STRATEGY
of the Institute of Nuclear Problems of the Belarusian State University long-term development in the area of NanoElectroMagnetics

Developed under the FP7 BY-NanoERA project supported by the European Commission

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List of Abbreviations

NEM	Nanoelectromagnetics
INP BSU	Research Institute for Nuclear Problems of the Belarusian State University
CNTs	Carbon nanotubes
NC	Nanocarbon
NS	Nanostructures
PCA	Program Component Areas
EM	Electromagnetic
EMC	Electromagnetic compatibility
THz	Terahertz
MW	microwave
SWOT	Strengths, Weaknesses, Opportunities, Threats
ERA	European Research Area
FP7	EU 7th Framework Programme for Research, Technology and Development for 2007-2014
H2020	EU Framework Programme for Research and Innovation for 2014-2020
QDs	Quantum dots
SPFAR	State Programs of Fundamental and Applied Research
BRFFR	Belarus Republican Foundation for Fundamental Research
IRSES	International Research Staff Exchange Scheme
COST	European Co-operation in Science and Technology

1. Introduction: Rationale for strategic planning

This document is a strategy of the Research Institute for Nuclear Problems of the Belarusian State University (INP BSU) further developing in nanoelectromagnetics (hereinafter – the Strategy).

The Strategy is a framework that underpins the INP BSU activities in the said research area for the upcoming decade and reinforcing its capacities through the institutional development of this still-young research discipline. It formulates mission statement, describes the INP BSU strategic vision and goals till 2025 and proposes an action plan by which these goals will be achieved. The document includes the research program component areas and identifies specific objectives toward meeting the INP BSU vision.

1.1 What is Nanoelectromagnetics?

Nanoelectromagnetics (NEM) is **electromagnetics** of **nanoscale** elements, including electrical conductors and semiconductors which are **quantum mechanical** one- or zero-dimensional systems. The basic concept of nanoelectromagnetics originates from preceding experience in classical electrodynamics enriched by the present-day concepts of condensed matter physics. As each interdisciplinary area, NEM for its further successful development requires an intensive knowledge and practice exchange between variable research areas, such as basic and applied electromagnetics, chemistry and technology of nanostructures and nanostructured materials, physics of nanostructured systems, etc.

By 2013, the INP BSU team has completed a large number of national and international projects and grants in NEM, especially in the area of carbon nanotubes (CNTs) with a focus on THz applications of carbon based nanostructures. According to international evaluations, the scientific output is evident through high level publications which give the team members a status of internationally recognized experts[1]. At the same time, the INP BSU starts to more and more think about significant practical potential of the knowledge it accumulated. This understanding heated by favorable overall conditions for nanoscience and nanotechnologies development at home and around the globe calls the INP BSU to re-think its Strategy.

1.2 Time is right

In 2010-2013, the INP BSU coordinates the By-NanoERA project “Institutional Development of Applied Nanoelectromagnetics: Belarus in ERA Widening” funded by the European Commission within the 7th Framework Programme for RTD, Grant Agreement №266529. The aim of the action is to support the further integration of the INP BSU in the European Research Area (ERA) in NEM via providing opportunities for profound collaboration with the highly performing complementary research centers in the EU - Institut fuer Festkoerperphysik, TUB (Berlin Germany), Central Laboratory of Physico-Chemical Mechanics, Bulgarian Academy of Sciences (Sofia, Bulgaria); Frascati National Laboratory, National Institute of Nuclear Physics (Frascati, Italy), Institute of Electronic Structure and Laser (IESL) (Heraklion, Crete, Greece) – and in Belarus (Belarusian Institute of System Analysis and Information Support of Scientific

[1] A benchmarking exercise was implemented in 2012 by a group of international independent experts from Austria and UK in several institutes in Armenia, Belarus, Kazakhstan and Bulgaria working in nanotechnology. The exercise was undertaken within the FP7 IncoNet EECA project (“S&T Cooperation Network for Eastern European and Central Asian Countries) supported by the European Commission. In Belarus, the INP BSU has been evaluated.

and Technical Sphere and Science & Technology Park "Polytechnic" of the Belarusian National Technical University).

Within this project a set of networking and training activities is foreseen with a strong involvement of already existing and new partners from the EU member states and associated countries to support national RTD in applied nanoelectromagnetics, contribute to young researchers' career development, intensify information and experience exchange between Belarus and EU teams thus contributing to creation of the European research network in applied NEM, increase visibility of the INP BSU in the ERA and its participation in the EU-funded programs. The current document is one of the key deliverables of the project.

Despite the fact that developing a Strategy **is a must** for the INP BSU, it's also **a need and a will** of the team to summarize the existing body of knowledge, monitor the overall tendencies of the nanoscience development, explore the changing funding instruments at the turn of budget cycles on the national (2011-2015/2016-2020) and EU level (2007-2013/2014-2020) and adjust its goals and plans to the changing circumstances.

Which are the most important external circumstances that may influence the INP BSU?

On the national level, a Concept for setting up and developing of a nanoindustry in Belarus till 2020 and appropriate action plan were adopted in February 2013[2]. While the share of budget funding for research in the total funding of R&D is decreasing (58% in 2010, 38% - 2012) and the total funding of R&D didn't surpass 1% GDP for years, the Government considers the nanoindustry to be one of the most prospective branches to invest in and plans to spend 30 mln USD annually to support it in 2013-2015. NEM and connected areas of research is completely in line with the thematic priorities defined by this paper.

As a first step, the Concept proposes to set up and equip 4 basic centers of collective us of research equipment for the needs of nanoscientists. The largest of them will be hosted by the Belarusian State University, the UNP basic university. Its envisaged budget for 2013-2014 is 9 mln USD. Also, it's planned to set up a specialized incubator of small business which will provide 830 jobs for nano-oriented SMEs. It's supposed to be hosted by the S&T Park "Polytechnic", the INP BSU partner organization. As a whole, implementation of the Concept will increase the number of employees in the national nanoindustry by 2016 up to 3.5 thous., including 1.8 thous. engineers. The Concept also raises such vital for the INP BSU challenges as education and technology transfer in nanoarea.

Another important steps are setting up of an Association of Nanoindustry (February 2013) and Interdepartmental Coordination Board on Developing the Nanoindustry in Belarus (July 2013)[3]. Prof. Sergey Maksimenko, Director of the INP BSU as a member of this Board has got an opportunity to influence the strategic development of nanotechnologies in Belarus and, in particular, to take part in priorities setting, budget distribution and developing mechanisms of the state support for the nanoindustry.

On the international level, the nanoscience and nanotechnologies belong to the most quickly developing areas. Within the last 11 years 60 leading countries have invested in nanoresearch over 67 bln USD. Most of industrialized countries and many catching up economies have adopted national strategies and implement action plans which include developing of a legal basis, instruments of support, management, etc. Also, the nanostrategy has been agreed on the

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[2] Approved by the Resolution of the Council of ministers of the republic of Belarus of 18.02.2013 №113.

[3] Approved by the Resolution of the Council of ministers of the republic of Belarus of 18.07.2013 № 640.

EU level. Taking into account high capital intensity of R&D and commercialization in this area, the focus is made on integration of all actors within the chain (researchers, developers, venture investors, entrepreneurs, consumers, ect) and setting up of cluster-type structures (technological platforms, national technological networks, associations, etc).

Thus, favorable overall conditions and recently set up national landmarks call the INP BSU to overview the past activities and update its Strategy.

1.3 Benefiting from recent achievements

In the nineties, many research institutions of the former SU faced the problem of surviving and keeping research capacity in drastically changing and aggressive environment. The later implies abrupt closing of many research directions, catastrophic brain drain and a lack of financing. As a result, many research teams had to minimize activities and concentrate on searching for new fields of application. Namely in that period, in the middle of the nineties, a small research group in the INP BSU has formulated a **strategic concept of its survival** which included a need

1. **To choose attractive and fashionable R&D topic and find unoccupied niche;**
2. **To show research progress recognizable by the scientific community on both national and international levels;**
3. **To enter into national R&D programs;**
4. **To join education process attracting young generation of researchers;**
5. **To establish international collaboration.**

Today, after fifteen years of the active work, we are happy to state significant progress in solving all these strategic tasks on the level of the core research team – the **INP's Laboratory of electrodynamics of nonhomogeneous mediums.** The research topic choice was dictated by the previous experience of key researchers involved in classical electrodynamics[4] and the understanding of the coming progress - development of nano-sized components of high-frequency electric circuits and complex high-frequency nano-scale systems.

Indeed, the emergence of nano-sized structures as key building block of nanoelectronic and nanophotonic devices has extended to the nanoscale, to such classical problems of the circuit theory as operational properties and electromagnetic compatibility (EMC) of circuit elements, noise control, and so on. However, such an extension implies radical modification of the basic principles of circuit theory, which relies on macroscopic electrodynamics.

