Form 21

APPROVED
JINR Vice-Director

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SCIENTIFIC AND TECHNICAL VALIDATION OF THEME PROLONGATION IN THE 2022—2023 JINR TOPICAL PLAN

Theme code 04-5-1131-2017/2021

Laboratory of Nuclear Reactions
Departments: Centre of Applied Physics, sector No 8, Scientific and Technical accelerator department

Research area: Condensed Matter Physics

Theme title Radiation physics, radiochemistry, and nanotechnology investigations using beams of accelerated heavy ions

Theme leader: S.N. Dmitriev, P.Y. Apel

Scientific programme
Short summary

The results obtained in the framework of theme 04-5-1131-2017/2021 during the past 5 years have demonstrated the necessity and relevance of research aimed at changing the properties of materials by bombardment with accelerated multiply charged ions and on the creation of new functional structures using techniques that combine exposure to ion beams and other physico-chemical interactions. At the same time basic research retains its primary role, since in its absence the generation and development of new practical applications is not possible. The next level of research in the field of radiation solid state physics, characterized by combining the experiment and theory and modeling of the track formation process in inorganic matrices using molecular dynamic simulation methods. Fundamentally new results were obtained in the field of modification of polymeric materials by heavy ion beams. In particular, it was found that the ion track technology allows to produce not only micro- and ultrafiltration membranes but it also can be employed for the fabrication of membranes for finer separation process, for example, for ion separation. Ion track technology approaches were be used in combination with new thin film, multilayer technologies and new promising materials (graphene, plasmonic materials). Based on the obtained results, it seems reasonable to continue the research activity in the framework of the present theme for the period which is synchronized with the 7-year plan for the development of JINR, i.e. till 2023 inclusive.

The main emphasis on the modification of the materials at the nanometer scale and on the study of the effects produced by heavy ions in matter with the aim of revealing the fundamental mechanisms and of the development of nanotechnology applications for ion beams will be kept. They will include also the development of new types of track membranes and functional materials, based on polymers treated with ion beams, to be used in various fields of technology and medicine; the development of nuclear physics

methods both for the investigation of new synthesized materials and for environmental monitoring; the modernization of the FLNR accelerator complex for applied research.

In the field of radioanalytical studies, the methods of X-ray fluorescence, Gamma-activation, neutron activation, gamma- and alpha-spectrometry will be applied to the determination of elemental composition of both the environmental samples and the artificially synthesized samples of nanostructured materials. This will include the development of nondestructive methods for the examination of cyclotron targets and tests of promising target materials for thermal and radiation stability in harsh environment of nuclear physics experiments at FLNR.

The broad instrumentation base of the FLNR laboratory complex, which was substantially supplemented in 2017-2021 with high quality equipment (in particular, with a transmission electron microscope Talos F200i) and serves to gain versatile scientific information, first of all in research works on the nanometer scale, will be employed. Further progress of applied research requires new approaches to the strategy of development of accelerator instrumentation. For technical, organizational and economic reasons, an optimal solution will be the creation of a new dedicated accelerator but not the exploitation of separate channels on the DC280, U400 and U400M accelerators. The new accelerator, the DC140 cyclotron, will be significantly more powerful than IC100, which is under operation at present, and will provide beam parameters necessary for radiation materials science, production of track membranes, testing of microelectronics, and other potential applications. The plan for the next two years implies the construction of three specialized beam lines at the DC140 cyclotron that meet the requirements of all main directions of applied research at FLNR.

The expansion and development of the instrumentation park will be continued in 2022-2023, which will make it possible to perform investigation of materials structure on a higher level. The possibility of the creation of new devices and materials, the functioning of which is based on specific properties of nanostructured bodies, will be explored. These are SERS-sensors made of a track membrane covered with nanoparticles of noble metals; composite track membranes with nanofibers fabricated from polymers with selective adsorption properties; membranes for blotting; membranes with superhydrophobic surface for membrane distillation. To meet these challenges, the ion-track technology methods will be coupled with the thin film coating technology, nanofiber electrospinning technology, synthesis of metal nanoparticles, and other modern approaches. Studies of unique properties of symmetric and asymmetric track-etched nanopores, including electrokinetic phenomena, osmotic phenomena and ionic selectivity in electrolyte solutions. The process of vacation formation in 2D-materials under heavy ion bombardment will be studied aiming at clarification of the possibility to fabricate membranes for desalination and molecule separation possessing unprecedented permeability. The fields of applications will be focused on the strategic areas such as energetics, safety, ecology and health.

