**Annex 3.**

***Form of opening (renewal) for Project /***

 **APPROVED**

 **JINR DIRECTOR**

 **/**

 **" " 2023 г.**

**PROJECT PROPOSAL FORM**

**Opening/renewal of a research project/subproject of the large research infrastructure project within the Topical plan of JINR**

**1. General information on the research project of the theme**

* 1. **Theme code /** (for extended projects) - *the theme code includes the opening date, the closing date is not given, as it is determined by the completion dates of the projects in the topic.*
	2. **Project** **code** (for extended projects)

**1.3 Laboratory**

Flerov Laboratory of Nuclear Reactions

**1.4 Scientific field**

Condensed Matter Physics, Radiation and Radiobiological Research

**1.5 Title of the project**

Radiation tolerance of materials to high intensity heavy ion beams impact

**1.6 Project leader(s)**

D. Sc. V.A. Skuratov

**1.7 Project deputy leader(s) (scientific supervisor(s))**

PhD R.A. Rymzhanov

**2 Scientific case and project organization**

**2.1 Annotation**

Structural modifications induced by swift heavy ions still remain uncertain in view of extremely small spatial (nanometers) and temporal (femtoseconds) scales and an extremely high level of initial excitation of the material in the nanometric proximity of the ion path. Evident lack of adequate models does not allow to distinguish the mechanisms and parameters controlling the desired transformations. Understanding the fundamental mechanisms of excitation of materials in high-energy heavy ion tracks will reveal the role of various parameters governing the subpicosecond kinetics of excitation of the electronic and ionic subsystems of the material. The study of the kinetics of the electronic and ionic subsystems in ion track will help to determine the spatial and temporal distributions of the properties of this excitation forming the driving forces of structural-phase changes in ion tracks.

The aim of the project is to further acquire a set of basic data for improved understanding of the fundamental physics of intense ionization in materials showing promise for nuclear and nanotechnological applications and the irradiation testing of target materials for nuclear physics experiments. We expect to get new knowledge concerning evolution of defect structure in nuclear ceramics under dense electronic excitations simulating the fission fragment impact. As an innovative approach, it is proposed to study dense ionization effects on pre-existing defect structure formed by conventional radiation (hundred keV and unit MeV ion irradiation), that is most reliable case of fission product damage simulation.

Main approach to achieve goals of the project will be using of modern techniques for structural analysis - high resolution transmission electron microscopy in combination with molecular dynamics modelling of ion track formation processes. Structural changes will be studied also using scanning electron microscopy, X-ray diffraction, confocal Raman and luminescence spectroscopy, real-time optical spectroscopy during ion irradiation. Radiation stability of promising reactor and target materials for nuclear physics experiments will be evaluated by micro/nanomechanical testing.

The experimental base of this project is the transmission electron microscopy of FLNR JINR and Centre for High Resolution Transmission Electron Microscopy of Nelson Mandela University (SA), IC-100, U-400 and DC-140 FLNR JINR cyclotrons, ECR irradiation set-up and DC-60 INP (Astana) cyclotron, XRD set-up of BSU (Minsk) and FLNP JINR.

During the project activity we expect to achieve following results:

* Improved understanding of the fundamental physics of intense ionization in solids, based on determined dependence of the kinetics of structural changes in the tracks of swift heavy ions in the near-surface regions of nanostructured dielectrics: nanoparticles, interface layers, thin films.
* Results of modeling with molecular dynamics methods of the relaxation kinetics of the lattice and the processes of formation of structurally changed regions in the near-surface and interface regions of composite materials excited by ions: nanoclusters in the matrix, layered structures.
* The data on combined effects of dense ionization and helium on fission product transport properties in protected layers and inert matrix fuel hosts.
* Database on ion track parameters in conventional and nanostructured ceramics showing promise for nuclear applications.
* The data on long term stability of target materials during intense heavy ion irradiation.

**2.2 Scientific case** (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks)

**Aim**

The aim of the project is to further acquire a set of basic data for improved understanding of the fundamental physics of intense ionization in materials showing promise for nuclear and nanotechnological applications and the irradiation testing of target materials for nuclear physics experiments.