Milestones in the development of electrodynamics have always been related to practical problems arising from new ideas relating to the transmission and processing of electromagnetic signals. Advances in quantum electronics led to the development of the theory of open quasi-optical resonators[5]. The synthesis of high-quality optical fibers made fiber-optic communication feasible, which led to the development of the theory of open dielectric waveguides (including irregular and nonlinear waveguides)[6,7]. Progress in microwave microelectronics stimulated research on the electrodynamics of microstrips and other planar structures[8]. Modern electromagnetic theory is characterized by the development of highly efficient numerical

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[4] A.S. Ilyinsky, G.Ya. Slepyan, and A.Ya. Slepyan, *Propagation, Scattering and Dissipation of Electromagnetic Waves*, Peter Peregrinus, London (1993).
[5] L. A. Weinstein, *Open Resonators and Open Waveguides*, Golem, New York (1969).
[6] V. V. Shevchenko, *Tapers in Open Waveguides*, Golem, Boulder, CO (1971).
[7] M. J. Adams, *An Introduction to Optical Waveguides*, Wiley, New York (1981).
[8] K.C. Gupta, R. Garg, and R. Chadha, *Computer Aided Design of Microwave Circuits*, Artech House, Boston (1981).

methods simulating diffraction from lossy objects of arbitrary spatial configurations. Undoubtedly, electromagnetic simulation of nanostructures is one of the main research directions for modern electrodynamics. Thus, as the main result of the past period we state the following:

A new research discipline – nanoelectromagnetics – has been introduced as a synthesis of classical microwave electrodynamics and present-day concepts of the condensed matter physics.

On this way, many electromagnetic problems of nanostructures exemplified by carbon nanotubes (CNTs) and quantum dots (QDs) have been solved and published in high-ranked scientific journals, see Refs.[9] as examples. Basic approaches of nanoelectromagnetics have been published as book contributions[10,11,12].

In addition to high publication activities, several other facts related to the INP BSU staff achievements have contributed to the visibility growth:

- Prof. Gregory Slepyan is the Editorial Board member of the journal Electromagnetics (Taylor&Francis),
- Prof. Sergey Maksimenko is the Associate Editor of the Journal of Nanophotonics (SPIE),
- In 2008, S. Maksimenko has been elected a SPIE Fellow,
- G.Slepyan (2006) and S.Maksimenko (2007) were awarded the Belarus National Scholarship for Advanced Achievements in Research,
- Review[13] refers to our approach in nanoelectromagnetics as a Belarus method.

As a whole, **recognizability of the group on both international and national nano R&D markets has been reached.**

The team **participates in several national R&D programs,** such as State Programs of Fundamental and Applied Research (SPFAR) "Microelectronics", "Nanotechnology", "Photonics", and closely collaborates with the Belarus Republican Foundation for Fundamental Research (BRFFR). The projects being carried out are all in the field of applied nanoelectromagnetics, some of them are listed below:

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[9] O.M.Yevtushenko, et al., ***Phys. Rev. Lett.* 79**, 1102 (1997); G.Y. Slepyan, et al., ***Phys. Rev. B* 60**, 17136 (1999); I.V. Bondarev, et al., ***Phys. Rev. Lett.* 89**, 115504 (2002); C.Stanciu, et al., ***Appl. Phys. Lett.* 81**, 4064 (2002); G.Y. Slepyan, , ***Phys. Rev. A* 66**, 063804, (2002); G.Y. Slepyan, et al., ***Phys. Rev. B* 70**, 045320 (2004); A.M. Nemilentsau, et al., ***Carbon* 44**, 2246 (2006); G.Y. Slepyan, et al., ***Phys. Rev. B* 73,** 195416 (2006); A.M. Nemilentsau, ***Phys. Rev. Lett.* 99**, 147403 (2007); M.V. Shuba, et al.. **Phys. Rev. B 76**, 155407 (2007); G.Y. Slepyan, et al., ***Phys. Rev. B* 76,** 195328 (2007); O.V. Kibis, et al., ***Phys. Rev. Lett.* 102**, 023601 (2009); M.V. Shuba, et al., ***Phys. Rev. B* 79**, 155403 (2009); K. G. Batrakov, et al, **Phys. Rev. B 79**, 125408 (2009), G.Ya. Slepyan, et al, **Phys. Rev. B 81**, 205423 (2010), D. Seliuta, et al, **Appl. Phys. Lett. 97**, 073116 (2010), A. M. Nemilentsau, et al, **Phys. Rev. B 82**, 235411 (2010), A. M. Nemilentsau, et al, **Phys. Rev. B 82,** 235424 (2010), M. V. Shuba, et al, **Phys. Rev. B 85,** 165435 (2012), G.Ya. Slepyan, et al, **Phys. Rev. B 85,** 245134 (2012), M.V. Shuba, et al, **Nanotechnology 23** 495714 **(2012),** S. Mokhlespour, et al, **Phys. Rev. B 86,** 245322 (2012)

[10] S.A. Maksimenko and G.Ya. Slepyan, Electromagnetics of Carbon Nanotubes, in "Introduction to Complex Mediums for Optics and Electromagnetics", Ed. by: W. Weiglhofer and A. Lakhtakia, SPIE Press 2003, 507-546.

[11] S.A. Maksimenko and G.Ya. Slepyan, Nanoelectromagnetics of low-dimensional structures, in "The Handbook of Nanotechnology: Nanometer Structure Theory, Modeling, and Simulation," Ed. by: A. Lakhtakia, SPIE Press, 2004, pp. 145-206.

[12] A.M. Nemilentsau, G. Ya. Slepyan, S. A. Maksimenko, O. V. Kibis, M. E. Portnoi, Terahertz radiation from carbon nanotubes, The Handbook of Nanophysics, Vol. 4: Nanotubes and Nanowires, editor: Klaus D. Sattler, Taylor & Francis, London, in press (ISBN: 978-1-4200-7542-7)

[13] C. Rutherglen and P. Burke, Nanoelectromagnetics: Circuit and Electromagnetic Properties of Carbon Nanotubes ***Small* 5,** 884 (2009)

- Physical basis and instrumentation design for the diagnostics of nano-dimentional heterostructures in microwave range, SPFAR “Electronics” 4.21;
- Light interaction with carbon nanostructures and their composites, SPFAR “Nanotech” 1.9;
- Physical basis of quantum optics of nanostructured systems, SPFAR “Photonics” 1.21;
- Carbon nanotubes as light sources in far- and near-IR ranges, BRFFR F06-101;
- Physical properties of carbon nanotube arrays in strong electric and magnetic fields, BRFFR F06F-013.

Success in the research would not be possible without **wide international collaboration established** during last ten years. The collaborative work of the team was supported through a number of international research grants. Among them 7 INTAS projects (two of them are Young Scientists INTAS Fellowships) and two projects of the NATO Science for Peace Programme. Also, a set of bilateral projects supported by DFG (Deutsche Forschungs-gemeinschaft) and BMBF (Federal Ministry of Education and Research of Germany) have been carried out in collaboration with the Berlin Technical University and Max Born Institute. Five young researchers from the INP BSU team got fellowships from the World Federation of Scientists, National Scholarship Programme.

In parallel with the By-NanoERA project implementation, several the other complementary international research projects have been carried out and three new international projects started being supported via the International Research Staff Exchange Scheme of the FP7 “People” Programme (IRSES):

- **Terahertz applications of carbon nanotubes,** International Bureau of BMBF (Germany), project BLR 08/001. Project leaders: Prof. Ch. Thomsen, Institut fuer Festkoerperphysik, TUB (Germany) and S.Maksimenko, INP BSU (Belarus), 2008-2010
- **Nanocarbon based composite materials for electromagnetic applications,** ISTC project B-1708, 2009-2012, Project manager S.Maksimenko
- **Terahertz applications of carbon-based nanostructures,** EU FP7 TerACaN project FP7-230778, Call ID “FP7-PEOPLE-2008-IRSES” 2009-2012, Principal Researcher: Dr. M. Portnoi, University of Exeter (UK)
- **Nano carbon based components and materials for high frequency electronics,** EU FP7 CACOMEL project FP7-247007, Call ID “FP7-PEOPLE-2009-IRSES”, 2010-2013, Principal Researcher: Prof. Ch. Thomsen, Institut fuer Festkoerperphysik, TUB (Germany)
- **Fundamental and Applied Electromagnetics of Nano-Carbons,** IRSES-GA-2012-318617 project FAEMCAR (2012-2016), Principal researcher Prof. Philippe Lambin, University of Namur (Belgium)
- **Nano-thin and micro-sized carbons: Toward electromagnetic compatibility applications,** IRSES-GA-2013-610875 NAmiceMC (2014-2017), Principal researcher Prof. Alain Celzard, Université de Lorraine (France)
- **Carbon-nanotube-based terahertz-to-optics rectenna**, FP7-PEOPLE-2013-IRSES 612285 CANTOR (2014-2017), Principal Researcher: Dr. M. Portnoi, University of Exeter (UK).