Expected main results in 2022:

1. Determination of threshold values of specific ionization energy losses of heavy ions for the formation of latent tracks in $Y_4Al_2O_9$, Al_2O_3, TiO_2, Si_3N_4 nanoparticles.
2. Creation of experimental set-up for homogeneous doping of materials with helium and hydrogen ions with energies of 1-4 MeV.
3. Determination of the conditions for the formation of nanoholes and nanochannels in graphene oxide under high-energy heavy ion impact.
4. Experimentsl study and theoretical description of electrokinetic and osmotic properties of track-etched membranes with pore radii of 10-20 nm.
5. Determination of ion-selective properties of membranes obtained from ion-irradiated polymer foils using soft photolysis and liquid extraction of photolysis and radiolysis products from tracks.

6. Development of hybrid membranes composed of a Ti-coated track etched membrane and a layer of nanofibers produced by electrospinning from chitosan, collagen and hyaluronic acid.
7. Development of the fabrication method for track-etched membranes on the basis of the biodegradable polymer polylactide.
8. Study of the membrane distillation process for the desalination of seawater using composite track-etched membranes with a thin hydrophobic layer.
9. Study of elemental composition of modified track-etched membranes and their Cs cation sorption ability using nondestructive XRFA method.

Expected results on completing theme:

1. Complete comparative analysis of the parameters of latent tracks caused by fast heavy ions in nanoparticles and bulk poly- and single-crystal oxides and nitrides using high-resolution transmission electron microscopy and molecular dynamic simulation.
2. Collecting data on the processes of formation and evolution of gas porosity in ferritic and austenitic steels implanted with ions of MeV energies and irradiated with heavy ions of fission fragments energy.
3. Collecting data on the processes of nanostructuring of graphene oxide (the formation of nanoholes and nanochannels) and changes in its electrophysical properties by irradiation with swift heavy ions.
4. Development of new generations of functional track membranes and track-membrane-based advanced materials for optical, medical, biochemical and sensor application.
5. Development of methods for the formation of hydrophobic and superhydrophobic polymeric layers, from active gas phase, on the surface of track-etched membranes. Detailed study of their morphology and assessment of their applicability to membrane distillation.
6. Development of new nondestructive methods for the determination of qualitative and quantitative analysis of composition of cyclotron targets and tests of promising target materials for thermal and radiation stability in harsh environment of nuclear physics experiments at FLNR.
7. Creation of three specialized beam lines at the DC140 dedicated cyclotron for applied research.

Participating countries:

Belarus, Bulgaria, China, Czech Republic, Germany, Hungary, Kazakhstan, Moldova, Mongolia, Poland, Romania, Russia, Serbia, Slovak Republic, South Africa, Spain, USA, Vietnam.

List of participants and organizations

List of Activities

	Activity or Experiment Laboratory or other Division of JINR	Leaders Main researchers	Status
1.	**Investigations of radiation damages in solids and formation of nanostructures** FLNR	**V.A. Skuratov** **P.Y. Apel** V.A. Altynov, I.V. Blonskaja, O.M. Ivanov, L.I. Kravets, O.V. Kristavchuk, N.S. Kirilkin, E.A. Korneeva, N.E. Lizunov, A.N. Nechaev, A. Olejniczak, K. Olejniczak, O.L. Orelovich, D.V. Shchegolev, V.K. Semina, V.V. Shirkova, A.S. Sohatsky, R. Rymchanov, A. Rossouw, G.V.Serpionov, I.I. Vinogradov, Y. Yamauchi	Data taking