**Relevance and scientific novelty**

Research activity using swift heavy ion (SHI, M> 4, E> 1 MeV/amu) beams has been and still remain one of the most rapidly emerging direction of radiation physics of solids and radiation materials science. Such work is widely carried out in all centers with accelerators of this class like GSI, GANIL and others. In large measure, this is due to the unique nature of structural imperfections that are not reproducible under any other types of radiation or other impacts. In addition, a wide variation in the mass and energy of ions as well as in damage production rates, makes it possible to study radiation defects formed both in elastic collisions and via ionization energy losses. This, in turn, opens up opportunities for studying the effects caused by the entire spectrum of radiation in nuclear reactors, first of all by neutrons and fission fragments.

Structural modifications induced by fission products, i.e. atoms with a mass ranging from 80 to 155 and an energy of about 100 MeV, still remain uncertain because the effects cannot be investigated using classical low-energy ion implanters. In particular, dense ionization, that is a main peculiarity of fission fragment effect in comparison to convenient irradiation, may introduce phase transformations and accompanying volume changes in swift ion (fission fragment) track region in ceramics considered as promising inert matrix fuel hosts. This can consequently produce unacceptable stresses in fuel pin assemblies, limiting the fuel performance. Such swift ion radiation-induced changes are poorly understood and cannot be predicted from neutron or conventional (low energy) ion irradiation behavior. To date, only a few data concerning the microstructural response of nonfertile ceramics to ion irradiation of fission energy are available and external bombardment with energetic ions offers a unique opportunity to simulate fission fragment-induced damage. As an innovative approach, it is proposed to study dense ionization effects on pre-existing defect structure in materials formed by conventional radiation (hundred keV and unit MeV ion irradiation), that is most reliable case of fission product damage simulation. To our knowledge, no such systematics experiments have been yet carried out.

Besides the production of specific ion track associated defects, dense ionization may affect diffusion and migration of fission products (FPs) in materials used as protective layers coated fuel kernel, like pyrolytic carbon and silicon carbide that is of considerable practical value for retention of the radiological important products in spent nuclear fuel. For over a decade, scientists have investigated the migration behavior of fission products not taking into account that during the fission process in nuclear reactors, nuclides with a large range of energy are released in the presence of helium coming from actinide radioactive decay and nuclide transmutation. Therefore, protected layers will be subjected to FPs of different energies in the presence of He. In a nuclear reactor environment, a lot of alpha particles are produced from nuclear reactions. In advanced fission reactors, the He generation rate is reported to be 2.5 He -atomic parts per million (appm)/(displacement per atom) (dpa) [1]. Helium has been reported to form bubbles in SiC. It has also been shown that the creation of bubbles/cavities induces deleterious effects on the physical integrity of SiC (e.g. formation of cracks, surface swelling and exfoliation) used in a nuclear context. This compromises the physical integrity of SiC and might have serious implications for SiC as the main barrier of fission products. To the best of our knowledge, the influence of He bubbles in the migration behavior of important fission products has not been investigated. Therefore, combined effects of dense ionization and helium on FPs transport properties in protected layers and inert matrix fuel hosts are of topical interest in radiation material science. Usually for the modelling of these effects, single or multi energy helium ion implantations in tens keV-units MeV range are used. Such approach cannot provide the uniform spatial distribution of implanted atoms that strongly complicates the interpretation of experimental results. To overcome this problem, dedicated irradiation facilities, providing spatial homogeneity of implanted ions should be used.

Irradiation with heavy ions of 1–3 MeV/nucleon energies is characterized by pronounced inhomogeneous ionization and nuclear stopping profiles. As a result, the level of energy losses varies over a very wide range, which, in turn, leads to an inhomogeneous spatial distribution of the radiation damage and the associated mechanical stresses. The range of ions with the above energies, depending on the density of the material, does not exceed several tens of microns. For energies of ~ 1 MeV/nucleon, which are of the greatest interest from a practical point of view for the simulation of the fission fragments impact, this value is in the range of several microns to ~ 10 microns. Therefore, to get reliable information about the stress profiles, it is necessary to use experimental methods with a spatial resolution of ~ 1 micron. Such accuracy can be achieved in techniques that are based on the use of the piezospectroscopic effect, which connects the spectral shift in optical absorption, luminescence, or Raman scattering spectra with the level of mechanical stresses. First results, received during current research activity have demonstrated significant potential of this experimental technique [2]. One of the most relevant tasks for which such an approach can be used is the comparison of stress profiles in candidate materials for inert matrix fuel hosts after under ion bombardment with specific ionizing energy losses which are higher or lower than the threshold for radiation damage formation via electronic excitations. To date, the build-up and accumulation of stress with swift heavy ion fluence and energy has been studied for very limited numbers of ceramics and oxides using mainly non depth resolved X-ray diffraction techniques providing integrated information from total probed volume.

