell N=126 and new isotopes of transuranium elements.

- ***Nuclear structure of elements of the "second hundred"***

Experiments on α-, β-, and γ-spectroscopy of the isotopes of transfermium elements will continue at the SHELS and GFS-III separators using the GABRIELA and SFiNX detecting systems, which will allow us to obtain data on the structure of nuclear levels and clarify the parameters of models describing SHE.

- ***Development of research on the chemical properties of SHE***

Using the new GFS-3 set-up (SHE Factory) as a pre-separator for transporting nuclear reaction products to radiochemical set-ups, experiments on studying the properties of SHE in the elementary state will be conducted.

The construction of a separate set-up optimized for radiochemical studies is planned for further development of research on the chemical properties of superheavy elements. Beams extracted from the DC-280 cyclotron will be used.

- ***Study of the mechanisms of reactions with stable and radioactive nuclei; search for new types of decay***

The ACCULINNA-2 separator is the basic facility in investigations of the properties of light exotic nuclei, medium-mass nuclei with $Z \leq 36$, and reaction mechanisms leading to their production. The analysis of the experimental data obtained at the separator in the period 2018–2020 will continue. Following the commissioning of the U-400M cyclotron in 2022, the study of the ^{7}H structure will continue (measuring the width of the ground state with a good energy resolution of ~ 150 keV). We also plan on obtaining data and identifying ^{7}H resonance levels in the energy range E_T<12 MeV. Moreover, precision measurements of angular and energy correlations of ^{7}H decay products will be studied. In addition, we will prepare and begin the implementation of the programme on the experimental study of the structure of other neutron-rich nuclei: ^{10}He, ^{11,13}Li, ^{16}Be, ^{18,19}C, and ^{26}O. Particular attention will be given to modeling of future experiments with a tritium target employing the ACCULINNA-2 fragment separator.

We will analyze the possibility of conducting experiments at ACCULINNA-2 aimed at measuring the fission barriers of the ^{244,246}Pu nuclei produced in transfer reactions involving the ^{6}He and ^{8}He beams and the ^{238}U target at E ~ 6 MeV/A.

The high-resolution magnetic analyzer MAVR will be used for studying the characteristics of reactions with weakly bound stable and radioactive nuclei in the vicinity of the Coulomb barrier and the mechanism of nuclear reactions with cluster nuclei. These studies will in particular allow the assessment of the role of exotic nuclei in astrophysical nucleosynthesis.

- ***Update of the network knowledge base on low-energy nuclear physics***

Work on updating the network knowledge base on low-energy nuclear physics NRV will primarily focus on maintaining the currently operating system at http://nrv.jinr.ru and on developing the upgraded one at http://nrv2.jinr.ru using cutting-edge Web technologies.

Work stages (year of completion specified):

1. Studies of superheavy elements and synthesis of new elements using the GFS-2 separator (2023)
2. α-, β-, and γ-spectroscopy of heavy and superheavy nuclei at the SHELS set-up (2023);
3. Chemical properties of heavy nuclides at the GFS-3 separator (2023).
4. Study of fusion–fission, quasi-fission, fast fission, and multi-nucleon transfer reactions (2023);
5. Investigation of the structure of exotic nuclei close and beyond the limits of nuclear stability using the ACCULINNA-1, ACCULINNA-2 and COMBAS set-ups (2023);
6. Study of reactions induced by beams of stable and radioactive nuclides leading to the formation of exotic nuclei (2023);
7. Theoretical studies of the nuclear structure and nuclear reactions (2023);
8. Development and update of the network knowledge base on nuclear physics NRV (2023).

Expected results upon completion of the theme

Synthesis of superheavy elements with Z=114–120 and study of their properties at the Factory of Superheavy Elements. Investigation of their α-decay products. The acquisition of data on the chemical properties of superheavy elements. Synthesis of new heavy and superheavy nuclei in multi-nucleon transfer binary processes and quasi-fission and study of their properties. α-, β-, and γ-spectroscopy of the isotopes of heavy and superheavy elements. Investigation of nuclear reactions involving light stable and radioactive nuclei.

Production of nuclei close the limits of nuclear stability and study of their properties. Theoretical studies of nuclear structure and reactions involving light stable and radioactive nuclei. Development and update of the network knowledge base on low-energy nuclear physics. Development of physics set-ups and construction of new separators for studying nuclei at stability limits.