	LIT	V.V. Trofimov	
	FLNP	M.V. Frontasyeva, A.I. Kuklin, I.A. Bobrikov	
	LRB	I.V. Koshlan	
2.	**Production of ultra-pure isotopes**	**N.V. Aksenov**	Manufacturing
	FLNR	A.Yu. Bodrov, G.A. Bozhikov, I. Chuprakov, N.S. Gustova, A.Sh. Madumarov, S.V. Mitrofanov, A.V. Sabelnikov	
3.	**Radioanalytical studies**	**M.V. Gustova**	Data taking
	FLNR	D. Abdusamadzoda, N.S. Gustova, S.P. Kaplina, T.N. Sabelnikova, M.G. Voroniuk	
4.	**Project of specialized beam lines at DC-140**	**S.V. Mitrofanov**	Preparation
	FLNR	S.L. Bogomolov, O.A. Chernyshev, B.N. Gikal, G.N. Ivanov, I.A. Ivanenko, N.Yu. Kazarinov, V.A. Kostyrev, N.F. Osipov, S.V. Pashchenko, N.N. Pchelkin, V.A. Semin, V.A. Veryovochkin	
	VBLHEP	A.A. Fateev, 2 pers.	

Collaboration

Country or International Organization	City	Institute or Laboratory
Belarus	Minsk	BSU
	Gomel	GSU
Bulgaria	Plovdiv	PU
China	Beijing	PKU
Cuba	Havana	CEADEN
CzechRepublic	Prague	CU
	Brno	BUT
	Olomouc	UP
	Rez	NPI CAS
Germany	Darmstadt	GSI
Hungary	Budapest	GetGiroKft
Kazakhstan	Nur-Sultan	BA INP
		ENU
		NU
	Almaty	PhysTI
		MSU
Mongolia	Ulaanbaatar	CGL
Moldova	Kishinev	MoldSU

		NRC NUM
Poland	Warsaw	INCT
		WUT
	Lublin	UMCS
	Torun	UMK
Russia	Moscow	IC RAS
		ISPM RAS
		GPI RAS
		LPI RAS
		MAI
		MIEM
		RIVS
		NMRC RB of Ministry of Health RF
		SINP MSU
	Chernogolovka	BInEPCP RAS
		ISSP RAS
	Dubna	Trackpore Technology
	Kaliningrad	IKBFU
	Krasnodar	KSU
	Novosibirsk	ISP SB RAS
	Obninsk	REATRACK-Filter
	St. Petersburg	Ioffe Institute
	Vladimir	Vladisart
	Saratov	Saratov GMU
Romania	Bucharest	CSSNT-UPB
		IFIN-HH
		UPB
	BaiaMare	TUCN-NUCBM
	Magurele	INFLPR
Serbia	Belgrade	INS "VINCA"
Slovakia	Bratislava	IEE SAS
		PF SK
SouthAfrica	Pretoria	UP
	Bellville	UWC
	PortElizabeth	NMU
	Stellenbosch	SU
Spain	Valencia	UV
	Barcelona	ICREA

USA	Stanford, CA	SU
	Knoxville, TN	UTK
	OakRidge, TN	ORNL
Vietnam	Hanoi	IOP VAST

Implementation timeframe: 2022–2023

Total estimated program costs: 1657.1 thousand US dollars.

NN	**Name of budget articles**	**2022**	**2023**
1	Wages (art.1 – art.3)*	142.0	142.0
2	MNTS (art.4)	50.0	50.0
3	Materials, equipment (art.5+6+9+10+18+19)	500.0	500.0
4	Electricity/water (art.7+art.8)		
5	Operational expenses (art.11 - art.17)**	74.7	82.2
6	Administrative expenses	55.8	60.4
	TOTAL:	**822.5**	**834.6**

Other sources of financing:

1. **Participant countries authorized representatives' grants and co-operation programs with participant countries.**
2. **RSA–JINR agreement.**
3. **FLNR extrabudgetary funds – 500 thousand US dollars per year.**

ENDORSED:

JINR Chief Scientific Secretary

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Director of the Laboratory

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Head of the Planning and Finance Department

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Scientific Secretary of the Laboratory

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S.r of the JINR Research Organization Department

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Economist of the Laboratory

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Head of the JINR Research Organization Department

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Theme Leader

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