The relaxation of the initial material excitation in the vicinity of the SHI trajectory result in formation of structurally modified regions with sizes up to 10 nanometers in diameter and 10-100 micrometers in length. Such a spatially anisotropic structural nanomodification has no analogues and can be used for the production of nanostructured materials. Techniques based on the use of SHI irradiation are already effectively used in technologies for production of track membranes, quantum dots, conducting channels in layered structures and modification of nanostructures.

The unique ability to control properties only by changing the size of crystallites/grains has greatly expanded the application of nanostructured materials, including their work in strong radiation fields. According to the literature, radiation resistance can be significantly increased with a decrease in grain size by increasing the total area of the intergranular boundaries, which are sinks for point defects, that is, to promote their enhanced annihilation [3]. This is true for all types of radiation, with the exception of swift heavy ions which create specific extended defects - latent tracks, the size of which in dielectrics is comparable to the grain size. The formation of such structural imperfections can be a critical factor determining the long-term radiation stability of material irradiated by FPs. Therefore, studies of ion tracks in materials with different grain sizes in a wide range of electronic stopping powers are undoubtedly new and relevant. Of particular interest from a fundamental and practical point of view is the comparison of threshold conditions for the formation and parameters of latent tracks in nano- and conventional materials (poly- and single crystals). This will provide new experimental data, both for the verification of existing and for the development of new atomistic mechanisms for the formation of latent tracks, especially in radiation-resistant dielectrics. In addition, these data will be used as initial (input) parameters for computer modeling of track formation processes that is one of the tasks of the proposed project.

Of particular interest is the radiation tolerance of nanosized materials to effects of high-energy heavy ions for by oxide dispersion strengthened (ODS) alloys. As is known, ODS steels, due to the introduction of thermally stable oxide nanoparticles (Y-Ti-O, Y-Al-O) into the material matrix, which serve as barriers to the movement of dislocations and effective sinks for radiation defects, have high radiation resistance to vacancy swelling. Based on the results of a large number of studies, it has been found that neutron irradiation and irradiation with low-energy ions do not lead to critical changes in the structure and morphology of nanoparticles up to very high radiation damage doses [4]. At the same time, as is known, dielectric materials are sensitive to SHI irradiation: due to the effects of high ionization density, latent tracks can form in their structure, the characteristic size of which (2–10 nm) is comparable to the size of nanoparticles. This can cause amorphization of oxides and even their dissociation, which in turn will affect the mechanical properties of ODS steel. Because high performance characteristics of ODS steels are dependent on nanosized particles that, the study of their stability upon irradiation with heavy ions of fission fragment-energy is of considerable interest. Such systematic studies have not previously been carried out. During the implementation of the previous theme, it was shown that SHI irradiation of Y-Ti-O (Y2TiO5, Y2Ti2O7) particles leads to the formation of amorphous latent tracks [5], with an increase in the irradiation fluence, the tracks begin to overlap, which leads to complete amorphization of particles and, to a decrease in the radiation resistance of ODS steel.

At the same time, tracks are not observed in Y-Al-O (Y4Al2O9) particles embedded into a metal matrix, although they are registered in isolated nanocrystals. Determining the exact threshold energies of the electronic energy losses for the formation of latent tracks in nanoparticles of oxides and carbides, such as Me23C6, will make it possible to correlate the experimental electron microscopic data with the results of calculations in the i-TS inelastic thermal spike model and computer simulation by molecular dynamics methods. It should be noted that the results obtained, including by the participants of the proposed project, are presented in a limited number of works and further research in this area will certainly be new and relevant. Of particular importance is the study of the evolution of the microstructure of oxide and carbide nanoparticles by transmission electron microscopy depending on the irradiation temperature and the level of specific ionization energy losses, the effect of the initial particle structure on the track morphology, and the influence on the processes of formation of tracks of the surrounding metal matrix.