List of participants and organizations

Activity or Experiment Laboratory or other Division of JINR Responsible person	**Leaders** Main researchers	**Status**
1. Synthesis of new isotopes of superheavy elements at DGFRS	**V.K. Utyonkov**	Data taking
FLNR	F.Sh. Abdullin, D. A. Ibadullayev, N.D. Kovrijnykh, D.A. Kuznetsov, A.N. Polyakov, O.V. Petrushkin, R.N. Sagaidak, V.D. Shubin, V.G. Subbotin,M.V. Shumeiko, D.I. Solov'ev, Yu.S. Tsyganov, A.A. Voinov, A.M.Zubareva	

2.	**α-, β- and γ-spectroscopyof heavy nuclei at the SHELS and DGFRS-3 separator**	**A.V. Yeremin**	Data taking
	FLNR	V.I. Chepigin, M.L. Chelnokov, A.V. Isaev, I.N.Izosimov, D.E. Katrasev, A.A. Kuznetsova, O.N. Malyshev, R.S. Mukhin, Yu.A. Popov, V.M. Popov, A.G. Popeko, E.A. Sokol, A.I. Svirikhin, V.A. Sbitnev, M.S. Tezekbaeva	
3.	**Chemical properties of superheavy elements**	**S.N. Dmitriev**	Data taking
	FLNR	N.V. Aksenov, Yu.V. Albin, A.A. Astakhov, A.Yu. Bodrov, G.A. Bozhikov, I. Chuprakov, N.S. Gustova, K.V. Lebedev, A.Sh. Madumarov, E.V. Melnik, A.V. Sabelnikov, G.Ya. Starodub, G.K. Vostokin, M.G. Voronyuk	
4.	**Experiments at the magnetic analyzer of superheavy atoms MASHA**	**A.M. Rodin**	Data analysis
	FLNR	E.V. Chernysheva, A.V. Guljaev, A.V. Guljaeva, A.B. Komarov, L. Krupa, A.S. Novoselov, A.Opihal, A.V. Podshibyakin, V.S. Salamatin, S.V. Stepantsov, V.Yu. Vedeneev, S.A. Yukhimchuk, A. Kohoutova, P. Kohout	
5.	**Study of the processes of fusion-fission, quasi-fission and multi-nucleon transfer reactions. CORSET-DEMON, CORSAR, and MiniFOBOS set-ups**	**M.G. Itkis** **E.M. Kozulin**	Data taking
	FLNR	A.A. Alexandrov, I.A. Alexandrova, T. Banerjee, I.N. Dyatlov, O.V. Falomkina, E. I. Galkina, Z.I. Gorya'nova, Yu.M. Itkis, D.V. Kamanin, V.V. Kirokasian, N.I. Kozulina, G.N. Knyazheva, E.A. Kuznetsova, D. Kumar, C.H. Meghashree, E. Mukhamedzhanov, K.V. Novikov, A.A. Ostrouchov, A. Pan, I,V, Pchelintsev, Yu.V. Pyatkov, E.O. Savelieva, Yu.B. Semenov, A.N. Solodov, A.O. Strekalovsky, O.V. Strekalovskiy, R. S. Tikhomirov, I.V. Vorob'ev, A.O. Zhukova, V.E. Zhuchko	
	LIT	P.V. Goncharov, G.A. Ososkov, A.V. Uzhinsky, V.B. Zlokazov	
6.	**Study of the structure of exotic nuclei near and beyond the drip-lines at the ACCULINNA-2 and COMBAS fragment separators**	**A.S. Fomichev**	Data analysis
	FLNR	A.G. Artukh, E. Batchuluun, S.G. Belogurov, A.A. Bezbakh, V. Chudoba, M.S. Golovkov, L.V. Grigorenko, A.V. Gorshkov, V. A. Gorshkov, E.M. Gazeeva, A. Ismailova, G. Kaminski, S.A. Krupko, S.A. Klygin, G.A. Kononenko, K.A. May, B. Mauyey, I.A. Muzalevskiy, E.Yu. Nikolskii, Yu.L.	

		Parfenova, W. Piatek, S.A. Rimzhanova, Yu.M. Sereda, S.I. Sidorchuk, R.S. Slepnev, P.G. Sharov, S.V. Stepantsov, A. Swiercz, P. Szymkiewicz, G.M. Ter-Akopian, M. N. Tran, R. Wolski, A.N. Vorontsov, B. Zalewski	
	BLTP	S.N. Ershov, N.B. Shulgina	
7.	**Investigation of reactions induced by stable and radioactive ion beams leading to the formation of exotic nuclei. Development of MAVR and MULTI set-ups**	**Yu.E. Penionzhkevich**	Data taking Manufacture
	FLNR	D.T. Aznabaev, A. Azhibekov, I. V. Butusov, T. Isataev, S.M. Lukyanov, V.A. Maslov, K.O. Mendibaev, R.V. Revenko, A. V. Shakhov, I. Sivacek, N.K. Skobelev, Yu.G. Sobolev, V.I. Smirnov, S.S. Stukalov, D.A. Testov	
8.	**Theoretical studies of nuclear reaction mechanisms**	**A.V. Karpov**	Data taking Data analysis
	FLNR	E.A. Cherepanov, A.S. Denikin, I. A. Egorova, M.A. Naumenko, V.A. Rachkov, V.V. Samarin, V.V. Saiko	
9.	**Development and update of the network knowledge base on nuclear physics**	**A.V. Karpov** **A.S. Denikin**	Data taking
	FLNR	M.A. Naumenko, V.A. Rachkov, V.V. Samarin, V.V. Saiko	
10.	**Laser spectroscopy of isotopes**	**S.G. Zemlyanoy**	Data taking
	FLNR	K.A. Avvakumov, G.N. Myshinskiy, T. Tserensambuu, V.I. Zhemenik, B. Zuzaan	