The INP BSU team is also actively involved into the preparation of COST action submission **“Nanoelectromagnetics facing societal challenges”, acronym “NEMASO”.** To move towards societal challenges stated by HORIZON 2020, the upcoming EU Framework Programme for Research and Innovation NEM as any interdisciplinary research topic needs an intensive knowledge exchange between different scientific communities. The platform stemming from the proposed COST action will cover NEM fundamentals and numerous applications - applied NEM of carbonaceous structures, QDs and hybrid structures for electromagnetic applications, nanophotonics, photovoltaics and metamaterials, NEM for biomedical applications, NEM for ICT, etc. Being widely available, it will help research groups representing these areas to keep contacts among themselves, and also with producers and users.

With time, the INP BSU started to become aware of the potential commercial value of their research results. The well-developed electromagnetic theory could be transferred into commercially distributed codes for the analysis of high frequency electronic circuits. Other potential applications are to use the optical properties of materials which include carbon nanotubes for technological applications - for shielding material in reactors, shielding materials for electromagnetic shielding and materials which can be applied in cancer treatment. It's clear, however, that the partial shift of activities towards the knowledge transfer and commercialization will require new competencies and skills, new schemes to support these activities, thorough analysis and prioritizing of application areas to start with and partnerships with industry. The next chapter elucidates the actual trends in NEM necessary to be analyzed prior strategic planning.

1.4 Where to move? Modern trends in Nanoelectromagnetics and its applications

The Analytical review "Modern development trends in nanoelectromagnetics" published online [14] was developed as a deliverable of the By-NanoERA project and scientific basis for this Strategy. It defines the development trends of NEM, a new field of science that represents a synthesis of classical radio physics and electrodynamics with quantum theory of solids, statistical physics, physical kinetics, quantum chemistry, computational mathematics. In the review, the main types of nanostructures (carbon nanotubes, quantum walls, quantum wires, quantum dots, plasmonic nanowires, etc.), the theoretical methods of NEM and links with the other fields of science (materials science, nanotechnology, biophysics and medicine) are presented. The key NEM applications in nanoelectronics and nanophotonics are described (circuits, nanoresonators and nanoantennas, amplifiers and generators microwaves of terahertz and optical frequency), as well as in the materials science (synthesis of composite metamaterials for radar absorbing coatings). The probable ways of NEM development and its future applications in various fields of science, technology and medicine are analyzed.

Ongoing rapid progress in the synthesis of different nanostructures, and their fascinating physical and chemical properties not associated with bulk materials, have motivated a significant and long-lasting increase of human resources and financial investments in this research field worldwide. This area combines the exciting progress in fundamental research with the immediate promise of its realization in new devices and products with high societal impact and commercial potential. Advances in the physics and technology of nanoctructures have led to the creation of a basis for their wide application in nanoelectronics, nanophotonics, nanomedicine and materials science. CNTs, in particular, are proposed as building blocks for the realization of different integrated circuit elements and EM devices, such as transmission lines, field-effect transistors, interconnects, nanoantennas, and active elements functioning in terahertz and infrared regimes. Recently, regular structures often classified as metamaterials have received special attention for producing EM filters, perfect absorbers of EM radiation, and for amplification devices of THz signals. New specific applications arise – such as chemical and biological sensors, therapeutic techniques including selective photothermolysis of cancer cells, and photo- and thermo-acoustic imaging – which require analyzing advanced electromagnetic functionalities of chemically modified CNT and other forms of nanocarbon. The recently discovered graphene provides a bridge between condensed matter physics and quantum electrodynamics, opening new

[14] http://www.nano.bsu.by/deliverables/prognosis

perspectives for carbon-based electronics. Along with the widespread bio-medical and electronics applications of nanomaterials, the design and fabrication of effective EM coatings for microwave and radio frequencies has become a pressing problem. In order to improve EM coatings, e.g. for ICT and aerospace applications, novel composites based on NC and other NS will be implemented. This project will also include physics of quantum dots, carbon NS and hybrid structures (like, e.g. QD+CNT) for photovoltaic (PV) applications. Furthermore, we shall embed CNTs and NCs in sculptured thin films with various internal porous morphologies for THz and IR applications. The practical realization of all mentioned devices, elements, and materials requires precise theoretical modeling and comprehensive experimental study of their EM properties.

The main conclusion of the prognosis is that for further development in the field of NEM the INP BSU needs to concentrate on the following subjects:

- ✓ electromagnetic effects in nanostructures: simulation and experiment,
- ✓ carbon nanotubes, graphene and other forms of nanocarbon in electromagnetics,
- ✓ nano-resonators, -antennas, -transmission lines,
- ✓ optical nonlinearity at the nanoscale,
- ✓ nanostructured composite materials and thin films: synthesis and physico-chemical properties,
- ✓ nanostructured composite materials for electromagnetic protection and protection against ionizing radiation,
- ✓ ordered nanostructures and metamaterials to control electromagnetic fields,
- ✓ biomedical applications of metal nanoparticles and nanocarbon,
- ✓ operation of quantum light and single-photon devices.

1.5 Relying upon the INP BSU core team

The core INP BSU team working in the area of NEM is made by the permanent staff of the **Laboratory of electrodynamics of nonhomogeneous media,** which is a part of the Research Institute for Nuclear Problems of the Belarusian State University located in Minsk, Belarus.

The Belarusian State University, BSU is a national leader of the higher education in Belarus. It is a complex research and educational establishment with a clear innovative strategic focus. The organizational structure of the university includes

- 19 faculties,
- 3 research institutes,
- 4 national R&D centers,
- 114 research laboratories and
- 6 innovative industrial enterprises.

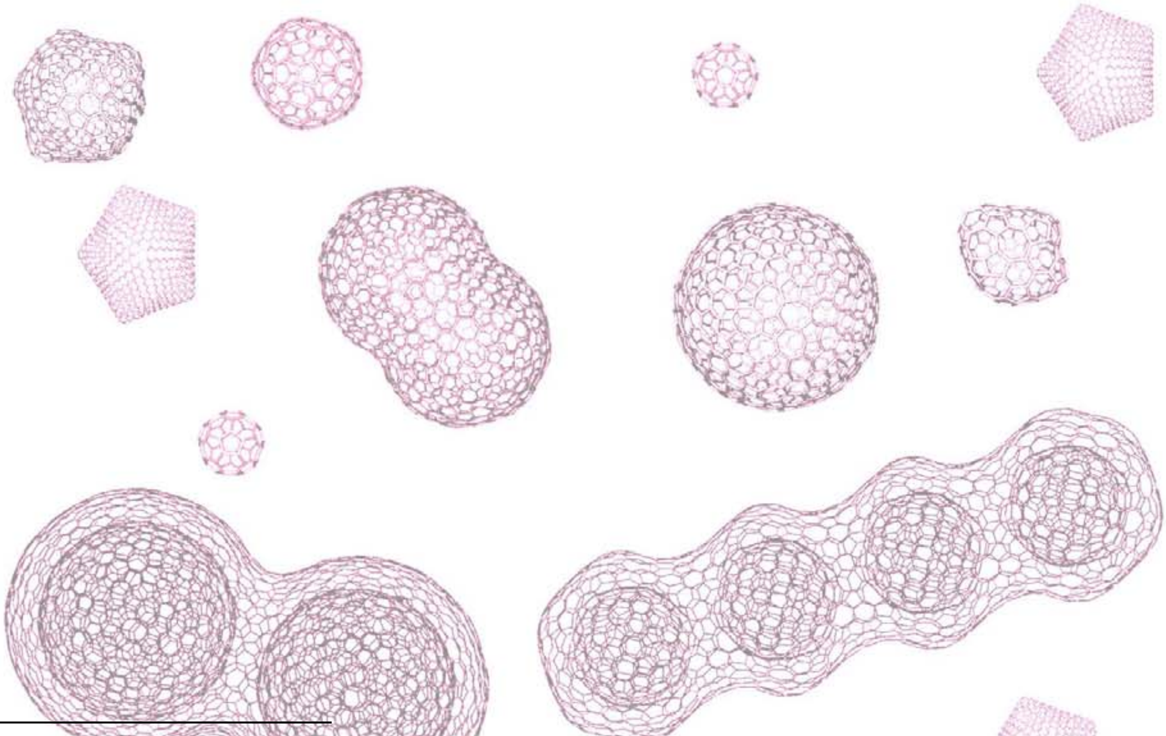
Almost 880 professional researchers form the R&D staff. Physics and chemistry of new materials (including nanostructures), informatics, research instrumentation and equipment (including instrumentation for radioactive pollution monitoring), biology, etc., are the main areas of the R&D activities of the university.