Of undoubted interest are also tasks aimed at studying the processes of recrystallization of latent tracks during post-radiation annealing, which will make it possible to obtain new data on the recovery processes of the crystal structure of track regions in nanoparticles dissolved in metal matrices. It should also be noted that almost all works on the structural effects of ionization in nanosized materials are devoted to metal and semiconductor nanoparticles in dielectric matrices, while the results of studying the properties of oxide particles in metal matrices are presented in only a few publications.

The interface between media, i.e. solid surface layer or interface region in nanostructured or composite materials, is the most sensitive region to extreme excitation induced in SHI tracks. The principal features of the processes occurring in SHI tracks near the surface of irradiated materials and requiring detailed investigation are: (a) the emission of excited electrons from the surface of the irradiated material and their spatial and temporal inhomogeneity of the generated density of excited electrons and holes and their energy; (b) excess potential energy of the interface, which changes the dynamics of atoms in the near-surface region (up to several tens of nm). It is worth noting that the most interesting for applications and technologies of nanostructural changes are the methods based on the effects related with the irradiation of surfaces and interfaces of solids. For example, the technologies for creating quantum dots and conducting channels in layered structures irradiated with high-energy heavy ions are already developed and used.

However, the implementation of nanotechnology based on SHI irradiations is constrained by deficient knowledge of the basic physical processes that characterize the interaction of such ions with solids. Extremely small spatial (nanometers) and temporal (femtoseconds) scales and an extremely high level of initial excitation of the material in the track lead to the fact that the effects observed upon irradiation of SHIs cannot be satisfactorily explained within the framework of models based on macroscopic approaches. In turn, the lack of adequate models does not allow to distinguish the mechanisms and parameters controlling the desired transformations. Understanding the fundamental mechanisms of excitation of materials in high-energy heavy ion tracks will reveal the role of various parameters governing the subpicosecond kinetics of excitation of the electronic and ionic subsystems of the material in the nanometric proximity of the ion path. The study of the kinetics of the electronic and ionic subsystems in the SHI track will help to determine the spatial and temporal distributions of the properties of this excitation forming the driving forces of structural-phase changes in tracks.

To fulfill the objectives, it is planned to use the Monte Carlo (MC) model developed by an international team with the active participation of FLNR part [6,7]. This model describes the passage of ions through matter, generation of fast δ-electrons, ionization cascades, redistribution of valence holes, Auger decays and radiative decays of holes in deep shells, as well as electron emission from the surface. The model uses the formalism of the dynamic structure factor and the complex dielectric function, which makes it possible to take into account the collective reactions of both subsystems to excitation in SHI tracks at ultrashort spatial and temporal scales. This model will be used to calculate the energy density distribution of electrons and holes near the ion trajectory in three-dimensional geometry in order to take into account all the features of the processes occurring near the surface and interfaces. The model has been successfully used to describe the processes of excitation of solids upon irradiation with high-energy heavy ions. The results of applying the approach showed good agreement with the experimental data, which allows using this approach in the present project.

Within the framework of the project, the calculation of energy transfer by electrons and holes created by ion irradiation to the ionic subsystem of the material will be carried out. Energy transfer occurs as a result of their interaction with optical phonons, and the Monte Carlo model will be used for the description. The distribution of atomic velocities obtained as a result of calculations will be used to describe the relaxation kinetics of the material lattice using classical molecular dynamics in the LAMMPS program. It should be noted that this approach has been successfully applied to describe damage caused by high-energy heavy ions in bulk samples of Al2O3, Mg2SiO4, MgO, Y3Al5O12.

The track structure of swift heavy ions obtained using the molecular dynamics method will be analyzed using modern numerical methods of statistical physics and crystallography: dislocation analysis, common neighbor method, Wigner-Seitz point defect analysis, X-ray diffraction simulation, coordination analysis, etc. For a direct comparison of the data obtained with the results of experimental studies, the simulation of transmission electron microscopy (from the MD results) will also be carried out.