Collaboration:

Country or International Organization	City	Institute or laboratory
Belgium	Brussels	ULB
	Leuven	KU Leuven
Bulgaria	Sofia	INRNE BAS
CERN	Geneva	CERN
China	Beijing	PKU
	Lanzhou	IMP CAS
Czech Republic	Olomouc	UP
	Prague	CTU
	Prague	VP
	Rez	NPI CAS
Egypt	Giza	CU
	Shibin El Kom	MU
Finland	Jyvaskyla	UJ
France	Caen	GANIL

	Orsay	CSNSM
	Orsay	IPN Orsay
	Saclay	SPhN CEA DAPNIA
	Strasbourg	CRN
	Strasbourg	IPHC
Germany	Darmstadt	GSI
	Mainz	JGU
	Tubingen	Univ.
India	Kolkata	VECC
	New Delhi	IUAC
	Roorkee	IIT Roorkee
	Rupnagar	IIT Ropar
Italy	Catania	INFN LNS
	Legnaro	INFN LNL
	Messina	UniMe
	Naples	Unina
Japan	Tokai	JAEA
Kazakhstan	Almaty	IETP KazNU
	Almaty	INP
	Nur-Sultan	ENU
Mongolia	Ulaanbaatar	NRC NUM
Poland	Krakow	INP PAS
	Poznan	AMU
	Warsaw	HIL UW
	Warsaw	UW
Republic of Korea	Daejeon	IBS
Romania	Bucharest	IFIN-HH
Russia	Dimitrovgrad	SSC RIAR
	Gatchina	NRC KI PNPI
	Moscow	MSU
	Moscow	NNRU "MEPhI"
	Moscow	NRC KI
	Moscow	SINP MSU
	Moscow, Troitsk	INR RAS
	Sarov	VNIIEF
	St. Petersburg	Ioffe Institute
	St. Petersburg	KRI
	St. Petersburg	SPbSU
	Voronezh	VSU
Slovakia	Bratislava	CU
	Bratislava	IP SAS
South Africa	Somerset West	iThemba LABS
	Stellenbosch	SU
Spain	Huelva	UHU
Sweden	Goteborg	Chalmers
	Lund	LU
Switzerland	Villigen	PSI
Ukraine	Kiev	KINR NASU
United Kingdom	Manchester	UoM

USA	College Station, TX	Texas A&M
	East Lansing, MI	MSU
	Livermore, CA	LLNL
	Nashville, TN	VU
	Oak Ridge, TN	ORNL
Vietnam	Hanoi	IOP VAST
	HoChiMinh City	VNUHCM

Implementation time frame: 2022–2023.

Total estimated cost of theme: USD 18032.3k

(USD, in thousands)

NN	**Budget item**	**2022*****	**2023*****
1	Wages (items 1– 3)	2 933.3	2 933.3
2	International cooperation on research and development (item 4)	400.0	400.0
3	Materials, equipment (items 5+6+9+10+18+19)	2 600.0	2 200.0
4	Electricity, water (items 7+8)		
5	Operating costs (items 11–17)	47.4	52.2
6	Basic facility	2 197.9	2 254.5
7	Administrative and economic expenses	966.6	1 047.2
	SUBTOTAL:	**9 145.2**	**8 887.1**

Other financing sources

- Joint projects Germany–JINR, South Africa–JINR;
- Grants from the Plenipotentiaries of the JINR member states (Bulgaria, Kazakhstan, Poland, Romania, Czech Republic, Slovakia);
- Grants from RSF.
- Grants from the Ministry of Science and Higher Education of the Russian Federation.

APPROVED BY:

JINR Chief Scientific Secretary

_____/S.N. Nedelko/

“_____“_____2021

FLNR Director

_____/S.I. Sidorchuk/

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Head of Planning and Finance Department

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FLNR Scientific Secretary

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Head of Science Organization Department

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FLNR Economist

_____/T.V. Mamonova/
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Senior Researcher of the Science Organization Department

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Theme leaders

_____/ M.G. Itkis/
_____/ S.I. Sidorchuk/
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