The Research Institute for Nuclear Problems, INP BSU is one of the 3 research institutions belonging to the BSU. The major areas of its research activities are nuclear physics and physics of elementary particles, nuclear optics of polarized mediums, electrodynamics of condensed matter with complex structure, applied electrodynamics of microwaves, physical basis of free electron lasers, methods and equipment for radiation and ecological disasters prevention, environmental monitoring systems, radiation protection in medicine and industry. Since the mid-nineties, a new area - physics of electromagnetic properties of nanostructures - is developed in the INP's **Laboratory of electrodynamics of nonhomogeneous media.**

The current activities of the Lab are focused on fundamental and applied nanoelectromagnetics that is defined by the national thematic priorities of S&T activities for 2011-2015[15] and national research priorities formulated in the List of priority areas of basic and applied research[16]. Nano-technologies and nano-materials are connected there to energy efficient technologies and radio-electronic technologies and systems.

Today, the staff of the Lab that is the INP BSU core team completely dealing with NEM is comprised of 20 employees, including 15 researchers and 5 technicians. 25% of employees are women. Half of the staff is under 35. In 2012, 50% of researchers and technicians spent at least 1 month doing research abroad.

In our understanding, this nucleus has got prerequisites for further successful developing in terms of competencies and size and reaching its vision.



[15] Approved by the Decree of the President of Belarus №378 of 22 July 2010

[16] Approved by the Regulation of the Council of Ministers of № 585 of 19 April 2010.

2. STRATEGIC VISION

2.1 Vision & mission

FACING THE FUTURE: By 2025, the INP BSU will become a center of excellence in Nanoelectromagnetics benefiting from its leading position in Belarus nanotechnology community and complete integration in the European Research Area. In alliance with the Belarusian State University, it will be an important center of nanoscience education and innovations in Belarus and Eastern Europe.

It will be also well recognized in the areas of nanoscale thermodynamics; physics of ionizing radiation interaction with the nanosized objects and spin physics of nanostructures.

The INP BSU **realizes its mission in**

1) **carrying out the highest quality research in NEM and connected areas to support the Belarus nanotechnological research endeavor and further increase partnerships with world class research centers and industrial companies in the country and outside it to apply the research results in such social challenges as**
   - ***Higher and post-graduate education,***
   - ***Secure, clean and efficient energy,***
   - ***Health, demographic change and wellbeing;***

2) **maintaining the Institute's scientific vigour by continuous renewal and updating of its research interests and skills and providing wide opportunities to its staff for career development along their professional life,**

3) **training and developing high quality young researchers.**

The ambitious vision and mission stated above will be achieved in the case of availability of the following **main interdependent pre-conditions**, each equally critical for the success of the INP BSU:

1) **an updated research program in which the modern trends in NEM and its applications are reflected, as well as research–industry interactions and commercialization aspects,**
2) **sufficient and stable financing,**
3) **enhanced international partnerships which, above highly performing research players, include industry and innovation intermediaries,**
4) **highly qualified and motivated core team working in close contact with the host University,**
5) **appropriate research infrastructure,**

given that the overall circumstances for developing of the nanoindustry in Belarus (setting up companies engaged in production of nanotechnological products, involving Belarusian nano-producers in global nanotechnology chains, developing a specialized infrastructure for nano-industry, etc) and in the world are positive.

In fact, these pre-conditions are the goals the INP BSU has to succeed for achieving its vision. To analyze challenges and barriers on this way, a SWOT analysis has been undertaken.

2.2 SWOT analysis and its recommendations

A SWOT analysis of the INP BSU activities in NEM and nanoscience and nanotechnology as a whole was implemented in 2012 as part of the benchmarking exercise for several institutes in Armenia, Belarus, Kazakhstan and Bulgaria working in nanotechnology. It was carried out by the group of international independent experts from Austria and UK with involvement of the INP BSU team within the framework of the FP7 IncoNet EECA project ("S&T Cooperation Network for Eastern European and Central Asian Countries) supported by the European Commission.

The SWOT analysis has covered such issues as

- mission statement,
- strategy and planning,
- staff and staff management,
- buildings and facilities,
- communication (publications, book chapters, reviews, conference organization and participation, website, mass media, links with industry),
- health and safety,
- intellectual property,
- funding and funding opportunities.

The results of the SWOT analysis are summarized in the Table 1.

Table 1 - SWOT analysis of the INP BSU activities in nanoscience and nanotechnology, including NEM.

Strengths • Team spirit and cohesion • Theoretical background and knowledge • Number of students and creative potential • International reputation • Very good publication record • Leadership • Pro-active internationalization and collaboration • Flexibility of organization and incentives • Exploitable IP • Low operational costs • Potential to develop from theory to experimental science • High average level in physics of young generation • Position between semi-conductor and electrical engineering community • Interdisciplinary position, cooperation with chemists and mathematics • Close cooperation with University • Exploitation of FP7	**Weaknesses** • Access to materials • Know-how in materials • Limited equipment, lack of characterization tools • Commercialization of R&D results – lack of implementation • Lack of need in industry, lack of possibilities to implement • Understanding of the market • Understanding of socio-economic needs • Understanding of commercial value of knowledge generated • Strategy development • Online presence • Performance measurement • Business development Know-how
Opportunities • Nano-technology market growth(alignment needed) • Recent Government initiatives on developing a nanoindustry in Belarus • Recognition as a center of excellence • Low cost outsourcing • Increased understanding through policy stakeholders and potential increase of funding	**Threats** • Lack of stable basic funding • Low basic funding • Lack of industry • Lack of infrastructure funding • Change in funding policy towards decreasing budget funding for R&D • Funding opportunities decreasing internationally

• Cooperation interest from abroad • Horizon 2020, instruments of European neighborhood policy • Participation in national R&D programs of Russia and Kazakhstan within Eurasian Union • Improvement of national innovation system • Transfer of knowledge to electrical engineering	• Adverse exchange rates • Nanotechnology going out of fashion • Bureaucratic burdens/ diversion of resources • Political instability in the region • Brain drain- young generation leaving • Economic outlook (recession) • Decrease of level of higher education

The main recommendations of the independent evaluators resulted from the SWOT analysis have included the following:

- ✓ To urgently increase state budget funding in order to support the development of the INP BSU and raise the basic salaries of scientists to reduce the strong dependence on external funds;
- ✓ To create a group on material growth that will provide nano-materials and increase the value chain in the Laboratory of electrodynamics of nonhomogeneous media. Also, it's recommended to develop own material basis to enable further developments in new topics and be a stronger partner in international collaborations;
- ✓ To further develop the INP BSU's experimental basis in material characterization (especially in the microwave -and THz range);
- ✓ To assess the scientific activities for their potential benefits in the Belarusian economy;
- ✓ To introduce training records to ensure that people continue to grow in terms of their capabilities and experience;
- ✓ To provide some basic training for researchers in commerce, marketing, negotiation, etc.;
- ✓ To formalize the process of securing promotion and the publicizing, develop criteria which have to be met in a way that each researcher realizes a potential career path in front of him/her;
- ✓ To establish a technology transfer office in the INP BSU to work at the interface between science and industry; to think about new approaches for engaging with industry.

The SWOT analysis and recommendations have been taken into account while formulating the INP BSU goals and objectives and particularly in developing a Research Program which component areas have been presented below.

2.3 Research Program Component Areas

No.	PCA Title	Description
1.	**Nano-cavities, -antennas, and -transmission lines, EM compatibility at the nanoscale**	The development of fundamentals of the electromagnetic compatibility (EMC) theory as applied to circuits with nano-sized components and demonstration of peculiar properties of nanocircuits irreducible to that of classical circuits and their impact on the circuit components performance. The EMC on the nano scale is expected to be complicated and topical problem in the nearest future. Even if today is too early to speak about development and production of multi-component and multifunctional nanoelectronic systems (today we rather deal with the formation of the component basis of nanoelectronics), such systems will appear very soon rising the nanoEMC problem to full extent. What we can conclude right now is that the EMC basic principles as applied to nanoelectronics must be drastically modified as compared

to their macroscopic analogues. Most critical challenges: (i) 3D control of circuit elements and interconnect features; (ii) Mitigate impact of size effect in interconnect structures; (iii) Pattering at nano dimensions; (iv) Integration of new process and structures into existing devices; (v) Identify solutions which address 3D structures and other packaging issues at nano level; (vi) quantum antenna; (vii) thermal noise on nanoscale.

2. Nanoscale devices. Theory and experiment

Recently, the idea to use the kinetic energy of CNT-guided electron beam for stimulated emission of IR and terahertz electromagnetic waves has been proposed. The main idea exploits a certain analogy between CNTs and macroscopic electron devices utilizing the wave slowing down in waveguides. However, practical realisation of the effect requires further investigation. Indeed, the typical group velocity of p-electrons in single-walled CNT turns out to be considerably smaller than the phase velocity of the retarded electromagnetic wave whereas these velocities must be the same to provide the effective Cherenkov generation. Therefore, the methods and systems providing additional slowing down of electromagnetic wave are required. Detail analysis of recently proposed and new mechanisms of the increase of the electromagnetic wave slowing down are planned to be considered. Experimental observation of this predicted effect of generation from CNT, CNT arrays and graphene-like structures will be provided.