**References**

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2. Ainash Zhumazhanova et al., Raman Study of Polycrystalline Si3N4 Irradiated with Swift Heavy Ions.Crystals 11(2021) 1313.

3. T.D. Shen. Radiation tolerance in a nanostructure: Is smaller better? Nucl. Instr. Meth. B 266 (2008) 921-925.

4. Kimura A. et al., High burnup fuel cladding materials R&D for advanced nuclear systems: nano-sized oxide dispersion strengthening steels. Journal of Nuclear Science and Technology 44(2007)323-328.

5. V.A. Skuratov et al., Radiation stability of the ODS alloys against swift heavy ion impact. J. Nucl. Mater. 442 (1-3) (2013) 449-457.

6. R.A.Rymzhanov et al., Insights into different stages of formation of swift heavy ion tracks. Nucl. Instr. Meth. B 473 (2020) 27–42.

7. N. Medvedev et al., Frontiers, challenges, and solutions in modeling of swift heavy ion effects in materials, Journal of Applied Physics 133 (2023), 100701

**Methods and approaches, techniques**

Main approach to achieve goals of the project will be using of modern techniques for structural analysis - high resolution transmission electron microscopy in combination with molecular dynamic modelling of ion track formation processes. Structural changes in SHI irradiated solids will be studied also using scanning electron microscopy, X-ray diffraction, confocal Raman and luminescence spectroscopy, real-time optical spectroscopy during ion irradiation. Long term radiation stability of promising reactor and target materials for nuclear physics experiments will be evaluated by micro/nanomechanical testing.

The experimental base of this project is the transmission electron microscopy of FLNR JINR and Centre for High Resolution Transmission Electron Microscopy of Nelson Mandela University (SA), IC-100, U-400 and DC-140 FLNR JINR cyclotrons, ECR irradiation set-up and DC-60 INP (Astana) cyclotron, XRD set-up of BSU (Mins) and FLNP JINR. Studies of dense ionization effects on helium porosity and FPs transport properties in nuclear cladding materials and inert matrix fuel hosts will be carried using set-up for uniform doping of targets with 0.5-1.2 MeV/amu light and heavy ions.

It is planned that during project implementation will be to be created or purchased following equipment:

* Specialized ion beam lines for material research and single event effects (SEE) testing of electronic components at DC-140 FLNR cyclotron, equipped with microbeam set-up, ion beam scanning systems and all necessary elements for ion beam parameters evaluation and control
* Dedicated chamber for high-intensity ion beam irradiation with a rotating target and adjustable temperature holder
* High temperature nanoindentation system for micromechanical testing of heavy ion irradiated materials

**Expected results**

During the project activity we expect to achieve following results:

* Improved understanding of the fundamental physics of intense ionization in solids, based on determined dependence of the kinetics of structural changes in the tracks of swift heavy ions in the near-surface regions of nanostructured dielectrics: nanoparticles, interface layers, thin films.
* Results of modeling with MD methods of the relaxation kinetics of the lattice and the processes of formation of structurally changed regions in the near-surface and interface regions of composite materials excited by ions: nanoclusters in the matrix, layered structures.
* The data on combined effects of dense ionization and helium on fission product transport properties in protected layers and inert matrix fuel hosts.
* Database on ion track parameters in conventional and nanostructured ceramics showing promise for nuclear applications.
* The data on long term stability of target materials during intense heavy ion irradiation.

**Risks**

Project implementation risks are associated with potential problems in the replacement of parts of electron microscopy and XPS facilities and corresponding service maintenance.

**2.3 Estimated completion date**

December 2028

**2.4 Participating JINR laboratories**

Frank Laboratory of Neutron Physics

**2.4.1** **MICC resource requirements**

|  |  |
| --- | --- |
| **Computing resources** | **Distribution by year** |
| 1st year | 2nd year  | 3rd year | 4th year  | 5th year  |
| Data storage (TB)- EOS- Tapes | - | - | - | - | - |
| Tier 1 (CPU core hours) | - | - | - | - | - |
| Tier 2 (CPU core hours) | - | - | - | - | - |
| SC Govorun (CPU core hours)- CPU- GPU | - | - | - | - | - |
| Clouds (CPU cores) | - | - | - | - | - |

**2.5. Participating countries, scientific and educational organizations**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Organization** | **Country** | **City** | **Participants** | **Type****of agreement** |
| Belarusian State University | Belarus | Minsk | M. Tivanov,V. Uglov,N. Kazyuchits | Joint work |
| Institute of Nuclear Physics | Kazakhstan | Astana | M. Zdorovets | Joint work |
| L.N. Gumilyov Eurasian National University | Kazakhstan | Astana | A. Akilbekov | Joint work |
| Nazarbayev University | Kazakhstan | Astana | A. Tikhonov | Joint work |
| Rzhanov Institute of semiconductor physics | Russia | Novosibirsk | I. Antonova | Joint work |
| Institute of Theoretical and Experimental Physics | Russia | Moscow | S. Rogozhkin | Joint work |
| VincaInstitute of Nuclear Sciences | Serbia | Belgrade | S. Petrovic, Z. Jovanovic | Joint work |
| Nelson Mandela University | South Africa | Gqeberha | J. Neethling | Joint work |
| University of Pretoria | South Africa | Pretoria | T. Hlatshwayo,E. Njoroge | Joint work |
| University of South Africa | South Africa | Pretoria | Y. Sithole | Joint work |
| Tshwane University of Technology | South Africa | Pretoria | M. Msimanga | Joint work |
| iThemba Lab | South Africa | Cape Town | М. Nkosi  | Joint work |

**2.6. Key partners** *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program. An example is JINR's participation in the LHC experiments at CERN).*

**3. Manpower**

**3.1. Manpower needs in the first year of implementation**

|  |  |  |  |
| --- | --- | --- | --- |
| **№** | **Category of personnel** | **JINR staff,****amount of FTE** | **JINR Associated****Personnel,****amount of FTE** |
| 1. | research scientists | 10 | 0 |
| 2. | engineers | 9 | 0 |
| 3. | specialists | 1 | 0 |
| 4. | office workers | 0 | 0 |
| 5. | technicians | 0 | 0 |
|  | **Total:** | **20** | **0** |

**3.2. Available manpower**

**3.2.1. JINR staff**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Category of personnel** | **Full name** | **Division** | **Position** | **Amount****of FTE** |
| 1. | research scientists |  |  |  |  |
| 1.1. |  | Pavel Apel | Center of Applied Physics | Head of the Center | 0,5 |
| 1.2. |  | Vladimir Skuratov  | Sector №8 | Head of sector | 1 |
| 1.3. |  | Alexander Sohatsky | Center of Applied Physics | Head of sector | 1 |
| 1.4. |  | Ruslan Rymzhanov | Sector №8 | Senior research scientist | 1 |
| 1.5. |  | Matlab Mirzayev | Sector №8 | Senior research scientist | 1 |
| 1.6. |  | Ekaterina Korneeva | Center of Applied Physics | Research scientist | 1 |
| 1.7. |  | Vera Semina | Center of Applied Physics | Research scientist | 1 |
| 1.8. |  | Vladimir Altynov | Center of Applied Physics | Research scientist | 0,5 |
| 1.9. |  | Alisher Mutali | Sector №8 | Junior research scientist | 1 |
| 1.10. |  | Nguyen Van Tiep  | Sector №8 | Junior research scientist | 1 |
| 1.11. |  | Nikita Kirilkin | Center of Applied Physics | Junior research scientist | 1 |
| 2. | engineers |  |  |  |  |
| 2.1. |  | Oleg Ivanov | Center of Applied Physics | Head of group | 0,5 |
| 2.2. |  | Oleg Orelovich | Center of Applied Physics | Head of group | 0,5 |
| 2.3. |  | Nikolay Lizunov | Center of Applied Physics | Senior engineer | 0,5 |
| 2.4. |  | Elena Piyadina | Center of Applied Physics | Seniorengineer | 1 |
| 2.5. |  | Valentin Shmarovoz | Center of Applied Physics | Seniorengineer | 1 |
| 2.6. |  | Alexey Markin | Center of Applied Physics | Engineer | 0,5 |
| 2.7. |  | Le Thi Phuong Thao | Sector №8 | Engineer | 1 |
| 2.8. |  | Diana Komarova | Center of Applied Physics | Engineer | 1 |
| 2.9. |  | Nikita Kurylev | Center of Applied Physics | Engineer | 1 |
| 2.10. |  | Meruyert Mamatova | Sector №8 | Engineer | 1 |
| 2.11. |  | Valeriy Kuzmin | Center of Applied Physics | Engineer | 1 |
| 3. | specialists |  |  |  |  |
| 3.1. |  | Natalia Kuzmina | Center of Applied Physics | Head of group | 0,5 |
| 3.2. |  | Irina Dukach | Center of Applied Physics | Lead documentation specialist | 0,5 |
| 4. | technicians |  |  |  |  |
|  | **Total:** |  |  |  | **20** |