3. NEM within the framework of biomedical and energy applications

The effective medium theory will be applied to calculate effective conductivity of diluted disordered composites with single-wall carbon nanotubes as inclusions. Two concurrent finite-size effects are taken into account: (i) the quantum interband transition through a narrow gap originated from the CNT surface curvature of a finite-radius CNT and (ii) axial plasmonic effect due to finite length of CNT. Since both effects manifest themselves primary in the terahertz range, we intend to prove that simultaneous consideration of both effects is allows correct interpretation of the frequency and temperature dependences of the effective conductivity, observed experimentally in the terahertz frequency regime. A rigorous quantum mechanical consideration to the conductivity problem in a single-wall CNT will be given and used for the evaluation of the effective conductivity of CN-based composites. The role of both mechanisms of the absorption will be studied and compared with available experimental results. It will be a theoretical basis for investigation of different nanocarbon applications, like e.g. for far-infrared and terahertz range thermolysis of cancer cells, for rectenas to be used in solar cells applications, etc.

4.	**Electromagnetic nanomaterials**	The aim is the development of the perspective functional polymer hybridcompostes containing modern forms of carbon and other nano-sized fillers as well as corresponding manufacturing, processing and recycling technologies in such way solving many important problems in chemistry/physics (synthesis and characterization of modern carbon forms, their compatibility with polymer matrix and it's improvement, new generation of nanomaterials with controlled electromagnetic properties), ecology (accumulation of the synthetic materials in the Earth ecosystem, pollution of the work environment with ultradisperse particles) and economics (effective manufacturing and processing technologies).
5.	**QDs, hybrid and ordered/regular structures in NEM: synthesis, characterization, EM applications**	The basic idea is to utilize the unique electromagnetic response properties of nanostructures such as quantum dots and nanotubes, for the development of novel artificial electromagnetic materials with controllable properties providing effective processing of the optical and terahertz radiation. Strongly slowed down plasmon-polariton modes in CNTs as well as observation of specific electronic properties of nano-carbon composites (hoping conductivity, high concentration of localized electrons at defects) may give rise to tunable quasi-resonant behavior in IR and THz ranges. Detection of the high-level transmission losses in the microwave range suggest that, if properly designed, such composite materials will provide ultra-wide band electromagnetic absorption. Quasi-ordering in such materials inspired by what we evidenced in biologic photonic crystals may offer a new tool for the tenability and controllability of the materials electromagnetic properties. Depending on the input parameters, metamaterials with enhanced dielectric properties in infrared and terahertz ranges, reduced electromagnetic fluctuations, enhanced limiting properties, etc. are planned to be developed. Combined excitonic composites with QDs as emitters and nanotubes as antennas constitute a separate important topic in this task.
6.	**Nanostructured materials for ionizing radiation protection with advanced consumer properties**	Composite materials comprising boron-doped carbon nanotubes and boron-nitide nanotubes are planned to be jointly designed and tested on the neutron facilities in National Institute of Nuclear Physics in Frascatti and in Joint Institute for Nuclear Research, Dubna, Russia. A purposeful work is undertaken to introduce this topic into research programs on national and international level and staff visits' support would be very helpful. We expect reaching advanced consumer properties of materials, especially for avionic protection and other space applications.

7. Material fabrication R&D aimed at enabling scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, including nanocarbon, polymer and non-organic matrix based composites materials. Includes R&D and integration of ultra-miniaturized top-down processes and increasingly complex bottom-up or self-assembly processes.

8 Education Education-related activities such as development of materials (lecture courses, handbooks, laboratories practicum, seminars, etc) for undergraduate programs, master and PhD students, and technical training. Research directed at identifying and quantifying the broad implications of nanotechnology as a whole and nanoelectromagnetics in particular for society, including social, economic, workforce, educational, ethical, and legal implications.

2.4 Goals and objectives

In order to implement its mission and make the vision a reality, and also with the reference to the research program above, the INP BSU has defined the following goals and objectives. Due to the rapidly increasing internationalization of research and innovation around the world, international cooperation may and will contribute significantly in reaching each of them.

GOAL 1: To provide R&D support for breakthrough projects in NEM, as well as bridging the gap between research and innovation within the main priorities:

- **nanoEMC,**
- **CNT and graphene based nanodevices,**
- **solar energy, energy saving,**
- **new and smart materials,**
- **nanostructures biomedical applications,**
- **radiation protective materials and technologies,**
- **nanoscience and nanotechnology education,**
- **innovations in the field of nanotechnologies.**

Objective 1.1 To provide the R&D background for nanoEMC

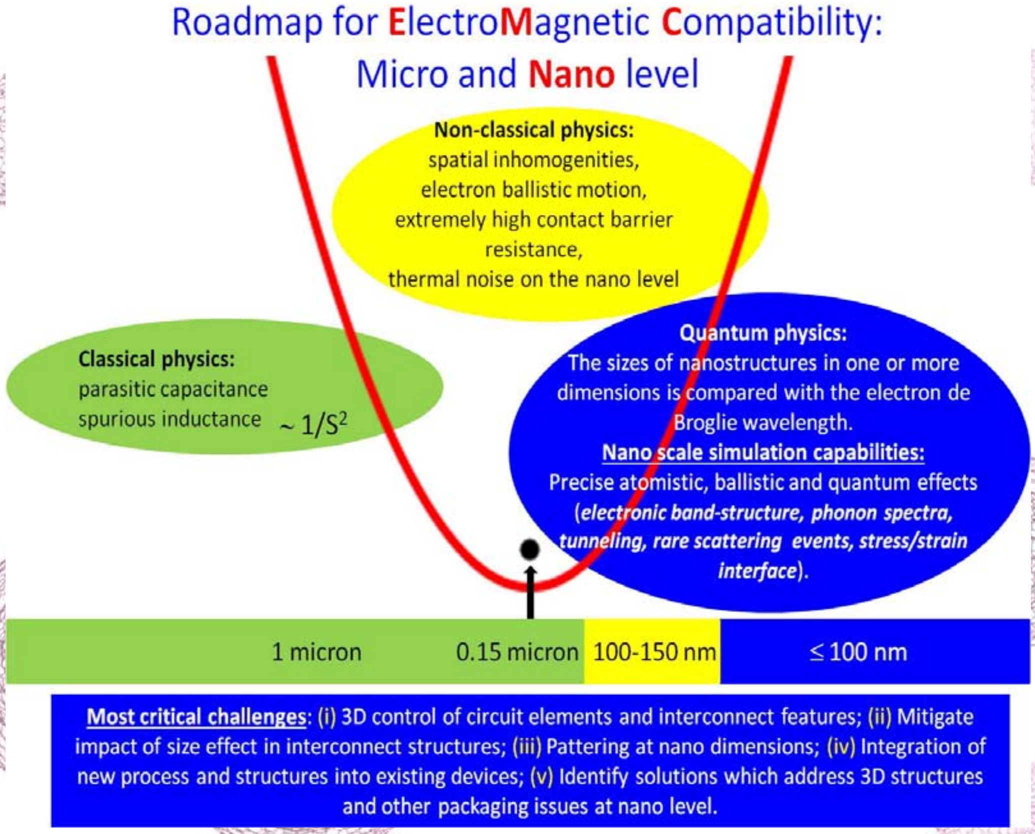
The development of fundamentals of the EMC theory as applied to circuits with nano-sized components and demonstration of peculiar properties of nanocircuits irreducible to that of classical circuits and their impact on the circuit components performance. The EMC on the nano scale is expected to be complicated and topical problem in the nearest future. Even if today is too early to speak about development and production of multi-component and multifunctional nanoelectronic systems (today we rather deal with the formation of the component basis of nanoelectronics), such systems will appear very soon rising the nanoEMC problem to full extent. What we can conclude right now is that the EMC basic principles as applied to nanoelectronics must be drastically modified as compared to their macroscopic analogues.

Objective 1.2 To transfer the knowledge in nanoEMC, nanoscale devices, etc to electrical engineering

This particular objective is closely related to the previous one because the traditional EMC activity mostly belongs to electrical engineering. What is important that for some ranges of electrical circuit parameters, already "nano" sized formally, one still has the classical physics dependences (when parasitic parameters of the circuit, like parasitic capacitance and spurious inductance are inversly proportional to the circuit (circuit elements) square, or even square square). At the same time, starting from some length parameters, depending on the frequency range, non-classical physics becomes important (usually it happens after 0.15 microns for optical frequencies). The phenomena of non-classical physics that are important to be taken into account for nanoEMC are: spatial inhomogenities, electron ballistic motion, extremely high contact barrier resistance, thermal noise on the nano level. Finally, after some lengths (literature gives 16 nm in at least one direction), quantum physics plays a significant role. In fact, quantum physics effects should be taken into account when the sizes of nanostructures in one or more dimensions are compared with the electron de Broglie wavelength. Nano scale simulation capabilities are Precise atomistic, ballistic and quantum effects (electronic band-structure, phonon spectra, tunneling, rare scattering events, stress/strain interface).

Thus, the most critical challenges are as follows (see the road map below):

(i) 3D control of circuit elements and interconnect features;
(ii) mitigating the impact of size effect in interconnect structures;
(iii) pattering at nano dimensions;
(iv) integrating new process and structures into existing devices;
(v) identifying solutions which address 3D structures and other packaging issues at nano level;
(vi) quantum antenna;
(vii) thermal noise on nanoscale.



Objective 1.3 To bridge a gap between applied NEM in the field of electromagnetic materials and the industry (small and medium enterprises)

A complex of recommendations on the composition and geometrical parameters of nanocarbon inclusions, on the choice of polymer matrix and on the technology for EM coating on a basis on nanocarbons has been formulated by INP BSU team. At the same time, before to go to the next step, to commercialize R&D results, to produce smart electromagnetic materials using existing facilities in Belarus, EECA countries and Europe, it is necessary to provide a comprehensive research of other customer properties of effective EM sense composites - mechanical and thermal. For that, cooperation with Belarus and international research community in polymer science, mechanics and thermal research has to be reinforced.

Objective 1.4 To transfer the fundamental NEM knowledge, including know-how in applications, to commercialize R&D results

The problem of intellectual property should be solved in the new level. The tendency to apply for national patents because they are cheaper than international ones has to be reviewed and a more strategic approach taken to secure international patents. Applications for international patents could be funded through a competitive process resulting in providing support only for the most potentially valuable patents. An annual review of the portfolio could be used to benchmark patents against new developments in competing technologies or moves in the markets.

In wide sense the commercial value of knowledge should be generated.

Objective 1.5 To provide a material basis for NEM

The first step in this activity is to reproduce known technologies of nanocarbon production. It will be also necessary to organize powerful characterization unit including SEM, TEM, optical microscopy analysis. In that sense, it would be very fruitful if the INP BSU as a part of BSU or separately will enter into some significant characterization center, e.g, nanocenter in Rome university la Sapienza, which provide for the annual fees all possible characterization of nanomaterial.

The next step will be to organize fabrication of nanocarbon in the values necessary for implementation of a number of innovative projects. And finally the INP BSU aims to fabricate polymer composites filled with different forms of nanoparticles and nonorganic composite nanomaterials for different applied tasks, including nuclear physics tasks.

Objective 1.6 To organize on the basis of the Laboratory of electrodynamics of nonhomogeneous media a Nanotechnology Research Center

A Nanotechnology Research Center will be established to consolidate efforts of the BSU units aimed at research and development and true cross-disciplinary education in nanotechnology and nanomaterials. To our vision, with the time, it will develop in a center of excellence of European level. To that, a new center of the collective use of research equipment to be set up in the BSU by 2015 in accordance with the Concept for setting up and developing of a nanoindustry in Belarus till 2020 will contribute.

There is good practice in the BSU and other Belarusian universities to accumulate expensive equipment in the centers of collective use. We suppose that INP BSU could organize such a center of collective use of equipment, like SEM, TEM, MW and THz spectroscopy, etc.

Objective 1.7 To ensure a sustainable transfer of knowledge in education

Participation of the INP BSU staff in education process in BSU**,** other Belarus and foreign universities, including developing and disseminating educational and training materials for young researchers, master and PhD students in the field of NEM will be highly promoted. The Nanotechnology Research Center will host multidisciplinary trainings in NEM by implementing such programs as, e.g., “Composite Nanomaterials”, “Functional Nanomaterials“, “Nano Devices”, “Nanobiotechnology”, etc.

Objective 1.8 To set up a Technology Transfer Office for fostering commercialization of R&D results

A Technology Transfer Office will be set up in the INP BSU to work at the interface between science and industry.

GOAL 2: To ensure sufficient and stable financing for the INP BSU research and innovation activities

In Belarus, the financial crisis has resulted in decreasing the budget support for science and innovation. As a consequence, the requirement of the Government towards the state owned research organizations on combining the budget and non-budget sources of funding has been tightened to 30:70, proving that up to half of the non-budget part has to be drawn from abroad.

In some years, the INP BSU managed to ensure equal shares of budget and non-budget funding, moreover, the non-budget part was entirely formed by the foreign sources. However, due to the highly competitive character of the international and foreign programs, the Institute takes part in, the stability of the foreign funds is an issue. Another one is the “0” share of the national non-budget funding.

Last but not least, the overall raise of the level of funding is vital: in 2010, the EU spent 122 thous. USD[17] per researcher while Belarus performed 5.5 times worse.

Objective 2.1 To get in and, whether possible, to coordinate national R&D programs within Research Program Component Areas and corresponding nanotechnology initiatives across multiple research institutions in Belarus and close neighbors (Russia, EECA)

It is necessary to support existing and develop new partnerships for identifying particular research tasks within the main ideas of nanoelectromagnetics in order to start up new R&D programs on the national level, bi- (Russia-Belarus) and multilateral level (EurAsEc, CIS).

Objective 2.2 To get into the most prestigious international programs which support nanoscience research and development of nanotechnologies

Horizon 2020, the Framework Programme for Research and Innovation[18] of the European Union for 2014-2020 (or H2020) presents variable opportunities to develop R&D and innovation activities in nanotechnologies in cooperation with the EU and the other world partners. Unlike the other international programs which, as a rule, support international mobility of researchers

[17] OECD.

[18] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Brussels, 30.11.2011, COM(2011) 808 final.

and provide single-investigator grants, the Horizon 2020 offers a balanced mix of funding instruments ranging from single-investigator grants for early stage and experienced researchers to grants for research centers, companies, including SMEs and user facilities, each of which play a unique and vital role in the discovery and innovation process.

The H2020 will be fully open to participation of Belarus teams. Their activities within a project will be funded on the same legal basis as the ones of the EU organizations.

The previous experience of the INP BSU in the 7th Framework Programme for RTD of the EU, high research performance, numerous international partnerships and growing visibility of the team all together give good chances for getting in the core activities of the H2020 in the area of nanosciences and nanotechnologies concentrated in the "**Industrial Leadership" priority**. This part of the Program aims at making Europe a leader in enabling and industrial technologies, with dedicated support for ICT, nanotechnologies, advanced materials, biotechnology, etc, while also providing support for cross-cutting actions to capture the accumulated benefits from combining several key enabling technologies.

Other potential niches for the INP BSU could be found in

- the **"Societal Challenges" priority** that brings together resources and knowledge across different fields, technologies and disciplines to cover activities from research to market in several priority areas, e.g. secure, clean and efficient energy, health, etc.
- the **"Excellent Science" priority,** where *European Research Council's* scheme on providing support for the talented and creative individuals and their teams to carry out frontier research.

Objective 2.3 To enlarge networks of partners on the principle of complementarity with a special focus on acquiring partners from industry

The INP BSU has gained a profound partner network of over 20 highly skilled research teams from many countries of the EU, Russia, Eastern Europe and the US. Within the previous decade, the members of the network in various combinations successfully raised funds from International Science and Technology Center, NATO, FP7, COST, World Federation of Scientists, German Federal Ministry for Education and Science, Russian Foundation for Basic Research, bi-lateral programs of science and technology cooperation with partner countries and funds supported from the Belarusian side by the Republican Foundation for Fundamental Research and State Committee for Science and Technology and other organizations providing funds for international collaboration. However, most of the financial instruments used by the INP BSU in the past on international, but also on national level were focused on supporting basic and applied research, while innovation activities (IPR, technology transfer, networking, partner search, marketing research, promotion, etc), though declared as urgent were not and still are not funded.

As soon as H2020 becomes more and more oriented towards innovation, it turns out to be clear that partnership with end-users is a must for a success of a research team. The call from the national authorities expressed in the Concept for Setting up and Developing of Nanoindustry in the Republic of Belarus[19] is actually similar.

One of the ways to widen contacts with industrial partners is participation, as far as it's possible for the non-EU partners, in the European Technology Platforms (ETPs). In parallel with their main mission - developing strategies and provide a coherent business-focused analysis of

[19] Resolution of the Council of Ministers of the Republic of Belarus of 18 February 2013 №113.

research and innovation bottlenecks and opportunities related to societal challenges and industrial leadership actions – ETPs mobilize industry and other stakeholders to work in partnership and deliver on agreed priorities, and also share information and enable knowledge transfer to a wide range of stakeholders[20]. As a first step, possibilities to join such ETPs, as Photonics21[21], EuMAT (ETP for Advanced Engineering Materials and Technologies[22]) and ETP on Nanomedicine[23] will be explored. The same approach should be used for cooperation with appropriate technology platforms set up in Russia.

Another tactic is to partly shift dissemination and promotion activities from purely scientific conferences towards participation in brokerage-type events, especially those with large representation of industry and/or involving the European Enterprise Network as co-organizer.

Objective 2.4 To explore the emerging opportunities, diversify instruments and geography of collaboration

The international collaboration has been evolving with time. Some of the new trends may influence activities of individual countries and even individual organizations. Thus, the decision of the European Commission on non-eligibility of partners from BRICs for automatic funding within H2020 may decrease the interest of researchers from these countries for participation in the program. As a result, several INP BSU partnerships with Russian research centers need to search for a new cooperation platform: the emerging opportunities here which should be carefully investigated include

- participation of Belarusian organizations in the Federal targeted programs of Russia (and vice versa)
- cooperation of the INP BSU with Skolkovo Fund, Russia.

Obviously, traditionally used instruments, such as joint calls of the Belarusian Republican Foundation for Fundamental Research and Russian Foundation for Basic Research should not be forgotten.

For various reasons, in Belarus, instruments for supporting international mobility and networking, as well as schemes for funding typical innovation activities are missing. Ideally, the international cooperation instruments should compensate the lack of national instruments and top-up national funding. A permanent monitoring of the new opportunities in this area is worth to pay attention for.

Besides the research projects and mobility schemes, support actions of ERA-WIDE and R2I type (FP7) will be of great interest for the INP BSU in future as they support activities other than research and, in particular, innovation, for which it’s hardly possible to get national funding but which are extremely important for success of the research. Since innovation is included in the priorities of the EU neighborhood policy priorities for 2014-2020, networking and capacity building projects for the benefit of Eastern Europe nanoindustry development and cooperation with the EU in this area will be (most probably) within the scope of the ENP instruments.

[20] COMMISSION STAFF WORKING DOCUMENT STRATEGY FOR EUROPEAN TECHNOLOGY PLATFORMS: ETP 2020, Brussels, 12.7.2013, SWD(2013) 272 final
[21] http://www.photonics21.org
[22] http://www.eumat.eu
[23] http://www.etp-nanomedicine.eu

With a current size of the INP BSU team, the number of its international collaborations seems to be sufficient. However, in case of enlargement the geography of cooperation could be expanded, e.g. in Belarus an infrastructure for supporting S&T partnership with several Chinese provinces is being developed that is a good pre-condition to kick-start.

Objective 2.5 To provide sustained online visibility of the INP BSU and NEM, as well as outreach activities

The NEM web-site, which is already exists (nano.bsu.by) will be restructured in order to provide well availability to NEM knowledge, the most important highlights of current research activities, etc and at the same time could be easily understood by potential end-users.

It is often the case that the general public, companies, governments and policy makers are not fully aware of the value of the science base within their countries and the positive impact that it has, or could have, on the economy. Communication is critical to ensuring that exciting new scientific findings are disseminated to a much wider audience than the scientific community. The INP BSU is becoming active in this area producing, brochures, newspaper articles, TV presentations and of course having a presence on the web through websites and social media. Modern design and targeted messages of web-site are key aspects of successful communication, as well as the use of pictures and illustrations to accompany texts which the INP BSU needs to recognize. Newsletters, which are targeted especially to industry should be used more extensively and should contain clear statements of 'what we can do to help your business'.

GOAL 3 To sustain a highly qualified and motivated core team working in close contact with the host University

Fundamental to the continued successful development of the INP BSU is the development of the resources necessary to support this effort. A substantial investment to which international cooperation is able to contribute, as it was mentioned above, strengthened by and dependent on personal research career development and international mobility, is needed to develop talent and resources required to achieve the INP BSU goals.

Objective 3.1 To ensure each member of the INP BSU team benefits from participation in international projects in terms of international mobility, acquiring new skills and best practices, exchanging results, publicizing and disseminating

The EU and national research policy in the EU member-states and many other countries of the world propose many instruments to support researchers' mobility addressing PhDs, post-docs and experienced researchers. In some countries they are provided by governments or appropriate ministries and agencies, while in the others this function is performed by specialized organizations. Possessing the updated information about the availability of such grants for using them in full is one of the tasks for the INP BSU management:

Unlike the national schemes which usually fund short stays of individual researchers, the Marie Skłodowska-Curie Actions within the H2020 are open both to researchers and organizations (universities, research institutions, research infrastructures, businesses, and other socio-economic actors) from all countries, including third countries). They are open to all domains of research and innovation, from basic research up to market take-up and innovation services. Research and innovation fields as well as sectors are chosen freely by the applicants in a fully bottom-up manner.

The novelty here which should be carefully explored based on the previous INP BSU's experience in IRSES (within Marie Curie Actions in FP7) is *Research and Innovation Staff Exchange (RISE)* action. The RISE will promote international and inter-sector collaboration through research and innovation staff exchanges, and sharing of knowledge and ideas from research to market (and vice-versa) for the advancement of science and development of innovation. It will encompass an intersectoral or an international dimension, as well as combinations of both. It is designed to involve institutions from the academic sector and non-academic sectors (in particular SMEs), based in Europe (Member States and Associated Countries) and outside Europe (third countries). The action fosters a culture of innovation that welcomes and rewards creativity and entrepreneurship and helps to turn creative ideas into innovative products, services or processes.

Objective 3.2 Jointly with the host university to get into specialised international projects on professional training of young researchers in nanosciences

Cooperation with the host university, Belarusian State University, the leading one in Belarus is of utmost importance for the INP BSU. It could be strengthened for the benefit of the both sides by undertakin joint international actions, especially those connecting to post-graduate training of young researchers. The existing partnerships of the INP BSU with the universities and leading research centers of the EU should be re-considered in terms of this new possible area of join activities.

The Innovative Training Networks (ITNs) are part of the Marie Skłodowska-Curie Actions within the H2020. The ITN raises excellence and structures the initial and doctoral training of early-stage researchers, extending the traditional academic research training setting, equipping researchers with the right combination of research-related and transferable competences and providing enhanced career perspectives in both the academic and non-academic sectors through international, interdisciplinary and inter-sector mobility combined with the innovation-oriented mindset. Aiming to train a new generation of creative, entrepreneurial and innovative researchers, able to face current and future challenges and to convert knowledge and ideas into products and services for economic and social benefit, they are worth to put effort in.

The action will be implemented by supporting competitively selected joint research training and/or doctoral programmes, implemented by partnerships of universities, research institutions, research infrastructures, businesses, SMEs, and other socio-economic actors from different countries across Europe and beyond.

Objective 3.3 To introduce Innovation trainings for the INP BSU staff

the idea is to ensure that people continue to grow in terms of their capabilities and experience; to provide some basic training for researchers, in commerce, marketing, negotiation etc. to provide a team member opportunities to be a member of professional societies

Objective 3.4 To set up a national contact point for cooperation with the EU research and innovation programs in nanosciences and nanotechnologies

Setting up an contact point for Belarus cooperation with the EU in nanosciences and nanotechnologies in the leading national university and, more specifically, in the INP BSU which has the rich backgrownd in international collaboration in the EU and its member states funded programs seems to be a natural step forward in expanding the scope of the INP BSU activities.

It will increase visibility of the team within the national nano-research community and give an opportunity to provide the “first hand” information to researchers of the hosts, INP BSU and BSU. Also, it will increase the INP BSU visibility and cooperation opportunities in the EU via the network of H2020 national contact points. Bridging the national and EU nano-communities and possesing the “first hand” information on EU initiatives in the area of nanosciences and nanotechnologies will make the INP BSU an important actor in developing national nanoindustry in Belarus.

GOAL 4: To improve research infrastructure

Objective 4.1 To support, lobby and ensure the effective exploitation of a center of collective us of research equipment in the BSU

Following the Concept for setting up and developing of a nanoindustry in Belarus till 2020 a center of collective us of research equipment will be set up in the BSU by 2015. The INP BSU should take all possible benefits of that.

Objective 4.2 To benefit from an access to research infrastructure provided by international cooperation programs

Although it’s hard to expect direct foreign investments in Belarus national research infrastructure, the international cooperation makes some input in solving this problem, in particular by covering costs of research equipment purchased by Belarusian partners in large international programs (e.g. FP7, ISTC).

The other opportunity which it provides is an access for Belarusian scientists to research infrastructure in partner organizations in the EU and other countries within the framework of joint projects, staff exchanges, research visits, etc. To wider exploit this possibility, the international mobility should be increased.

A specialized section of the H2020 Excellent Science priority - *Research infrastructures* - ensures Europe has world-class accessible to all researchers in Europe and beyond. Neighboring countries, including Belarus can benefit from this in cooperation with EU researchers.

In order to have success in the strategic plan implementation the following additional objectives are supposed to be critical:

- introduction of effective systems of strategic and corporate management and planning
- implementation of effective personnel policies, including search, recruitment and training of personnel
- optimization and diversification of activities and assets of the Institute.

3. ACTION PLAN

In correspondence with the goals and objectives formulated above the following tentative action plan has been proposed.

GOAL 1: To provide R&D support for breakthrough projects in NEM, as well as bridging the gap between research and innovation within the main priorities:

- **nanoEMC,**
- **CNT and graphene based nanodevices,**
- **solar energy, energy saving,**
- **new and smart materials,**
- **nanostructures biomedical applications,**
- **radiation protective materials and technologies,**
- **nanoscience and nanotechnology education,**
- **innovations in the field of nanotechnologies**

Objectives	Tasks/ Activities	Timeline	Measure/ Documents	Resources needed
Objective 1.1 To provide the R&D background for nanoEMC	To identify partners for joint activities, in Belarus, eastern (China, S.Korea, etc) and western countries; To organize a series of seminars and workshops on the problem of EMC at the nanolevel; To modify EMC basic principles as compared to their macroscopic analogues.	2014-2015	Cooperation agreements; joint research projects, seminars/ workshops; a handbook on nanoEMC	Grants of the State Committee on Science and Technology of Belarus for organizing seminars with China and Korea institutions; NATO ARW programme, COST actions, ongoing existing FP7 IRSES projects and future H2020 programme, BRFFR–CNRS grants for organizing joint Belarusian-French scientific workshops;
Objective 1.2 To transfer the knowledge in nanoEMC, nanoscale devices, etc to electrical engineering	To organize a series of seminars/ workshops on the problem of EMC at the nanolevel; To apply for an innovation project with SME end-users from Belarus and other countries.	2015-2017	Innovative projects, workshops	HR, funding from the innovation foundations and special H2020 calls
Objective 1.3 To bridge a gap between applied NEM in the field of electromagnetic materials and the industry (small and medium enterprises)	To apply for innovation projects; To organize a spin-off company; To collaborate with the centers of technology transfer in order to find stakeholders for this EM materials activity	2016-2018	Innovative projects, spin-off company	Policy in the innovation sphere in Belarus
Objective 1.4 To transfer the fundamental NEM knowledge, including know-	To find recourses for producing software having significant commercial value in the field of nanoEMC; To organize a management unit	2017-2018	Commercial software in the field of nanoEMC, spin-off company	Contract with EMC company

how in applications, to commercialize R&D results	for intellectual properties estimation or to develop collaboration with the excising ones, to finalize innovative projects mentioned in the objectives 2-3 with the commercially interesting results; To set up a spin-off company			
Objective 1.5 To provide a material basis for NEM	To reproduce the known nanocarbon production technologies; To organize the characterization of nanomaterials, both on the basis of own INP BSU characterization unit and using international not free of charge possibilities; To fabricate polymer and nonorganic composites material in significant quantities, which are enough for formulated applied and innovative tasks.	2015-2020	Nanomaterials, data bases on their characterization	HR, equipment, finances for paying centers fees
Objective 1.6 To organize on the basis of the Laboratory of electrodynamics of nonhomogeneous media a Nanotechnology Research Center	To develop a concept of a Nanotechnology Research Center and its financial support and present it at the level of BSU and Ministry of Education of RB; To approve at the level of BSU and Ministry of Education of RB the statute of this center, to provide strong collaboration with technology transfer center; To organize a center of common use of expensive and unique equipment as a basis for nanotechnology research center well-being.	2014	Nanotechnology Research Center, Technology Transfer office, center of collective use of expensive and unique equipment	HR, special funding from Ministry of Education of RB
Objective 1.7 To ensure a sustainable transfer of knowledge in education	On the basis of Nanotechnology Research Center to train students according to novel programs based on lectures and practical classes of the Faculties of Physics, Chemistry, and partly Biology; To promote joining the professional societies for the staff.	2017-2025	Educational programs: “Comp osite Nanomaterials” “Functional Nanomaterials “Nano devices” "Nano biotechnology”. High level of expertise, membership in SPIE, IEEE, EMC, EMRS, etc	HR, funding from the Ministry of Education of RB, changes in the funding policies in Belarus, which is necessary to cover the professional societies fees
Objective 1.8 To set up a Technology Transfer Office for fostering commercialization of R&D results	A Technology Transfer Office will be set up in the INP BSU to work at the interface between science and industry.	2017-2025	Technology Transfer Office	HR, funding from the Ministry of Education of RB, innovative projects

GOAL 2: To ensure sufficient and stable financing for the INP BSU research and innovation activities

Objectives	Tasks/ Activities	Timeline	Measure/ Documents	Resources needed
Objective 2.1 To get in and, whether possible, to coordinate national R&D programs within Research Program Component Areas and corresponding nanotechnology initiatives across multiple research institutions in Belarus and close neighbors (Russia, EECA)	On the basis of existing state R&D programs to propose new ones with focus on applied NEM and to coordinate it; To propose a number of innovative initiatives covering global social priorities, like Secure, clean and efficient energy; Health, demographic change and wellbeing, and to coordinate it.	2014-2020	Programs, initiatives	HR
Objective 2.2 To get into the most prestigious international programs which support nanoscience research and development of nanotechnologies	To check the published calls of H2020 for determination of the most attractive subject to prepare the projects within PCA; To support existing and to develop new collaborations in the research sphere and with possible stakeholders; To prepare and widely disseminate R&D portfolio and newsletters concerning the team highlight activities in the field of NEM and relative fields; To take part in international events focused on finding partners for submitting the joint research projects.	2014-2023	Projects submitted to different EU and other international programs	HR, stable local funding
Objective 2.3 To enlarge networks of partners on the principle of complementarity with a special focus on acquiring partners from industry	To widely disseminate R&D activities within scientific publications, conference presentation and also within different public informative recourses (TV, newspapers, etc); To support the web-site; to collaborate with technology transfer centers	2014-2025	Papers, presentations, articles, etc	HR
Objective 2.4 To explore the emerging opportunities, diversify instruments and geography of collaboration	To advertize the perspective results having clear commercial value to hi-tech eastern companies in South Korea, China, Japan, etc; To prepare and support international patents with the help of such companies	2014-2025	International patent, international research projects	Cooperation agreements between INP BSU and hi-tech companies, resources for supporting the patents
Objective 2.5 To provide sustained online visibility of the INP BSU and NEM, as well as outreach activities	To support nano.bsu.by site; To update this site in order to make it more understandable for potential stakeholders and end-users	2017-2018	Web-site	HR

GOAL 3 To sustain a highly qualified and motivated core team working in close contact with the host University				
Objectives	Tasks/ Activities	Timeline	Measure/ Documents	Resources needed
Objective 3.1 To ensure each member of the INP BSU team benefits from participation in international projects in terms of international mobility, acquiring new skills and best practices, exchanging results, publicizing and disseminating	To submit and succeed in a number of exchange programs; To submit and succeed in a number of projects for carrier development; To organize training in the field of material growth, polymer production, etc for the team members; To develop a transparent scheme for estimation of researcher results	2014-2020	Projects, estimation scheme, training courses	HR
Objective 3.2 Jointly with the host university to get into specialised international projects on professional training of young researchers in nanosciences	On the basis of Nanotechnology Research Center to train students according to novel programs based on lectures and practical classes of the Faculties of Physics, Chemistry, and partly Biology; To support the young generation to take part in international programs, like Erasmus Mundus, Tempus, Russian Foundation for Basic Research, etc.	2017-2025	Educational programs: "Composite Nanomaterials" "Functional Nanomaterials " Nano devices" " Nano biotechnology" Early stage researcher fellowships	HR, funding from ministry of education of RB
Objective 3.3 To introduce Innovation trainings for the INP BSU staff	To provide team members with opportunities to be a member of professional societies; To provide some basic training for researchers, in commerce, marketing, negotiation etc.	2014-2017	Educational programs: "Composite Nanomaterials" "Functional Nanomaterials " Nano devices" " Nano biotechnology". High level of expertise, membership in SPIE, IEEE, EMC, EMRS, etc	HR, funding from ministry of education of RB changes in the funding policies in belarus, which is necessary to cover the professional societies fees
Objective 3.4 To set up a national contact point for cooperation with the EU research and innovation programs in nanosciences and nanotechnologies	To find out clear arguments why exactly the INP BSU should be approved as national contact point for cooperation with the EU research and innovation programs in nanosciences and nanotechnologies	2014	national contact point for cooperation with the EU research and innovation programs in nanosciences and nanotechnologies	HR Web-site Good online presence

GOAL 4: To improve research infrastructure				
Objectives	Tasks/ Activities	Timeline	Measure/ Documents	Resources needed
Objective 4.1 To support, lobby and ensure the effective exploitation of a	To organize center of collective use of expensive and unique equipment as a basis for nanotechnology research center	2014	Nanotechnology Research Center, Technology Transfer office,	HR, special funding from ministry of education of RB

center of collective use of research equipment in the BSU	well-being.		center of collective use of expensive and unique equipment	
Objective 4.2 To benefit from an access to research infrastructure provided by international cooperation programs	To increase the international mobility; To submit and win international research projects to have access to the unique equipment of projects' partners	2014-2025	Access to equipment	HR, funding from international projects