**3.2.2. JINR associated personnel**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Category of personnel**  | **Partner organization** | **Amount of FTE** |
| 1. | research scientists | - | - |
| 2. | engineers | - | - |
| 3. | specialists | - | - |
| 4. | technicians | - | - |
|  | **Total:**  | **-** | **-** |

**4. Financing**

**4.1 Total estimated cost of the project/LRIP subproject**

The total cost estimate of the project (for the whole period, excluding salary).

The details are given in a separate table below.

875 000 $.

**4.2 Extra funding sources**

Expected funding from partners/customers – a total estimate.

0 $.

**Project (****LRIP subproject) Leader** \_\_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_/

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: \_\_\_\_\_\_\_\_\_

Date of decision of the laboratory's STC: \_\_\_\_\_\_\_\_\_ document number: \_\_\_\_\_\_\_\_\_

Year of the project (LRIP subproject) start: \_\_\_2024\_\_\_\_\_

(for extended projects) – Project start year: \_\_\_\_\_\_\_

**Proposed schedule and resource request for the Project / LRIP subproject**

|  |  |  |
| --- | --- | --- |
| **Expenditures, resources,** **funding sources** | **Cost (thousands****of US dollars)/****Resource requirements** | **Cost/Resources,** **distribution by years** |
| 1st year | 2nd year | 3rd year | 4th year | 5th year |
|  | International cooperation | 150 | 30 | 30 | 30 | 30 | 30 |
| Materials  | 100 | 20 | 20 | 20 | 20 | 20 |
| Equipment, Third-party company services | 550 | 110 | 110 | 110 | 110 | 110 |
| Commissioning | 0 | 0 | 0 | 0 | 0 | 0 |
| R&D contracts with other research organizations  | 50 | 10 | 10 | 10 | 10 | 10 |
| Software purchasing | 25 | 5 | 5 | 5 | 5 | 5 |
| Design/construction | 0 | 0 | 0 | 0 | 0 | 0 |
| Service costs (*planned in case of direct project affiliation)* | 0 | 0 | 0 | 0 | 0 | 0 |
| **Resources required** | **Standard hours** | Resources |  |  |  |  |  |  |
| * the amount of FTE,
 | 20 | 20 | 20 | 20 | 20 | 20 |
| * accelerator/installation,
 | 20750 | 4150 | 4150 | 4150 | 4150 | 4150 |
| * reactor,…
 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Sources of funding** | **JINR Budget**  | JINR budget *(budget items)* | 875 | 175 | 175 | 175 | 175 | 175 |
| **Extra funding (supplementary estimates)** | Contributions by partners Funds under contracts with customersOther sources of funding | 0 | 0 | 0 | 0 | 0 | 0 |

Project Leader \_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

Laboratory Economist \_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

**APPROVAL SHEET FOR PROJECT**

TITLE OF THE PROJECT

SHORT DESIGNATION OF THE PROJECT

PROJECT

THEME

NAME OF THE PROJECT

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| AGREED |  |  |  |
| JINR VICE-DIRECTOR  | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF LABORATORY ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_ SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| THEME LEADER | \_\_\_\_\_\_\_\_\_\_\_ SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| PROJECT LEADER | \_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| APPROVED BY THE PAC  | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |