Fraunhofer ISI:
Dr. Thomas Reiss
Dr. Axel Thielmann

Fraunhofer NANOTECH:
Dr. Karl-Heinz Haas

ISS RAS:
Dr. Nadezhda Gaponenko

NANORUCER

“Mapping the NANOtechnology innovation system of RUssia for preparing future Cooperations between the EU and Russia”

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Final Report

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1 Executive summary

Nanotechnology is expected to influence almost all industries in the 21st century. The European Commission has taken various initiatives to support the development of this field. Important corner stones are the nanotechnology strategy from 2004 and the resulting action plan. Cooperation with 3rd countries is an important part of the European strategy. The 2009 work programme of NMP included a coordinated call with Russia. One of the topics was a support action on the "Mapping of nanotechnology and nanostructured materials research infrastructures in Russia". The NANORUCER project was selected from this call.

Based on the concept of sectoral innovation systems (SIS) an analytical framework for the empirical analysis of NANORUCER was developed, consisting of the following elements: a frame for structuring nanotechnology research, indicators for mapping the SIS, a compilation of suitable sources and tools for data gathering.

To obtain an overview of the current status of nanotechnology-related research activities in Russia compared to the EU and to other parts of the world, a performance analysis was carried out. Two specific functions of the SIS were considered: the generation of scientific knowledge and the transformation and application of this knowledge into the development of technologies, processes and new products. Scientific activities were measured using bibliometric indicators. Technological and developmental output was traced by patent indicators. This analysis reveals that Russia is an important player in the worldwide scientific nanotechnology community with a clear specialisation in nanooptics and nanophysics. Also most of the larger European countries have a focus on these areas. Accordingly, within these fields opportunities for cooperation are likely.

A core part of NANORUCER was the fine mapping of the Russian SIS in nanotechnology. Key agents (R&D organisations, enterprises, research infrastructure centres, business incubators, technology transfer centres) were identified and characterised in terms of their structures and functions. Results for R&D organisations and enterprises are documented in two searchable databases which are available publically on the NANORUCER website. This information pool was used firstly for elaborating an assessment of the Russian SIS in nanotechnology, and secondly to identify specific topics for future cooperation.

The analysis of the Russian SIS in nanotechnology reveals the following main strong points: a high level of education, in particular in mathematics, physics, chemistry and material sciences; a broad science base in nanotechnology-related research based on physical sciences; more than 700 R&D organisations with relevant activities in nanotechnology; scientific infrastructures for nanotechnology; a growing political support for nanotechnology in terms of funding and new initiatives for innovation. A main weakness is a strong imbalance between R&D activities and innovations-related activities. The private sector provides only low contribution to knowledge generation and innovation and science-industry interaction is weak. Particular strengths of the European SIS in nanotechnology include public funding; availability of research structures; the research base in nanooptics, nanophysics, nanobiotechnology and nanomedicine; well-developed institutional frameworks with respect to EHS issues, and in particular strong industrial sectors which are relevant for the application of nanotechnology (automotive industry, energy, chemistry, materials and manufacturing). Main weak points include a low level of private investment, in particular venture capital, and a fragmentation of R&D and innovation activities and support. One of the key problems of the future will be a lack of highly qualified personnel.

For future cooperation between Russia and the EU in nanotechnology mutual benefit could be generated best if Russian competencies and capacities in basic and theoretical research are combined with the innovation perspective and experience of European R&D actors. We suggest as a first step the identification of common goals for joint R&D activities, oriented along the grand challenges health, environment, energy and communication. In particular, we propose nanomaterials with a focus on metals and ceramics, and sensors and instruments as fields opening opportunities for short-term cooperation. Nanomagnets and nanocarbon-based applications offer mid-term opportunities. Superconductivity and quantum-computing provide a number of interesting topics for mid- to long-term cooperation. In addition, we suggest to joint forces for further developing institutional frameworks for nanotechnology within the global context, including, for example, standards, the EHS framework and regulation.

2 Summary description of project context and objectives

Nanotechnology and the nanosciences are often referred to as "key" or "enabling" since they can pervade almost all technological sectors and accordingly are expected to influence almost all industries in the twenty-first century.[1] These sectors include medical applications, information technology, energy production and storage,[2] manufacturing, instrumentation, and environmental applications. Accordingly, nanotechnology is seen as one of the most important fields of innovation and technology today.[3] Applications in nanotechnology typically build upon the special features and functions of nanomaterials and nanostructures, in particular due to the enhanced surface to volume ratio. Thus, nanotechnology does not constitute a product per se but is typically present and integrated in a large variety of different applications in a large number of industrial sectors. It therefore can be understood as an enabler of innovative technologies and applications by substituting and improving existing products or leading to fundamentally new products.

In order to support the exploitation of the expected potential of nanotechnology and the nanosciences, large amounts have been invested in development. Worldwide, the respective private and public investment was around €9 billion in 2005. The most important investors are Europe (€2.5 billion), Japan (€2.7 billion), and the United States (€3.5 billion).[4] Considering funding and investment, the world market being influenced by nanotechnology has been estimated to be in the range between €100 and €1,000 billion between 2005 and 2015.[5] One market estimate for 2015 even approaches US$ 3,000 billion for manufactured goods incorporating nanotechnology, which would be a

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1 *Communication from the Commission: Towards a European Strategy for Nanotechnology*, at 4, COM (2004) 338 final (Dec. 5, 2004).

2 *See generally* Axel Thielmann & Oliver Rothegatter, *Trends in Battery Technology Patents Indicating the Onset of a New Battery Generation Based on Nanomaterials*, 5 NANOTECH. L. & BUS. 391 (2008).

3 Axel Zweck et al., Nanotechnology in Germany: From Forecasting to Technological Assessment to Sustainability Studies, 16 J. Cleaner Production 977 (2008).

4 Oliver Pfirrmann, Stand und Perspektiven der Beschäftigung in der Nanotechnologie in Deutschland. Arbeit und Soziales - Eine Expertise auf Grundlage vorhandener Studien und Expertengespräche [Status and Perspectives of the Occupation in Nanotechnology in Germany] (2008).

5 Growth Market Nanotechnology: An Analysis of Technology and Innovation (Norbert Malanowski et al. eds., 2006).

significant percentage of the world gross national product (GDP in 2007 was about US$50,000 billion).

For a number of years the European Commission has adopted various initiatives to support the development of nanotechnology and the nanosciences. In 2004 the European Commission released a communication presenting its strategy for nanotechnology,[6] followed by the resulting Action Plan 2005-2009,[7] then the first implementation report in 2007,[8] and a second implementation report in October 2009.[9]

The importance of nanotechnology and cooperation with countries outside the European Union (Third Countries, which are neither Member nor Associated States), including Russia, is pointed out in these early EU strategy documents as an important part of the European strategy. Accordingly, the 2009 work programme of NMP (the Nanosciences, Nanotechnologies, Materials and New Production Technologies theme, the EU's main instrument for funding research) included a coordinated call with Russia for grant proposals on nanotechnology-based sensors with a total EU funding of €4.65 million and comparable funding from the Russian Federation. The call requested proposals in three separate areas of research: optical-chemical sensing with nanoparticles, nano-waveguides and photonic structures; wireless surface acoustic wave physical sensors for operation in a wide temperature range; sensing of toxic and explosive agents in air based on metal-oxide semiconductor nano-structured materials.[10]

A further topic was specified in another coordination call - a support action on the "mapping of nanotechnology and nano-structured materials research infrastructures in Russia."[11] The NANORUCER project was selected from this call.[12]

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6 *Communication from the Commission: Towards a European Strategy for Nanotechnology*, COM (2004) 338 final (May 5, 2004).

7 *Communication from the Commission: Nanosciences and Nanotechnologies: An Action Plan for Europe 2005-2009*, COM (2005) 243 final (June 7, 2005).

8 *Communication from the Commission: Nanosciences and Nanotechnologies: An Action Plan for Europe 2005-2009. First Implementation Report 2005-2007,* COM (2007) 505 final (Sept. 6, 2007).

9 *Communication from the Commission: Nanoscience and Nanotechnologies: An Action Plan for Europe 2005-2009. Second Implementation Report 2007-2009,* COM (2009) 607 final (Oct. 29, 2009).

10 Commission Calls for Proposals Under the 2008 and 2009 Work Programmes of the 7th EC Framework Programme for Research, Technological Development and Demonstration Activities and under the 2009 Work Programme of the 7th Euratom Framework Programme for Nuclear Research and Training Activities, 2008 O.J. (C 296/21) 6.

11 *Id.*

NANORUCER carried out an analysis of strengths and weaknesses of the Russian nanotechnology innovations system and a mapping of research activities in Russia on nanotechnology and nano-structured materials. A systematic comparison with corresponding EU activities will allow to identify opportunities for future EU-Russia cooperation.

The overall **aim** of the NANORUCER support activity was to pave the way for future cooperation between the EU and the Russian Federation in the field of nanotechnology and nano-structured materials (NN) as formulated in the description of the NMP work programme topic addressed.

The following three **objectives** were set to deliver to this overall aim through corresponding work packages (Figure 1) as described below:

Objective 1: Mapping of nanotechnology and nano-structured materials activities in Russia

In order to achieve this objective we have designed work packages 1, 2 an 3. During WP 1 the methodological and analytical framework for the mapping exercise was developed. Within WP 2 an overview performance analysis of NN activities in Russia and other countries was conducted, and WP 3 was concerned with the field work in Russia for fine mapping its NN activities.

Objective 2: Assessing the capacities of Russian NN R&D activities in order to identify strengths and weaknesses

WP 4 was concerned with the assessment of the Russian NN R&D capacities and delivered to this objective.

Objective 3: Identifying opportunities for cooperation and developing recommendations and a specific action plan

For achieving this objective it is necessary to compare Russian NN activities with respective activities in European countries and to use this comparison for identifying those opportunities for cooperation where both partners would benefit most. Accordingly during WP 5 European NN activities were summarised based on already available information using the same analytical framework as in WP 4. Following, WP 6 was concerned with the elaboration of opportunities for cooperation and the development of recommendations and a concrete action plan.

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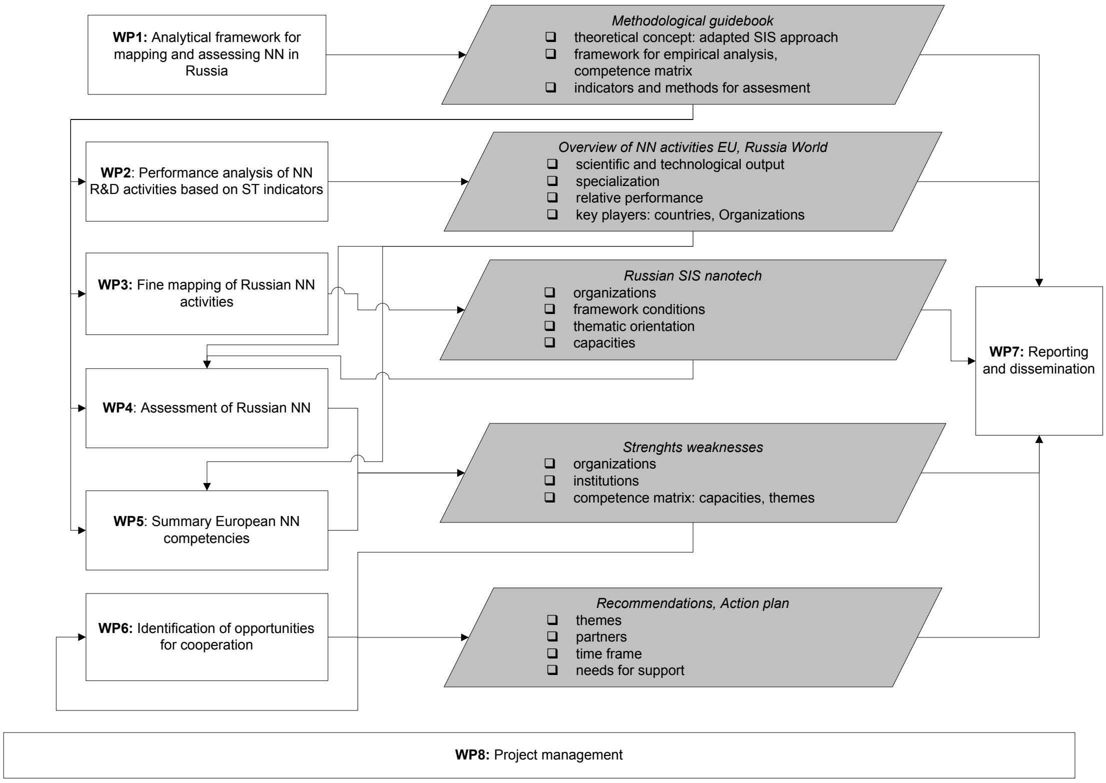
12 www.nanorucer.eu.

Figure 1: Graphical presentation of the components of NANORUCER and their relationships



3 Main results

3.1 Approach

The methodological approach is based on the concept of Sectoral Innovation Systems (SIS), developed by Franco Malerba[13]. Malerba defines a SIS as a "set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A SIS has a knowledge base, technologies, inputs and an (existing and potential) demand. The agents composing the sectoral system are organisations and individuals (e.g. consumers, entrepreneurs, scientists). Organisations may be firms (e.g. users, producers and input suppliers) and non-firm organisations (e.g. universities, financial institutions, government agencies, trade-unions, or technical associations), including sub-units of larger organisations (e.g. R&D or production departments) and groups of organisations (e.g. industry associations). The SIS approach tries to explain the creation, transfer, and implementation of knowledge and innovations in a sector. It helps to understand the institutional boundaries of a sector, the key players and their interactions, and the knowledge base and innovation processes specific to a sector. The SIS model focuses on the systemic failures that are of specific importance to all actors. The SIS in nanotechnology is an emerging system. For emerging systems, it is most important to explain the emergence and evolution of the system, capacity building within the system, as well as the imbalances and frictions, which hamper knowledge production, transfer, and commercialisation.

Based on this concept an analytical framework comprised of the following elements has been developed within NANORUCER: approaches and strategies for structuring the field, indicators for mapping the Russian NN system of innovation, sources to be used for the empirical work and tools for the empirical part of the study.

A first step for structuring the field was the elaboration of a suitable definition and delineation of nanotechnology. Until now there is still no unified and internationally accepted clear definition of nanotechnology. In order to be consistent with the performance analysis carried out within NANORUCER, we applied the definition of the European Patent Office (EPO) (Scheu et al. 2006[14]): "The term nanotechnology covers

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13 Malerba, Franco (2002). "Sectoral systems of innovation and production." In: Research Policy 31(2): pp. 247-264.

14 Scheu, M. et al. (2006): Mapping nanotechnology patents: The EPO approach. In: World Patent Information 28 (2006), pp. 204-211.

entities with a controlled geometrical size of at least one functional component below 100 nm in one or more dimensions susceptible to make physical, chemical or biological effects available which are intrinsic to that size. It covers equipment and methods for controlled analyses, manipulation, processing, fabrication or measurement with a precision below 100 nm."

As a tool for gathering and presenting in a systematic way activities of research organisations or firms in the nanotechnology and nano-structured materials research (NN) area, a competence matrix was developed which characterises the NN field along two dimensions: applications and markets for results of NN R&D activities and sub-technologies and -functions of NN.

For the analysis of publications and patent applications in nanotechnology during the performance analysis of NANORUCER search strategies for the respective data have been developed. In the case of patent analyses, relevant documents were identified in the databases of the EPO by retrieving patent applications which had been assigned a specific tag, labelling all those patents which are relevant for nanotechnology. The EPO assigns this Y01N tag to all respective patent applications and updates it continuously. The nanotechnology patent family is subdivided into six fields: nanobiotechnology; nanotechnology for information processing; storage and transmission; nanotechnology for materials and surface science; nanotechnology for interacting; sensing or actuating; nanooptics and nanomagnetics. For elaborating a search strategy for publications in nanotechnology several published approaches were compared. Finally, a key word-based search using the prefix "nano" was used for the analysis.

The two core parts of the mapping of the NN SIS in Russia comprise the mapping of universities and research organisations and the mapping of companies active in NN. For characterising these actors two sets of indicators have been developed: a set of input indicators which provide information on the resources, the internal strengths and the framework conditions for doing nanotechnology R&D and production, and a set of output indicators which are used for capturing the performance dimension. Input indicators refer, for example, to available facilities, human resources in terms of number, qualification, level of expertise, type of position and age and funding, including differentiation between private and public sources and characterisation of the different types of sources. Output indicators refer to scientific performance as measured by publication counts or contributions to scientific conferences or membership in review panels. The networking within scientific communities is considered, for example, by measuring involvement in external projects. Technological performance is measured by patent applications. Technology transfer activities are reflected, for example, by the number of spin-off companies. In the case of industry, additional output measures were used related to commercial activities. These include economic data such as turnover, share of exports or market shares, but also product- and service-specific indicators related to R&D activities, production, marketing, distribution and services provided.

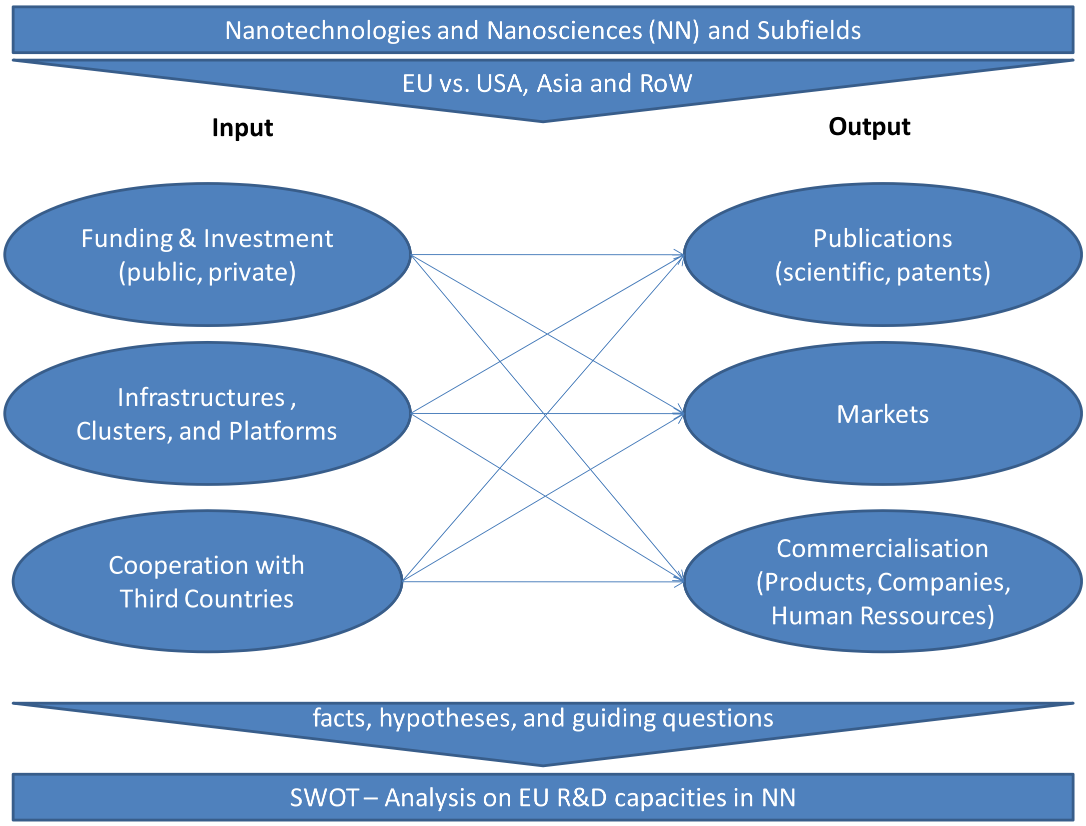
Specific tools have been developed for the NANORUCER field work. For mapping of NN activities of research organisations, universities and companies, questionnaires have been developed, one specific questionnaire for the research institutions and universities and another one for companies. Both questionnaires are structured in the following way:

- Section 1 with general information about the organisation
- Section 2 aiming at characterising the NN activities
- Section 3 concentrating on the resources such as human capital, financing or funding and facilities
- Section 4 concerned with information about the various activities of the organisations in the NN field
- Section 5 asking for current bottlenecks and possible solutions for the further development and application of NN in Russia

In order to obtain a complete picture of the nanotechnology SIS in Russia, NANORUCER did not only focus on research organisations and companies active in nanotechnology. Rather, other important domains of the SIS are included in the mapping. In particular this refers to private funding activities in terms of venture capital, innovation infrastructure and policy-making and implementation. For gathering information from venture capital firms, incubators and funding agencies, information guidelines were developed which focus on a limited number of key elements in order to improve participation and response in the mapping activities.

The Europe SIS in NN was assessed using existing data. A set of input and output variables was used for that purpose (figure 2). The analysis focuses on a comparison of the EU with Asia and the USA (and partly Russia) with respect to funding (public and private), research infrastructures and clusters, and cooperation with Third Countries as input indicators and publications (scientific publications and technology patents), market data, and commercialisation activities (e.g. in terms of products, companies and human resources) as output indicators. These few but important indicators allow for a rough but representative overview of the current EU position in the global context. The assessment was validated during an expert-workshop on March 25th 2011 in Brussels.

Figure 2: Framework for assessing the European SIS in NN.



The identification of topics suggested for future cooperation between European and Russian groups in NN is based on various strands of NANORUCER research. We started with a performance analysis of R&D activities in NN in European countries and Russia, using bibliometric and patent indicators. This analysis allowed to identify specialisation patterns of Russia compared to other regions of the world. A second core activity within NANORUCER was the mapping of the Russian nanotechnology SIS. Key actors of the nanotechnology innovation system could be identified and in particular their competences and interest in future cooperation could be elaborated. All in all 84 R&D organisations and 50 companies suggested topics for future cooperation. Thirdly, the European situation in NN was analysed based on already available information from other projects and studies. Thereby European competences could be assessed in a SWOT analysis. Fourthly, a very important contribution to the identification of future opportunities for cooperation was made by representatives of the Russian nanotechnology research communities during two NANORUCER workshops in Moscow held in January 2011 and April 2011. A final strand of information was the assessment by

European experts which was carried out during a workshop in Brussels in March 2011, followed by a series of personal interviews in order to assess cooperation opportunities.

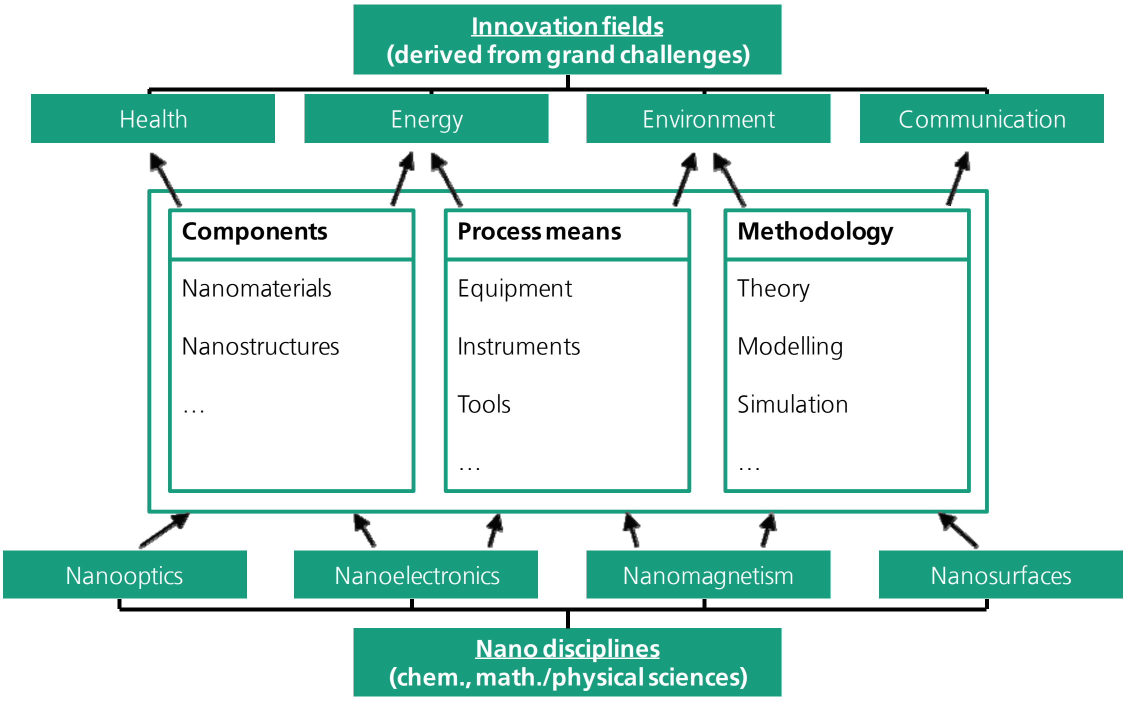
In order to select core topics for future cooperation the following set of criteria was applied:

- Competences and capacities: Cooperation would only be meaningful if both partners could contribute required competences in the fields under consideration and also the needed capacities in terms of human resources, equipment and infrastructures.
- Synergies: Competences and capacities of cooperation partners should be combined in a way which allows taking advantage of synergies.
- Mutual benefit: The benefit from cooperation should not be one-sided but rather be generated for both parts of the cooperation in a comparable way.
- Competitive advantage: Via cooperation a position of competitive advantage should be achieved by the cooperation parties which for example should also consider the potential to secure knowledge by IPR.
- High impact: Cooperation topics should have the potential to contribute to handling grand challenges, thereby generating future economic, social or environmental impact.
- Different time perspectives: Topics should be differentiated along the timeline and include short-term (2-4 years), medium-term (4-6 years) and long-term (7-10 years) activities.

For describing the opportunities for cooperation a strategic framework was developed (figure 3). Accordingly topics were mapped along three main dimensions:

- Innovation areas related to grand challenges
- The enabling dimension including components, process-means, methods, nanostructures and nanomaterials, tools, models and equipment
- Scientific disciplines.

Figure 3: Strategic framework for mapping cooperation topics



3.2 Overview: performance in NN

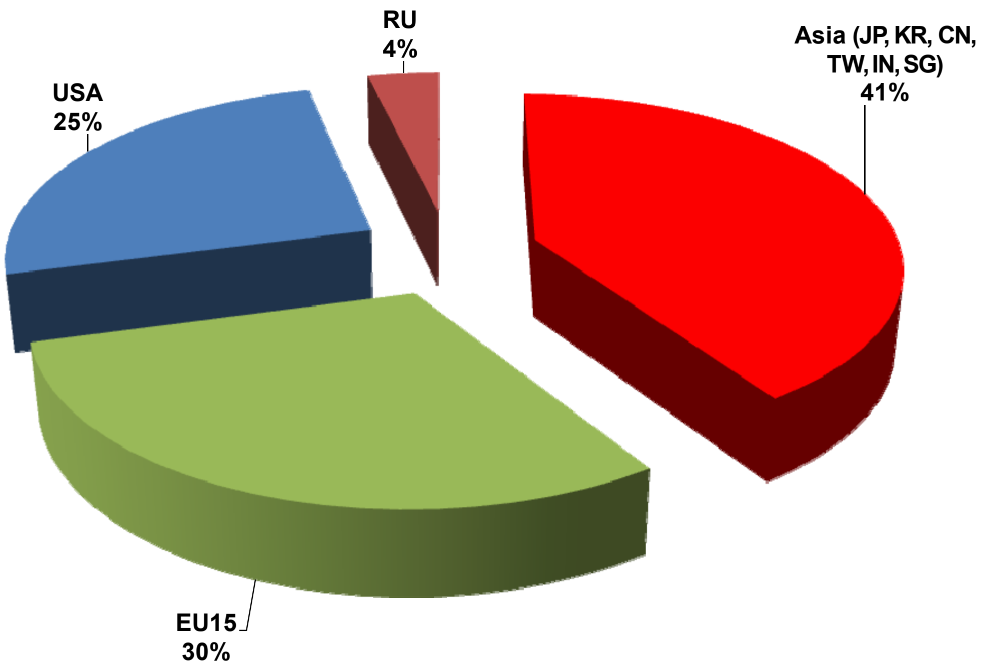
The performance analysis consists of two main parts. The first part is concerned with the analysis of scientific publications covering an overall analysis of NN but also the analysis of NN subfields. The second part comprises a patent analysis in NN. For that purpose patent applications at the European Patent Office were analysed.

Publication analysis

In order to obtain a first overview of worldwide publication activities in nanotechnology, we retrieved all publications during the period 2000-2009 from the SCI and analysed the contributions of different world regions to the total publication counts (figure 4). Accordingly, the Asian region as defined by the most active countries Japan, Korea, China, Taiwan, India and Singapore was publishing most nanotechnology papers, achieving a share of 41 per cent of the total of 432,004 publications identified by the search strategy used. Europe, defined as EU15[15], contributed about 30 per cent and the United States 25 per cent of total publications. Russia obtained a considerable share of 4 per cent of all worldwide publications.

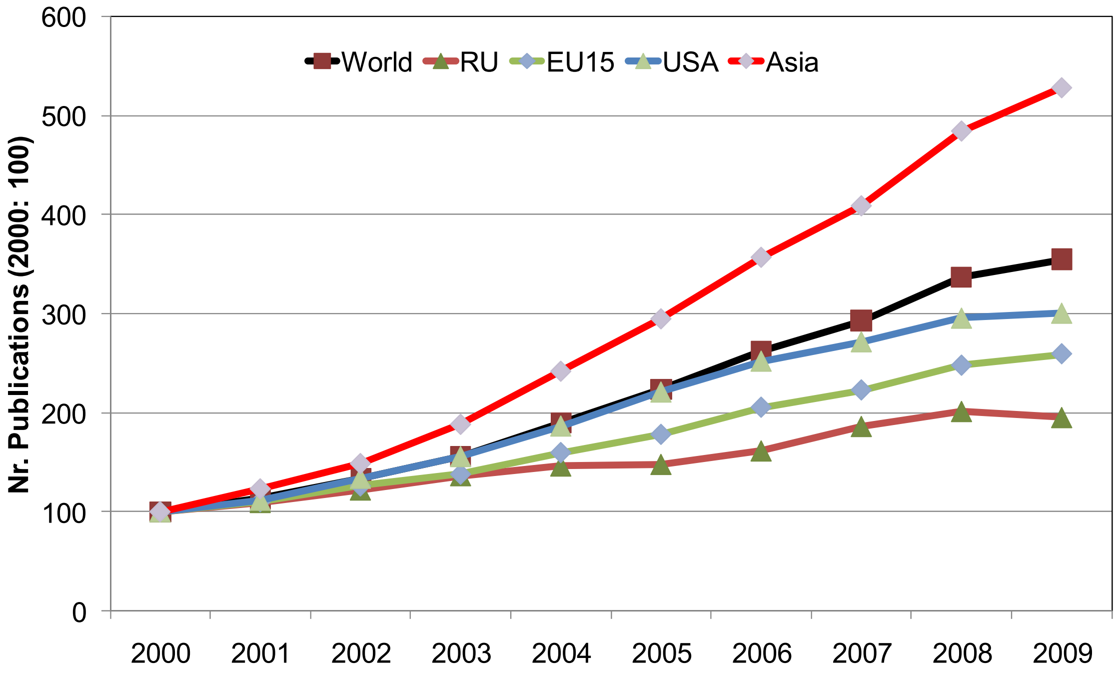
15 EU15 covers more than 90 per cent of all publications of EU27 (for details see annex methodology).

Figure 4: Share of world regions in total nanotechnology publications over the period 2000-2009



Scientific activities in nanotechnology as measured by publication output developed very dynamically over the ten-years-period considered. On a world level the number of publications increased by a factor of 3.5 between 2000 and 2009 (figure 5). The world-wide growth of nanotechnology publications is in particular remarkable if we compare it to the development of all worldwide publications which increased only by a factor of 1.3 over the ten-years-period considered. The most dynamic region was Asia where we observe an increase by a factor of almost 5.5 during this period. The Asian growth is mainly driven by China, Korea, India and Taiwan, while we observe a less dynamic development in Japan. But also in the USA, Europe (EU15) and Russia publication activities grew considerably during the last ten years. While the USA could almost triple its publication output, in the case of Russia we observe a doubling of the number of publications.

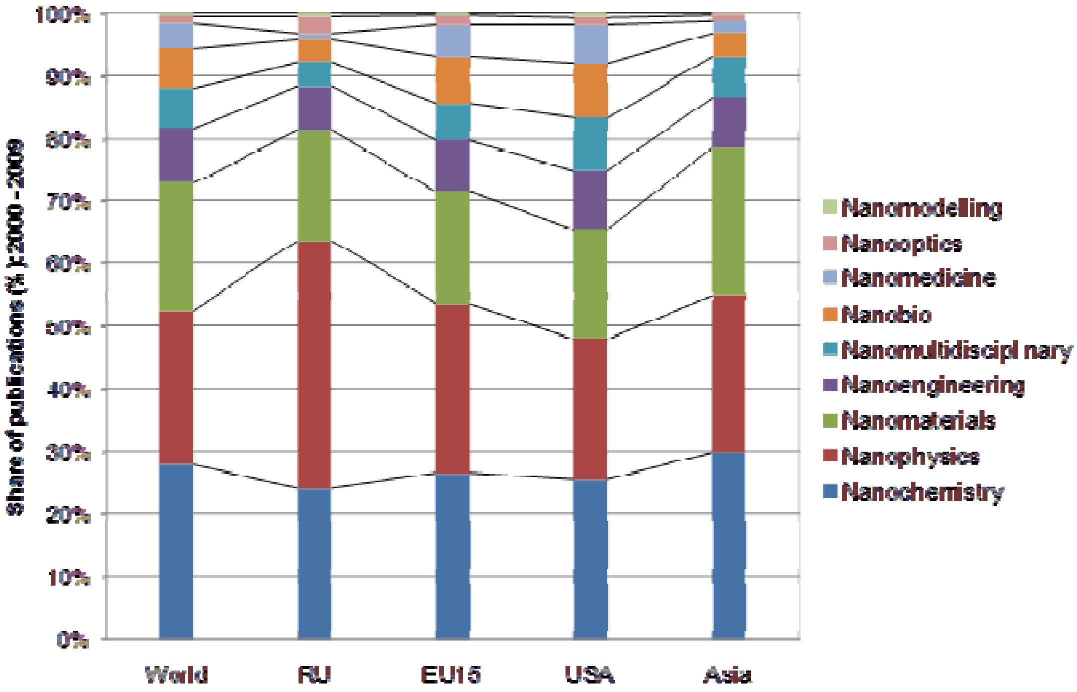
Figure 5: Dynamics of nanotechnology publication activities in different world regions over the period 2000-2009



An important goal of the performance analysis was to identify focal points of research activities in different nanotechnology subareas in Russia compared to European and world regions. For that purpose we divide the total field of nanotechnology into the following subfields: nanochemistry, nanophysics, nanomaterials, nanoengineering, multidisciplinary nanoactivities, nanobio, nanomedicine, nanooptics and nanomodelling. As indicated by publication activities these fields vary considerably in size. We observe three large fields - nanomaterials, nanophysics and nanochemistry making together more than 70 per cent of all nanotechnology publications. On the other hand, nanomodelling and nanooptics belong to the smaller fields contributing 0.4 and 1.1 per cent, respectively to all publications. The other fields range between 4.1 and 8.6 per cent.

Specialisation of different regions within the described nanotechnology subfields were analysed by calculating the share of publications in nano subfields in all publications of the respective regions. As shown in figure 6 Russia seems to be different from the other world regions in terms of focal activities mainly in two ways. Firstly, looking at the smaller fields there is a much stronger focus on nanooptics in Russia, while nanomedicine seems to be less important. Concerning the larger fields, Russia has the strongest focus on nanophysics compared to the other regions of the world.

Figure 6: Publication shares of nano fields over the period 2000-2009 for different world regions



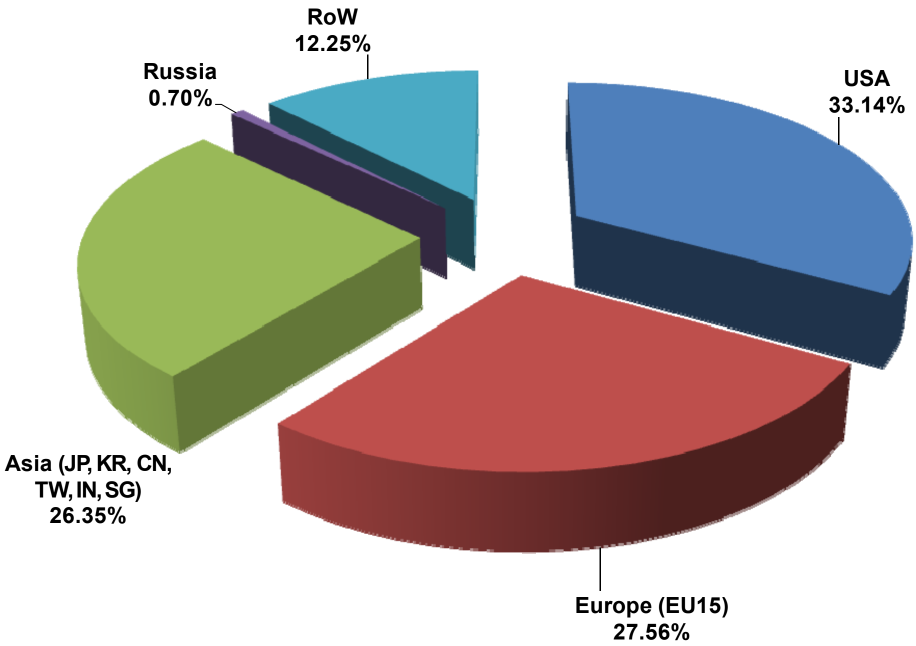
In summary, this analysis could provide some first hints for potential fields of future cooperations. In the case of fields where Russia is an important player in the European context in terms of publication output (nanophysics, nanooptics, nanomodelling), we would expect a rather high number of potential subfields and research groups from Russia being interested in offering cooperation opportunities. On the other hand, in the smaller fields which are mainly concerned with the intersection of nanotechnology and life sciences, identifying potential themes and partners in Russia for cooperation might be more difficult.

Patent analyses

In order to obtain an overview of the contribution of different world regions to world-wide patenting activities in nanotechnology, we analysed the contribution of different regions to world-wide patent applications at the European Patent Office including EP and PCT applications over a 10-years period (1997-2006).

The United States turned out to be the most active contributor to patenting activities achieving a share of about one third of all patent applications. Europe defined as EU15 contributed almost 28 per cent of all patent applications, a similar share as the Asian countries with roughly 26 per cent. Russia obtained a share of 0.7 per cent of all patent applications (figure 7). If we compare this share of Russia with the corresponding share of Russia in publication activities (4 per cent, figure 1), the propensity to patenting in Russia seems to be much lower compared to publication propensities. About 12 per cent of all patent applications were contributed by the rest of the world (RoW).

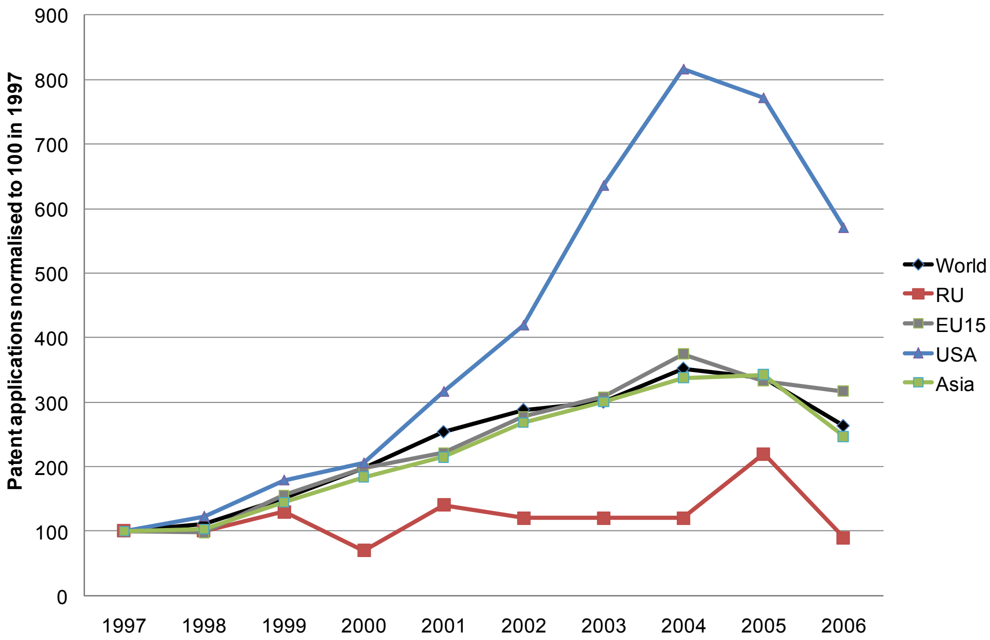
Figure 7: Share of world regions in total nanotechnology patent applications over the period 1997-2006



The dynamics of patent applications in nanotechnology in different world regions is shown in figure 8. On a world level we observe a rather strong growth of patenting activities between 1997 and 2005 where patent applications grew by a factor of roughly 3.5. Towards 2006 patenting activities seem to drop again. Due to the high share of the USA in all patent applications, the worldwide dynamics is strongly influenced by the behaviour of the United States. For this region we observe a very strong growth of patenting activities by a factor of 8 between 1997 and 2004 followed by a considerable drop towards the year 2006. The dynamics of patenting activities in Europe and Asian countries is similar to the worldwide activities. In the case of Russia we observe a rather stable development with no remarkable growth.

The worldwide decline of nanotechnology patent applications between 2004 and 2006 which is driven largely by the patenting behaviour of the United States seems to be a specific phenomenon for nanotechnology since patenting activities over all technologies continued to increase during this period at the world level and also at the level of the United States (data not shown).

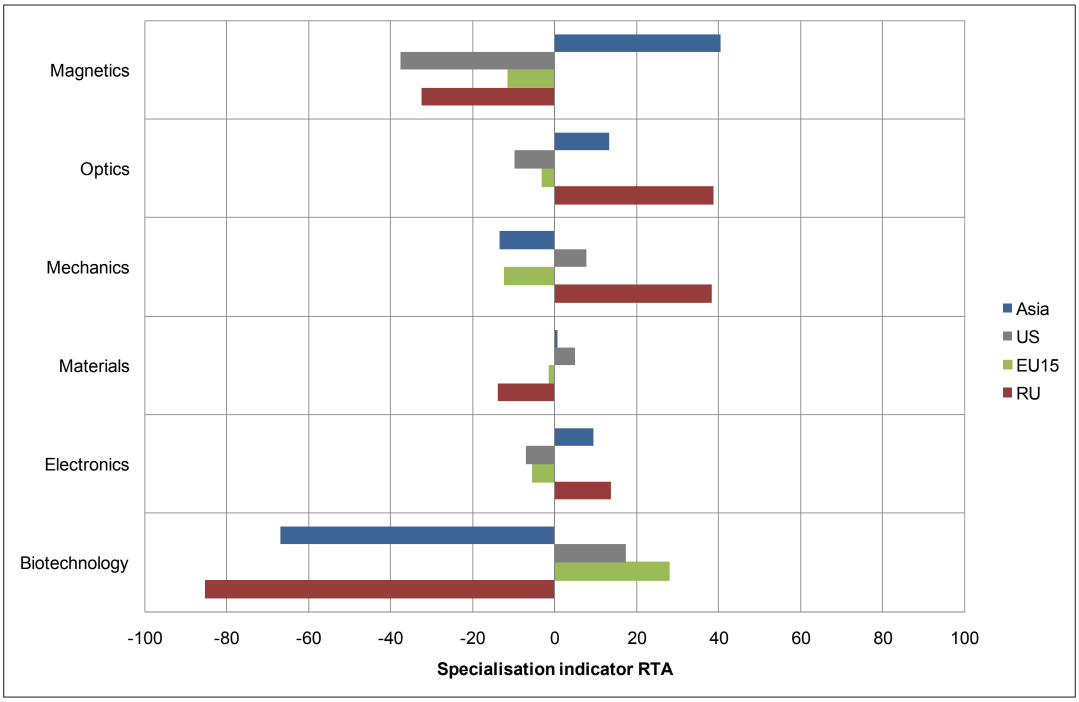
Figure 8: Dynamics of nanotechnology patent applications in different world regions over the period 1997-2006



In order to analyse patenting activities of Russia and other world regions in different subfields of nanotechnology, we differentiate nanotechnology into six subareas: nanomaterials, nanoelectronics, nanooptics, nanobiotech, nanomechanics, nanomagnetics. These fields have been defined by the EPO and cover different categories of the international patent classification (IPC). Accordingly they can be used for analysing subfield-specific patenting behaviour. Nanomaterials comprises the largest of these subareas corresponding to 35 per cent of the 17.359 total nanotechnology patent applications worldwide over the period 1997 to 2006. Nanoelectronics with 26 per cent is another larger area. Nanooptics and nanobiotech each contribute 12 per cent, nanomechanics 9 per cent and nanomagnetics 6 per cent of the worldwide total nanotechnology patent applications.

For a detailed analysis of the relative specialisation of Russia in different nanotechnology fields, we calculated the patent specialisation indicator RTA (figure 9). Basically, this indicator relates the share of patent applications of a specific country in a specific field to the share of all patent applications of this country in all patent applications world-wide. Thereby, this indicator provides information on relative specialisation of different countries, compensating for size effects and different propensities to patenting. This analysis indicates that Russia presents a clear specialisation in nanooptics and nanomechanics. None of the other three major regions considered is characterised by a similar specialisation pattern. Nanobiotechnology, on the other hand, is the subfield where Russia is not specialised in. Interestingly, the Asian countries express a similar underspecialisation in nanobiotechnology.

Figure 9: Relative specialisation of different world regions in nano subfields over the period 1997-2006



In summary, the performance analysis indicates that Russia is an important player in the world-wide scientific nanotechnology community. With respect to scientific activities, we observe a clear specialisation of Russia in two subfields of nanotechnology, namely nanooptics and nanophysics. On the other hand, the intersection between nanotechnology and life sciences as defined by the scientific fields nanomedicine and nanobiotechnology is a field were we observe lower intensities of scientific activities in Russia. Thus, the analysis of scientific performance using bibliometric indicators gives some first ideas about potential nanotechnology subfields for future cooperation between Russia and European countries. The fields of nanooptics and nanophysics, where we observe a clear specialisation of Russia are also areas where most European countries present rather intensive activities. Accordingly, we would expect a number of interesting opportunities for cooperation within these larger subfields. On the other hand, life sciences-related nanotechnology research could be an area where European countries and Russia could contribute complementary competencies for joint activities, combining rather intensive strong European research activities with currently lower and more focussed Russian activities.

3.3 The Russian SIS in NN

The mapping of the Russian SIS in NN comprises the following elements:

Gathering information about the main actors of the Russian NN innovation system; setting up the database structure for the different types of actors; analysis and mapping of information collected by scientific NN subfields and regions of the Russian Federation; developing of databases for R&D organisations, research infrastructure centres, business incubators, venture funds and nano companies; elaboration of maps of the distribution of the different actor types across the regions of the Russian Federation.

With respect to **research organisations** two databases were set up. The first database of R&D organisations in NN is structured into the following sub-directories:

D1: name of organisation

D2: contact information

D3: contact person

D4: location

D5: fields of NN

D6: type of organisation (academic research institute, university, organisation of ministries and agencies, organisation of branch science transformed during the privatisation, private research organisation)

D7: year of foundation

D8: human capacities (staff number, number of R&D personnel, differentiation of R&D personnel into post-doctoral degree holders and PhD holders)

D9: facilities available at the organisation (open field)

This database provides a comprehend overview of research organisations of the Russian Federation which carry out R&D in NN. Over 700 organisations are included from large well-known research institutes to small emerging units. Organisations are spread over all regions ("okrugs") of the Russian Federation. Analysing the type of organisations indicates that 28 per cent belong to the academic sector, represented by the organisations of the Russian Academy of Sciences, the Russian Academy of Medical Sciences, the Russian Academy of Architecture and Building, the Russian Academy of Agricultural Sciences and by the research institute of all regional branches of the Russian Academy of Sciences. The university sector comprises the largest share of all R&D organisations containing information on over 280 organisations, corresponding to 41 per cent of the total. The third largest sector comprises organisations of ministries and agencies including state research centres which got this status in the middle of the 19^{th} of the last century and are oriented mainly on applied studies and public research organisations which perform under the umbrella of federal ministries and agencies or under the umbrella of regional authorities. In this group we have available information of about 100 organisations.

Looking at the regional distribution of the organisations we observe a strong concentration in the central federal "okrug" which is Moscow and the region around Moscow, where about 50 per cent of all organisations are located. This concentration of NN activities around Moscow is in line with the general trends of regional distribution of Russian science and has its historical roots.

As a second database, a target database, of R&D organisations was elaborated based on information collected via a survey of R&D organisations in Russia. For the survey the 700 organisations identified for the first database were asked to provide more detailed information about their activities in NN. In addition to the basic structural and organisational information about the research organisations, the survey revealed structured information about activities in different nanotechnology fields, in different application areas of nanotechnology and also asked for assessments of framework conditions for doing nanotechnology research in Russia. In addition, organisations were asked to propose topics for future joint research activities between Russian and European research groups. Finally, detailed information about available facilities in the institutes and also lists of references were provided. Over 80 organisations of all types located in all federal "okrugs" participated in the survey. It turned out that the academic sector was more active in answering the questionnaires compared to universities. Therefore, about 40 per cent of the sample is represented by the academic sector, about 28 per cent by universities. Concerning the regional distribution we find the same concentration of organisations on the Moscow regions as already observed for the database of research organisations.

Most of the organisations are active in the area of nanomaterials which corresponds with the observations made during the performance analysis, indicating that nanomaterials and nanophysics belong to the strong points of Russian nanotechnology R&D activities. Interestingly, a rather large share of the institutes indicates to be active in the area of nanobiotechnology. However, a more detailed analysis of these data indicates that in many cases this orientation reflects more the expected future position of the institutes than the current activities. This may be an indication of the high expectations which are set into this area by a large share of the Russian nanotechnology R&D organisations.

In summary, the mapping of research organisations in nanotechnology in Russia provided a broad and detailed information basis for the identification of interesting topics and themes for future cooperation. The database is available on the NANORUCER website: www.nanorucer.eu.

In a comparable way to R&D organisations also for **industrial enterprises** two databases were set up. The first database of nano companies relies mainly on secondary information published by different actors of the Russian and the international nanotechnology arena. Most important sources for setting up the databases were the Ministry of Education and Science of the Russian Federation, RUSNANO, the National Nanotech Network, regional authorities and regional nanotech networks, information from the European Union, Internet sources, conference proceedings and information published in scientific journals. As an additional important source of information we could use the survey of R&D organisations. R&D organisations were also asked whether they had set up start-up companies in the nanotech area. Thereby we could identify 28 spin-offs from different research institutes and universities. The database was arranged into the following directories: D1 company name, D2 location and contact, D3 contact person, D4 function of contact person. The companies were also mapped across the federal okrugs of the Russian Federation and the subjects.[16]

All in all, the database of nano companies contained more than 410 company entries, including large well-known corporations as well as small emerging spin-offs. Concerning the regional distribution we observe a strong concentration in the Moscow region which is comparable to the concentration of R&D organisations. Roughly 50 per cent of the companies are located in this area. Behind Moscow the second important location is the St. Petersburg region were roughly 50 companies are located.

The second database, the target database of nano companies, was set up using additional information provided by a survey of nano companies carried out within NANORUCER. The target database contains the following information:

D1: name of organisation,

D2: location,

D3: contact person,

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16 Russia is defined as a Federation in its constitution; as a Federation Russia consists of 83 Federal subjects (members of the Federation). In terms of economic activities, subjects of the Federation have their own budget, develop programmes and actions to support activities oriented on their regional priorities.

D4: contact information,

D5: foundation year,

D6: year of start of nanotechnology activities,

D7: type of activities (R&D, production, service, marketing and distribution),

D8: founders of company,

D9: products

D10: main markets in terms of industrial sectors such as pharmaceuticals, chemicals, aerospace, transport, ICT,

D11: human resources,

D12: technological fields.

All in all, the target database contains detailed information of about roughly 50 nano companies in Russia. About 60 per cent of the companies are spin-offs from academia, more than 90 per cent of the companies provide R&D services in NN. Many of the companies also suggested topics for collaborative projects with the European partners. The database is available on the NANORUCER website: www.nanorucer.eu.

In addition to the main databases (R&D organisations and companies) within NANORUCER also databases of other important actors of the Russian nanotechnology SIS were elaborated:

- a database with information about 128 research infrastructure centres,
- a database with 33 business incubators,
- a database with 102 technology transfer centres and
- a database with 14 venture funds.

3.4 Assessment of the European and the Russian SIS in NN

Europe

The global distribution of R&D investments, publications and patents indicate that nanotechnology-related research and development activities are concentrated in a few countries and regions of the world. The United States dominates in this context, followed by Japan and some of the larger EU countries (Germany, France, UK). Nonetheless, some smaller countries also show up as being very active when considering size differences across countries (OECD 2009[17]).

With respect to nanotechnology ***funding***, the EU is quite strong and comparable to other world regions, like USA and Asia. Available data on ***public*** funding and regional centres of nanotechnology activity suggest that the EU and its Member States are competitive overall, even though there were time lags in the provision of public funds in the early years of this decade (EURONANO 2009[18]). In addition there are problems concerning implementation of public funding. These include, for example, fragmentation and parallelisation. There are many examples where parallel activities are funded by public money producing redundant results at all levels (local, regional, federal, European). Another problem concerns a lack of a focussed strategy for funding along the complete innovation chain. Basically the instruments are available for doing so, the money is there, however, coordination is lacking and accessibility is difficult. A more focussed and strategic funding approach would require identifying the key bottlenecks along the innovation chain and direct suitable funding instruments to those. Europe does not provide ***private*** funding (in particular venture capital) to the same extent as other regions like the US or Japan, which may hint to a worse performance in terms of commercialisation of nanotechnology.

Research ***infrastructures*** are excellent and strongly supported in the EU, t***echnology platforms*** and ***cluster*** activities are visible but could be coordinated and complement better with other activities and stakeholders for sake of defragmentation and improved synergies. ***Cooperation*** among the EU Member States as well as ***with Third Countries*** has been established in the past but will be of more importance in areas of joint global thematic and strategic interest and will have to be further developed (e.g. for regulation, standardisation, risk assessment, etc.).

Science and technology indicators remain the most reliable source of information for assessing the competitive position of world regions and countries. The EU Member States perform well in terms of R&D, especially with respect to ***scientific*** activity measured by ***publications***. In terms of technology development measured by ***patents***, the EU performance is solid yet not as strong as on the science side. While EU Mem-

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17 OECD (2009): Nanotechnology: An overview based on indicators and statistics, STI working paper 2009/7 Statistical Analysis of Science, Technology and Industry, OECD; http://www.oecd.org/dataoecd/59/9/43179651.pdf.

18 EURONANO (2009): Nanotechnology in Europe: Assessment of the Current State, Opportunities, Challenges and Socio-Economic Impact (Phase 1), Framework Service Contract 150083-2005-02-BE.

ber States are often on par with the US, nano-electronics is an area of relative weakness. The US remains the main competitor across all relevant areas. However, the rapid entry of "newcomer" countries such as BRIC countries and the South-East Asian countries should also be highlighted. All of these countries are characterised by rapid growth rates in the number of publications and patents although from low starting levels. These results suggest that the thrust of nanotechnology R&D may partly be shifting away from traditional countries which have had a longer history of involvement in nanotechnology (EURONANO 2009[19], OECD 2009[20]).

Typical of an emerging field, the level of uncertainty is high and there is considerable variety in ***market*** estimates. While these factors are not restricted to nanotechnologies, they must be taken into consideration when interpreting data. The potential socio-economic impacts of nanotechnology are considered very large especially in terms of forecast market size for nanotechnology-related ***products***, the multiplicity of applications and their potential to contribute to addressing global challenges (OECD 2009[21]). The USA is the strongest actor bringing nanotechnology products into the market, followed by Asia and the EU. With respect to firm/***company*** creation also the USA are leading world wide, however, Europe as a further player with substantial activity on the level of individual Member States. However, reliable assessments of these socio-economic impacts still suffer from a lack of indicators and statistics, jointly agreed definitions of nanotechnology and methodologies for its measurement. Available market forecasts, company and nanotechnology product inventories are only indicative while technology roadmaps are difficult to undertake due to the broadness of the field (OECD 2009[22]). The EU has great strengths in different **sectors** such as transport, energy, chemistry, materials; manufacturing, and medicine, where nanotechnology plays an important role and scientific strengths of the EU can be identified.

Besides the discussed indicators for measuring R&D performance and competitiveness, a number of key factors have to be mentioned, which are highly relevant for the future commercialisation and acceptance of nanotechnology:

Technology transfer between academia and industry is particularly important for nanotechnology. Due to the highly interdisciplinary nature of NN, this is more compli-

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19 See 18

20 See 17

21 See 17

22 See 17

cated compared to other technologies. The main challenge here is to balance undirected basic research aiming at pure scientific progress with a view on commercialisation prospects and the specific needs of users and markets. Direct collaboration between science and industry often helps in this respect, but raises the issue of how intellectual property is assigned to the individual partners (ZEW/TNO 2010[23]). If Europe is to operate as a single market for knowledge, it is not enough simply to increase public investment in research. Rather, it is important to create a framework that facilitates knowledge transfer by removing the barriers hindering collaboration between research and industry (EC 2009a[24]).

With respect to the ***market demand***, users typically do not adopt new technology solely based on their technical superiority but rather on a price-cost advantage over established technologies, taking into account issues such as safety, compatibility to other products and existing production processes, and acceptance by their own clients (ZEW/TNO 2010[25]). Creating new markets, however, with nanotechnology will change the game, but breakthrough products are needed (blockbusters, not otherwise achievable). As for any newly emerging technology, potential ***impacts of nanotechnology on environment, health, safety (EHS)*** have been discussed widely, since there is a widespread concern of potential negative effects from nanotechnology (ZEW/TNO 2010[26]). Investment in nanomaterials EHS risk research must be maintained or preferably increased to US levels to ensure that Europe remains competitive with respect to developments in global regulations (EAG 2009[27]). There is evidence that the US is investing in research into the environment, health and safety risks of engineered nanomaterials at annual rate that is three times the European level (EAG 2009[28]).

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23 ZEW/TNO (2010): European Competitiveness in Key Enabling Technologies. Final Report. Birgit Aschhoff, Dirk Crass, Katrin Cremers, Christoph Grimpe, Christian Rammer; Centre for European Economic Research (ZEW), Mannheim, Germany and Felix Brandes, Fernando Diaz-Lopez, Rosalinde Klein Woolthuis, Michael Mayer, Carlos Montalvo; TNO, Delft, the Netherlands.

24 EC (2009a): Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009, SEC (2009) 1468; Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009, Accompanying Document: COM(2009)607.

25 See 23

26 See 23

27 EAG (2009): NMP Expert Advisory Group (EAG) position paper on future RTD activities of NMP for the period 2010 - 2015. EUR 24179 EN. EC, November 2009.

28 See 27

Within the EC's Public Online Consultation on Nanotechnology experts and the general public identified many benefits in nanotechnologies, as well as potential risks (EC 2010[29]). More than 80 per cent have either high or reasonable expectations of nanotechnologies in general, but some areas are seen as more promising than others, with regard to their expected benefits and potential risks: ICT and energy are seen as the areas of application where the benefits far outweigh any potential risks. Applications in aerospace, construction, sustainable chemistry, security and environment are seen as areas that would bring high benefits. Applications in agriculture, food and household items are regarded with more scepticism, although potential benefits in these areas were also identified. Applications in healthcare are universally seen as very promising, but there is a strong perception of potential risks (EC 2010[30]).

Commercialising nanotechnology products broadly will require ***acceptance (and trust)*** by users and all other parties that may be concerned by nanotechnology products. Assessing and minimising perceived risk potentials are important activities. Certainty about regulatory issues is also critical for nanotechnology producers to decide about investment and directions of future research (ZEW/TNO 2010[31]). In order to enhance commercialisation prospects of new nanotechnology applications, measurement and testing methods have to be developed and validated. Clearly, infrastructures have a key enabling role in supporting this research. Based on this, ***standards*** have to be implemented and an effective regulatory framework should be put in place that takes into account EHS concerns, while at the same time acknowledges the progress that nanotechnology innovations can have for the environment and health. An open ***dialogue*** between governments, industry, research and the wider society should address EHS concerns and how these are dealt with (ZEW/TNO 2010[32]). Demand is also high for requirements to ensure that adequate information is provided on consumer products (EC 2010[33]).

On the other hand, there is a good or very ***good perception of EU governance*** related to nanotechnologies in terms of stakeholder consultation and setting research

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29 EC (2010): Report on the European Commission's Public Online Consultation TOWARDS A STRATEGIC NANOTECHNOLOGY ACTION PLAN (SNAP) 2010-2015 Open: 18.12.2009 to 19.02.2010.

30 See 29

31 See 23

32 See 23

33 See 29

priorities (EC 2010[34]). The Commission is also heavily involved in the current work within the OECD Working Party for Manufactured Nanomaterials (WPMN), which is developing test methods and guidelines for risk assessment and regulation. Moreover, the ISO standardisation work will facilitate a global convergence in standards for the implementation of regulation (EC 2009a[35]).

The assessment of the European SIS in NN is summarised in the following SWOT graph (figure 10).

Figure 10: SWOT analysis of the European SIS in NN

Strengths

- Public financing of R&D
- Public funding through EU
- Research infrastructure
- International collaboration
- Activities in risk assessment, EHS, standardisation, regulation, legislation, public dialogue
- PPPs enhancing NNs industrial focus
- Research base well established in terms of fundamental science (nanooptics, nanophysics, nanobio, nanomed)
- Strong industrial sectors where NN important (transport, energy, chemistry, health, manufacturing)
- Diversity of EU market
- Creation of companies

Opportunities

- Maintain scale of investment, concentrate on strengths (electronics, communication, transportation, chemistry, pharma, health, biotech, machinery)
- Nanotechnology for eco-efficient economy, sustainable energy systems , protection of climate and environment
- Focus research funding on realistic short- to medium-term prospects
- Collaboration with all stakeholders
- Further development of infrastructures and the educational system
- Adjust, validate and harmonise methods for risk assessment for nanomaterials

- Private investment
- Fragmentation in research, technology development and innovation
- Insufficient contact/exchange with Third Countries
- Commercialisation performance (understanding market demand, development of applications, number of products)
- Lack of appropriate human resources
- Cooperation between existing SME

Weaknesses

- New players (e.g. BRIC countries) overcompete
- NN getting negative image
- New questions relating to ethics, safety, security and respect for fundamental rights insufficiently tackled
- Commercialisation gap widening
- Lacking public acceptance due to nanotechnology products not complying with high levels of consumer, worker and environmental protection
- Lack of new scientists and engineers

Threats

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34 See 29

35 EC (2009a): Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009, SEC(2009)1468; Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009, Accompanying Document: COM(2009)607.

Russia

The analysis of the Russian SIS in NN is based mainly on the information elaborated during the mapping of the Russian NN SIS during NANORUCER. In particular the databases and surveys described above formed valuable sources of information. In addition, more than 200 interviews with managers of incubators, of venture funds or venture management companies were carried out. Statistical information from the State Statistical Committee of the Russian Federation, from the Ministry of Education and Science and from the Russian corporation RUSNANO could also be analysed for the assessment. This national information was complemented by available international sources provided, for example, by the OECD and by the European Commission. The analysis reveals the following main findings:

Currently the Russian SIS in NN is looking for **new trajectories**. It is marked by diversity and by a lack of coherence in different nanotechnology fields, with respect to different actors and also to strategic decisions in its current early and developing stage. Particular strengths of the Russian **educational and R&D system** in physics, chemistry and material sciences as well as a long standing tradition in nanoscale research, provide a good background for the future development of the NN-related SIS. Currently, the Russian SIS in NN can be characterised as a growing system with rapid institutional changes, emerging systems of governance and a geopolitical orientation mostly towards the European Union.

Key players in the Russian NN SIS are the Federal Ministry for Education and Science, the RUSNANO corporation and the Russian Academy of Sciences. In the research area only a few universities are playing an important role. The RUSNANO corporation is a rather new player but has been developing very rapidly into a strong organisation with global orientation.

Still, the Russian SIS in NN remains **fragmented** and misbalanced. We observe a rather strong R&D system which on the other hand is opposed to an underdeveloped financial and innovation system, less developed infrastructures, and accordingly a less developed nano market. In order to deal with these imbalances at the federal and regional level, new institutions have emerged for the coordination of different political bodies and for facilitating a dialogue between different stakeholders. However, strong departmental interests and path dependencies hamper the transition to a new model of policy development and implementation in NN.

Activities of public bodies are mainly oriented towards the development of research infrastructure, towards closing institutional gaps in the SIS and towards further developing human capacity. In this respect, such activities can be considered as comparable to other European countries. In particular public investment in NN development increased substantially after the presidential nanotechnology initiative was launched in 2007.

A main problem of the Russian SIS in NN is the **private sector**, in a sense that it does not provide significant contributions to knowledge generation. A non-competitive and monopolised home market, a non-effective system of technical regulations as well as a lack of in-house R&D capacity undermine the private sectors' motivation. The ins**titutional set up** of the SIS in NN is well developed, however, most R&D capacities are concentrated in the academic sector. Remarkably, academia provides R&D in all NN fields. However, strong imbalances could be observed. Namely there is rather large R&D capacity concentrated in the area of nanomaterials, while life-sciences-related fields are less dynamic. In basic research Russian nanoscience is still considered to be among the world's leading players, although new actors are emerging and competing increasingly with the Russian situation. These include in particular Asian countries, such as China, South Korea or Singapore.

The **home market** related to NN is dominated by foreign companies. The majority of Russian companies are small and medium-sized enterprises and spin-offs of academia. Administrative barriers, high-credit interest and lack of qualified personnel hamper business development in these small nano companies. Emerging companies already export nano-enabled products and have strong ambitions to expand their world market niche. However, a lack of experience and lack of public support impede such activities. These **problems in commercial development** of nanotechnology in Russia not least are influenced by cultural issues, since in general Russian R&D organisations do not have a tradition of commercialising research results. Among others a weak emphasis on generating IPR and strong patent portfolios among academia support this notion.

A summary of the assessment of the Russian SIS in NN is provided in the following SWOT (figure 11).

Figure 11: SWOT analysis of the Russian SIS in NN

Strengths	Opportunities
• Strong academic research • Integration of research into global networks • Growing public investment into research • High average educational level • Strong education in physics, chemistry, material sciences, mathematics • New educational initiatives • RUSNANO initiatives to support innovation (Nanocentres, venture funds, networking…) • Russian Venture Company • New legal basis supporting spin-off formation • Big home market • Large national corporations	• Global challenges open new opportunities for international cooperation • New markets through globalisation (e.g. BRICS) • Better coordinated governance approaches • Attracting talents from foreign countries • Improving competitiveness in sectors using nanotech (aerospace, nuclear energy, solar energy, metallurgy, electronics) • Improving technology transfer and innovation culture • Becoming leader in some global niches • Combine strengths in fundamental research with innovation perspective via EU-RU cooperation
• Brain drain • Ageing R&D personnel • Low private investment into R&D and innovation • Low public support for innovative companies • Low level of private innovation activities • Underdeveloped innovation infrastructure • Low level of IP protection • Underdeveloped banking system • Low level of managerial education • Raw materials, energy, metallurgy dominate economy • Market monopolisation • Globalisation mainly in energy and metallurgy sector	• Flow of nano-enabled products from Asian countries • Negative impact of nanotechnology on health and environment • Erosion of fundamental research capacities (brain drain) • Weakening R&D capacities no more able to serve new needs arising from global challenges • Foreign technologies becoming dominant
Weaknesses	**Threats**

3.5 Opportunities for cooperation

Following the approach described in the first section a total of seventeen core topics was identified which have been classified into seven fields (table 1). Each topic is described with a short one or two-page profile summarising the main features of the topic according to the described dimensions (see below). Finally a roadmap is developed positioning the topics along the timescale and indicating short-term, medium-term or long-term opportunities for cooperation.

Table 1: Overview of core topics

Area	No.	Topic
Nanometals	1	Plasma technology for production of metallic nanopar-ticles/-structures
	2	Metallic nanoporous filters/membranes
	3	Nanometals for extreme conditions
	4	Superhard/-tough composites with superconducting properties
	5	Vacuum-tight X-ray transparent Beryllium components
Nanoceramics	6	Process technology for nanoceramics
	7	Electroceramics
	8	Coatings for high-temperature shielding
	9	Shielding materials for electromagnetic radiation
Carbon-based materials	10	Nanocarbon-based sensors (e.g. CNT, graphene)
Nanomagnets	11	Nanomagnets and their optimised production
	12	Electronics/electronic devices based on spintronics
Sensors and Instruments	13	Plasmonic sensors and devices
	14	Advanced UHV-setup for analysing and modelling surface reactions for nanoelectronic devices
Superconductivity	15	Theory for nanoscale enhanced high-temperature superconductivity
	16	Nano-analysis and applications for superconducting devices
Quantum computing	17	Theoretical models for quantum computing

Profile of topics of interest between RF and EU

Topic No. 1	Plasma technology for metallic nanoparticles/-structures
Area	Nanometals
Characterisation	Metallic nanoparticles (NP) are basic building blocks for coatings and bulk materials. Nanograins in metals and coatings show improved hardness, corrosion and resistance compared to microscaled materials. Generating nanoscaled metallic structures on surfaces e.g. by plasma technology will be more important in the future. Beside the high surface area of NP also optical, electronic/magnetic properties are of importance.
Relevance for grand challenges and potential impact	Topic has high relevance in the field of energy (bulk materials and coatings e.g. batteries, fuel cells, wear resistant coatings), health (biosensors) and ICT (metallic nanostructures on surfaces as sensors)
Main R&D needs and barriers	Plasma technology is established for NP production. Main R&D needs are better control of NP sizes by flexible methods for production, including process simulation/control based on modelling tools. Understanding transport properties of nanoclusters will also allow better process control.
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	Nanoparticle production methods can be optimised in short term, nano-structured surfaces in medium term
Synergies	RF has high competences in metals processing, plasma technology and modelling The EU is looking for upscalable production technologies for nanoparticles and /-structures
References	No projects/ activities between RF and EU in the field of plasma technologies for metals Interest of actors in RF is visible Possible dual use should be considered (e.g. explosives) RusNano-Project: Clean Nanopowder production (Ni, W, Mb, Co, Rh) with Mendeleev Tech. University, St. Petersburg State University etc.

Profile of topics of interest between RF and EU

Topic No. 2	Metallic nanoporous filters/membranes
Area	Nanometals
Characterisation	Nanoporous materials are useful for separation of low molecular weight compounds or even gases. Ceramic materials are used for these purposes in some fields. The brittleness of ceramics however can be detrimental in some cases. Metals show higher ductility at higher temperatures and can also be chemically or catalytically active for separation of various compounds. The control of pore sizes in the low nm-regime including their homogeneous distribution however was not shown for metals so far.
Relevance for grand challenges and potential impact	Topic has high relevance in environmental and energy applications working at elevated temperatures such as oil refineries, gas separation (CO_2), hot gas filtration, catalysis etc.
Main R&D needs and barriers	Metallic foams with pores above 100 nm are described, but nanoporous bulk metals with defined small pores and high flux density combined with good mechanical and thermal properties need more R&D especially as far as processing is concerned. Thin nanoporous metallic films on porous ceramic substrates might also be an option including the use of nanoparticles on ceramics as catalysts
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	First components with pores around 100 nm could be available short term (improved metal foam technologies), below 100 nm or even below 10 nm pore sizes will be available medium to long term
Synergies	RF has competences in the field of nanometals and also interest in components for high temperature use in power plants, oil refineries etc. EU competences in the field need to be explored in more detail, in general there is interest in such materials.
References	Actors in RF visible, EU status in terms of ongoing R&D projects unclear RusNano-Projects in the field of nanoporous membranes only at low to medium temperatures so far.

Profile of topics of interest between RF and EU

Topic No. 3	Metals for extreme conditions
Area	Nanometals
Characterisation	High surface/interface area in nanometals, composites and coatings can improve mechanical and chemical properties, which lead to higher service temperatures, longer service life (abrasive wear) and better corrosion resistance.
Relevance for grand challenges and potential impact	Topic has high relevance especially in the field of energy (including machinery, power plants, aviation, and thermal energy systems) in order to improve energy efficiency and service life.
Main R&D needs and barriers	Further research is needed for a better understanding of the nano-scaled effects on various properties. It is necessary to prove that lab scale results for nano-scaled materials can be implemented in industrial relevant processes. Process control of relevant properties (including modelling and optimisation tools) is key topic.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	First applications have been implemented, however cooperation with industry is necessary to further explore and transfer the technology more markets, which can be done on short to medium time scale.
Synergies	RF has high competencies and a strong interest in the field of metals, processing and modelling. The EU is also interested in advanced materials for extreme conditions, which gives good complementary competencies and interest.
References	Various RF actors available. Materials for extreme conditions including metals part of EU calls RusNano-Project with Kurchatov Institute: Multilayer nano-structured coatings by PVD for highly wear resistant coatings on metals (mechanical engineering, aviation industries etc.)

Profile of topics of interest between RF and EU

Topic No.4	Superhard/tough composites with superconducting properties
Area	Nanometals
Characterisation	Superconductors can find more applications for transmission of electricity if their mechanical properties (brittleness) could be improved. Metal matrix nanocomposites with superconductors use the high surface and interfaces in nano-scaled materials in order to combine excellent mechanical with electronic properties.
Relevance for grand challenges and potential impact	Mechanically robust (hard/tough) superconducting composites can be used for cryogenic techniques, wear resistive parts of superconductive devices and in microelectromechanical systems (energy, ICT). This topic could also be relevant for electric cables (processing of high-temperature superconductors) with improved mechanical properties.
Main R&D needs and barriers	R&D needs for this topic covers all areas from basic understanding/ modelling of the interface metal/superconductor up to processing.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Topic can be implemented only in medium time frame (4-6 years)
Synergies	RF has excellent competencies in the field of metals, superconductors and modelling EU interest in the field probably only modest
References	RF actors and interest visible EU: small markets, see also superconductivity in general.

Profile of topics of interest between RF and EU

Topic No. 5	Vacuum-tight X-ray transparent Beryllium components
Area	Nanometals
Characterisation	Beryllium is used as lightweight material in rocket parts, as window material with high X-ray transparency and in nuclear energy applications including fusion reactors. Beryllium nanopowders can be used to form bulk materials or foils with high transparency combined with good mechanical properties (plasticity, toughness).
Relevance for grand challenges and potential impact	Be is useful as X-ray transparent material for synchrotrons, X-ray equipment, free electron lasers, fusion equipment etc. Some of them are important for energy and healthcare (diagnosis) uses.
Main R&D needs and barriers	Processing of Be-nanopowders for bulk or thin components is not straightforward and more R&D is needed. Alternatives (Be-free materials) with the same performance are also looked for worldwide.
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	Applications of Beryllium powders or composites have been described, but little research so far is dealing with the nanoscale enhancement of mechanical properties in order to be able to form thin components with good mechanical properties. Time scale would be medium.
Synergies	RF has competencies in the field and also strong interest. Politics of the EU not clear in this field, maybe interesting for new nano-infrastructure projects or fusion experiments (ITER) Small industrial relevant market
References	RF has projects in the field, Dual-use has to be checked

Profile of topics of interest between RF and EU

Topic No. 6	Process technology for nanoceramics
Area	Nanoceramics
Characterisation	Ceramics with nano-scaled structures/grain sizes show improved mechanical and thermal properties. Coatings, bulk materials and composites are often based on processing of nanoceramic powders. Beside the production of nanoparticles, the proper processing in order to keep the nanoscale features intact until the final product affords special methods for thermal treatment (fast annealing and sintering processes, use of microwaves or laser systems). Chemical methods allow homogeneous doping of ceramics, distribution of sintering aids or processing of transparent ceramics.
Relevance for grand challenges and potential impact	Topic has high relevance to all areas where ceramics are used mainly energy, health and environment. The topic is also relevant for topic 7 (electroceramics) with uses in the field of ICT. Ceramic multilayer processing: see also thermal barrier coatings.
Main R&D needs and barriers	The basic principles and structure/property relationships for nano-ceramics are well known; however some processing techniques can so far only be used on small scale and have not been implementable in large scale production facilities (especially bulk ceramics). Upscaling processing techniques including chemical nanotechnologies are therefore key areas.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Topic provides a number of close to market applications and the optimisation of processing could be realised on a short term time scale of 2-4 years for coatings, medium term for bulk materials.
Synergies	RF has high competencies in the field of powder processing (metals and ceramics), ceramic coatings, techniques for fast application of high energy doses are well known, and RF has a strong interest in the field. EU member states are also active in the field and therefore provide synergy potential.

Topic No. 6	Process technology for nanoceramics
References	Cooperations between RF and European countries on bilateral scientific basis have been active since quite some time. Projects/ activities between RF and EU: has to be checked. EU-calls have been published in the field, number of existing cooperations between RF and EU needs to be checked. RusNano-Project with Tomsk State University: Nano-Oxide coatings (micro-arc-technology) for metals (wear, corrosion protection); further RusNano-Project: Nano-structured ceramics for tribochemical, high friction (oil industries, metalworking industry) applications

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Profile of topics of interest between RF and EU

Topic No. 7	Electroceramics
Area	Nanoceramics
Characterisation	Nano-scaled electroceramics (coatings, multilayers or composites) can lead to improved electrical and mechanical properties of various components (microelectronic substrates, transducers, sensors, actuators etc.). Piezoceramics without Pb (environmental concerns), electroconductive and ion conductive ceramics e.g. for use in fuel cells are also key areas.
Relevance for grand challenges and potential impact	Topic has high relevance in ICT and in some energy applications (e.g. detectors). Environmental contributions can be the replacement of Pb in piezoceramics and sensors for better control of combustion processes (power plants, automotive).
Main R&D needs and barriers	Influence of grain size and interfaces on electrical properties are complex and not completely understood especially in some multicomponent systems with a high number of additives which are used only in very small amounts. Homogeneous doping is possible by chemical nanotechnology. Understanding has to be improved and processing has to be optimised. Overlap/interference with topic 7 processing of nanoceramics.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Topic provides close to market applications and some improvements can be realised on a short time scale.
Synergies	RF has various competencies (modelling and materials) and interest in the field. The EU is also active in the field. High interest in the EU due to applications in power plants, fuel cells, microelectronics and automotive industries.
References	Scientific bilateral cooperations between RF and EU countries are visible. COST No. 539 action “Electroceramics from nanopowders” with contribution from Russia has been funded in the past. EU-calls/projects have to be checked.

Profile of topics of interest between RF and EU

Topic-No. 8	Coatings for high-temperature shielding
Area	Nanoceramics
Characterisation	Coatings for shielding of metallic structures in power plants working at high temperatures using ceramic multilayers are called thermal barrier coatings TBC. Usually these systems are multilayers combining different functionalities needed e.g. mechanical robustness, thermal/corrosive shielding (of the metal substrate) and IR-reflectivity. Nano-scaled layers show improved functions in all these requirements and can therefore improve the whole system.
Relevance for grand challenges and potential impact	Topic has very high relevance for energy (power plants). Every increase in processing temperature will increase the energy efficiency.
Main R&D needs and barriers	Products using TBC are available, but the actual use of nano-scaled materials has not been implemented to the extent possible. The multifunctionality (multilayers) must be translated into to a simplification in processing of the component in power plants. Processing and materials optimisation are therefore key topics.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Time scale could be short to medium.
Synergies	RF has high competencies in ceramic coatings and also interest in the topic The EU will also be interested to improve TBC in power plants.
References	RF actors available. EU-call materials for extreme conditions probably partly covers the topic

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Profile of topics of interest between RF and EU

Topic No. 9	**Shielding materials for electromagnetic radiation**
Area	Nanoceramics
Characterisation	For shielding of electromagnetic radiation (microwaves, electromagnetic compatibility) metallic or magnetic compounds or electronically conductive ceramics can be used. Electronically conducting nanoparticles, carbon nanotubes or magnetic nanoparticles can be implemented into nonconductive ceramic materials to form shielding composites, with high efficiencies even under high mechanical or thermal stresses. Also electronically conducting ceramics could be used as matrix.
Relevance for grand challenges and potential impact	Topic has high relevance for all components and devices used in various fields e.g. health, energy and ICT, due to the ever increasing density in microelectronic devices.
Main R&D needs and barriers	The combination of electromagnetic shielding capabilities with mechanical robustness of ceramics affords the implementation of nanoparticles in high amounts into ceramic matrices. The optimisation of electromagnetic properties in combination with ease of processing is not solved in many cases.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Proof of principle has been shown, optimisation of processing could lead to solutions within 2-4 years
Synergies	RF has competencies in the field of metallic and magnetic nanostructures and also interest in the application field. The EU is also active especially in the field of electroceramics, which could provide synergies.
References	RF actors visible. There are no significant cooperations between RF and the EU visible in the field. Dual use has to be checked!

Profile of topics of interest between RF and EU

Topic No. 10	Nanocarbon-based sensors (e.g. CNT or particularly graphene)
Area	Carbon-based materials
Characterisation	Carbon-based materials such as graphene or carbon nanotubes (CNTs), possess unique characteristics making them very promising candidates for highly sensitive nanoscale sensors. They have a very high mobility at room temperature and hence a very high sensitivity and are recently discussed as very attractive ultra-sensitive and ultra-fast electronic sensor.
Relevance for grand challenges and potential impact	Such advanced sensors are relevant for chemical sensing functions (e.g. for smog/ gas detection in intelligent buildings) or biological/ biofunctional sensing (e.g. diagnostic devices). They are especially relevant for application fields like environment, safety and health.
Main R&D needs and barriers	R&D needs can be identified in materials and components development and advancing processing technologies. However fundamental understanding and the analysis of kinetics (non-equilibrium transport) of electrons in graphene is of importance and necessary in order to apply it to advanced nanotechnologies as well.
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	Carbon-based sensors are expected to be a medium to long term issue with moderate to extreme importance, depending on the progress achieved and the application field to be used for.
Synergies	Graphene- and other carbon-related structures are assessed as very promising materials with the potential for setting up R&D cooperations: C-based nanomaterials research in general (e.g. also production of controlled amount of material) has been identified as a relevant field for Russian-European cooperation with a long term perspective. Devices based on nanotubes, graphene, etc. are regarded to be a principle research field with strength in Russia and need for cooperation in the EU. On a short term perspective also research on carbons (in particular graphene) for electrodes that are conductive but very soft (see workshop results) has been identified to be of interest. Graphene for use in nanooptics is supposed to be a field with moderate strength of Russia but stronger need for EU cooperation. Thermoelectric elements based on graphene has been identified as a field with particular strength of Russia but with moderate need for EU-cooperation In total, there is a strong competence and interest from Russian researchers and interest as well as synergy potential from EU. The impact in general is high due to the broad potential for applications addressing grand challenges.

Topic No. 10	Nanocarbon-based sensors (e.g. CNT or particularly graphene)
References	The recent Nobel Price on graphene (by the Russian scientists Andre Geim and Konstantin Novoselov who are working in the UK) was mentioned as supporting the above notions and relevance of graphene (compare to further profiles).

Profile of topics of interest between RF and EU

Topic No. 11	Nanomagnets and their optimised production
Area	Nanomagnets
Characterisation	Magnetic materials with a fixed set of magnetic properties (e.g. coercive force, remanent magnetisation, etc.) are of interest to highly integrated devices (e.g. in spintronics) but have also a potential to be used as functionally designed particles, coatings or bulk materials for a broad number of applications. The optimisation of production technologies for nanomagnets is of importance in order to develop new and improved (e.g. by function, efficiency) applications with a shorter time to market perspective.
Relevance for grand challenges and potential impact	Nanomagnets have the potential to contribute to applications in several fields, such as health treatment (e.g. magnetic nanoparticles for diagnostics), Energy (e.g. Nd-Fe-Pb high-energy magnets for electromotor in electric vehicles, generators for wind energy), environment (e.g. nanomagnets for removal of soil contaminants) and ICT (e.g. spintronic devices, sensors).
Main R&D needs and barriers	A number of research needs can be identified, where Russia is strong and EU cooperations would be helpful, such as R&D on size induced magnetism, low-dimensional magnets, nano-structured high-energy magnets, magnetic semiconductors, quantum-spin dynamics in molecular nanomagnets. The focus of the R&D efforts would be on methods and tools to develop and optimise production technologies for nanomagnets (in contrast to nanomagnets for electronic devices, where also materials/components and processing are addressed).
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	The topic is believed to be relevant on a medium term time scale with moderate to very high importance (depending on the subtopic). Commercial applications are not expected on a short term time scale. However in some subtopics and research activities (e.g. measurements on nanomagnets, sensors based on multiferroics) cooperations on a short term time scale could be realised. R&D on nanomagnets for health treatment has a medium term perspective.

Topic No. 11	Nanomagnets and their optimised production
Synergies	Nanomagnetism was suggested as a very good area for collaboration where Russian strengths could be brought in. Russia has much know-how and competencies in the field of nanomagnets and has interest in cooperation with the EU. The USA is said to be very active and a strong competitor. Thus, the need for cooperation is strong for Russia as well as the EU. Synergies between Russia and the EU could help to accelerate the joint development of the field. For example, Russia could support in explaining EU experimental results (medium term issue).
References	-

Profile of topics of interest between RF and EU

Topic No. 12	Electronics / electronic devices based on spintronics
Area	Nanomagnets
Characterisation	In contrast to conventional computing devices, which require electric charges to flow along a circuit, spintronic devices use both the charge (electric property) and the spin (magnetic property) of the electrons. Advanced spintronics, like molecular spintronics will enable the manipulation of spin and charges in electronic devices containing only one or more molecules. The recent evolution and progress at the intersection of spintronics and molecular electronics promises exciting fundamental discoveries and applications in the future. Magnetic (but also non-magnetic) molecules are considered very promising for spintronics, as they can store a bit of information in an extremely small volume. Different materials may be applied, such as magnetic alloys, molecular nanomagnets (e.g. single molecule magnets – SSM), magnetic molecules as well as metamaterials with artificial magnetism, organic spin materials and nowadays graphene. Geim and Novoselov (Russian scientists, Nobel Prize 2010) demonstrated the ability of graphene to magnetise in a way, making it a useful material for spintronics. Besides the above mentioned materials, multiferroics (piezo-/ferroelectrics and/or magnetics) define a further category of materials which should be mentioned in this context. Multiferroic materials are materials (e.g. BFO perovskite as lead-free piezoelectric material or Barium titanate) in which unique combinations of (ferro) electric and magnetic properties can simultaneously coexist and exhibit a strong coupling between the two phenomena. They are potential cornerstones in future magnetic data storage, spintronic devices and sensors if a simple and fast way can be found to turn their electric and magnetic properties on and off.
Relevance for grand challenges and potential impact	Applications for such devices are e.g. hard disk drive read heads, magnetoresistive random access memory (MRAM), spin transistors, spin quantum computing. Such devices may be even powered by harvesting energy exclusively from the environment. Spintronics enables smaller, faster and more energy efficient and (ultralow) power computers and other signal storing and processing devices (e.g. sensors, detectors, memories). The R&D field has a clear and pronounced relevance to the ICT sector; however, the resulting devices may be applied to several markets (e.g. healthcare sector, environmental applications, automotive, etc.).

Topic No. 12	Electronics / electronic devices based on spintronics
Main R&D needs and barriers	R&D is needed from advanced materials and components to processing, methods and the development of tools for fabrication and integration. Challenges are e.g. to develop devices that work at ambient conditions or the development of new physical principles of operation of micro and optoelectronic devices based on functional materials (e.g. multiferroics).
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	The general topic has been identified to have a medium term perspective with moderate to very important relevance. However, due to strong activities in Russia potential cooperations (e.g. on sensors) could be realised on a short term already.
Synergies	Russia has strengths and competencies in fields, such as semiconductor spin manipulation, graphene, nanomagnets and multiferroics. Also, there is a strong interest from Russia and a need for EU cooperation.
References	To our knowledge to date there are no significant joint collaborations.

Profile of topics of interest between RF and EU

Topic No. 13	Plasmonic sensors and devices
Area	Sensors and Instruments
Characterisation	Plasmonics is a new branch of photonics employing surface plasmon polaritons. These arise from the interaction of light with collective oscillations of electrons at metal surfaces. Light at the plasmon frequency excites electronic motions at the surface of metals, which act like antennas and create very strong local optical fields. Plasmon-based devices have been used effectively in detecting and sensing applications, primarily due to their ability to locally concentrate light and due to their high sensitivity to changes in the background environment. Recent investigations on surface plasmon resonance (SPR) promise continuous enhancement of their sensitivity and their lower detection limit (e.g. through progress in the understanding and manipulation of localised SPR phenomena, optical transmission through nanostructures in metals, surface-enhanced spectroscopies, second harmonic interaction, etc.). Thus, surface but also volume plasmonic resonance sensors define a promising field for cooperation between Russia and the EU with the potential for a wide range of applications.
Relevance for grand challenges and potential impact	Effectively sensing the presence of molecules in gases, liquids or biological materials opens potential applications and markets in healthcare, environmental, ICT or further fields. Examples are carbon monoxide detectors (e.g. in private homes), sensors for measuring gases in catalytic nanoreactors and fuel cells, or the monitoring of biochemical processes (e.g. blood glucose sensors in the field of optical biosensing). Also, for many scientific and technical applications, ultrasmall and precise sensors are needed. Furthermore, plasmonics in PV has been pronounced by experts to be of high importance and a short term issue, which could profit from joint collaborations between Russia and the EU.
Main R&D needs and barriers	Detecting and sensing the presence of only small numbers of molecules requires strong amplifications, being able to detect small changes in sensor properties. Plasmonic effects in metal nanostructures are promising to do so, however still plasmonic sensors vary in size from several hundred microns to a few millimetres. This limits their potential for system integration. R&D on materials/components, processing and methods/tools is needed to further improve the sensitivity as well as integration and miniaturisation of size of plasmonics sensors.

Topic No. 13	Plasmonic sensors and devices
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	Sensors and instruments are regarded as short to medium term (2-6 years) R&D fields with moderate to extreme importance, depending on the specific subject. Therein, plasmonics in nanoelectronics is regarded to be highly important and has a short term perspective. Surface and volume plasmonic resonance sensors may be subject for short term cooperations between Russia and the EU (e.g. due to emphasised interest and running research from Russia).
Synergies	Russia has some background and competencies in the field and for the EU a strong need for cooperation has been identified. Interest from Russia has been formulated as well. A high synergy potential as well as impact due to the relevance to broad application fields can be expected.
References	The RAS has proposed a project “Development of highly sensitive plasmic sensor for detection traces in gas and liquid mediums”. On the surface of a metal film of a plasmic sensor they generated 2-D and 3-D nanostructures and it helped to increase the sensor sensitivity. RAS is interested in collaboration with specialists who can give sorbents, selective to different substances. Application of selective sorbents will make it possible to create highly sensitive sensors for detection of traces equal to the dog’s ability to perceive smells (Source: Deliverable D3.1).

Profile of topics of interest between RF and EU

Topic No. 14	Advanced UHV-setup for analysing and modelling surface reactions for nano-electronic devices
Area	Sensors and Instruments
Characterisation	Ultra-high vacuum (UHV) is necessary for a number of surface analytic techniques for microscopy/ spectroscopy such as STM, AFM, SEM, SPM, etc. in order to reduce surface contamination and to improve imaging and atomic resolution. UHV-technology setups on a laboratory level may be combined with one or more such microscopes (also combined with modelling and simulation approaches) to study and manipulate chemical surface/ interface reactions of nanostructures and nano-structured components to create and model electronic devices. The goal would be to develop advanced sensors and instruments as enabling technologies for nanotechnology.
Relevance for grand challenges and potential impact	The topic is relevant to the ICT-sector. Advanced devices, sensors and instruments may also be used for environmental, healthcare or other application fields. Furthermore, improved equipment and analytic techniques are of importance for the researchers themselves to gain more insights and a better understanding of the studies nanomaterials and -structures.
Main R&D needs and barriers	R&D needs focus on improved methods and tools as well as the development of common approaches for the measuring in nano-dimensions.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	Sensors and instruments as a whole are regarded as short to medium term (2-6 years) R&D fields with moderate to extreme importance for Russian and European cooperation, depending on the specific subject. The above topic may be suitable for a medium term perspective.
Synergies	Russia is regarded to be strong in this field and there is a substantial interest from Russian organisations to cooperate with the EU. There is believed to be a strong need for EU cooperation in the field as well. Thus, there is a potential for broader synergies. The impact of the topic is supposed to be moderate due to the indirect relevance to application fields via improved instrumentation.
References	To our knowledge there are no joint projects, programs or activities running between Russia and the EU. The topic has a short term perspective for the cooperations themselves due to existing equipment and background of the researchers at several Russian organisations and laboratories.

Profile of topics of interest between RF and EU

Topic Nr. 15	Theory for nanoscale enhanced high-temperature (high-T) superconductivity
Area	Superconductivity (SC)
Characterisation	Superconductors have no resistance and conduct electricity with 100% efficiency making them attractive for a broad number of energy applications. However, they work only at extremely low temperatures. Thus, high-temperature superconductors (especially with transition temperatures above 77K or −196°C, the boiling point of liquid nitrogen) are of much interest for affordable applications. In the past few years there has been some progress in the field, with the discovery of mercury barium calcium copper oxide as high-T superconductor at 135 K in 2009. However, a unified theory explaining high-T superconductivity and a full understanding of this phenomenon is still out of reach.
Relevance for grand challenges and potential impact	Promising future applications for high-T superconductors (apart from current applications as e.g. in medical imaging), where nanotechnology could play a role, include energy transmission, conversion and storage (e.g. smart grid, electric power transmission lines, transformers, storage devices). Also, nanoscale superconductors would be useful in ICT-devices such as superconductive transistors and eventually in ultrafast, power-saving electronics, e.g. by using superconducting multicomponent thin films.
Main R&D needs and barriers	Theoretical models for explaining (nanoscale enhanced) high-T superconductivity are needed to provide more insights and potential progress in the field.
Time scale ***(short: 2-4 y, medium: 4-6 y, long: 7-10 y)***	The topic has a medium to long term perspective with slight to extreme importance (depending on the progress and applications which may be realised).
Synergies	R&D cooperation on high-T (advanced) superconductors is very important. The EU can benefit from the strong competence and interest from Russia and synergies can be expected to be high.
References	There are some cooperations established (e.g. in developing superconducting devices): The L.D. Landau Institute for Theoretical Physics RAS develops the theory of superconductivity in highly disordered superconducting films since a number of years together with experimentalists from laboratory under the direction of Mark Sankers (Marc Sanquer) at the French research centre CEA-Grenoble.

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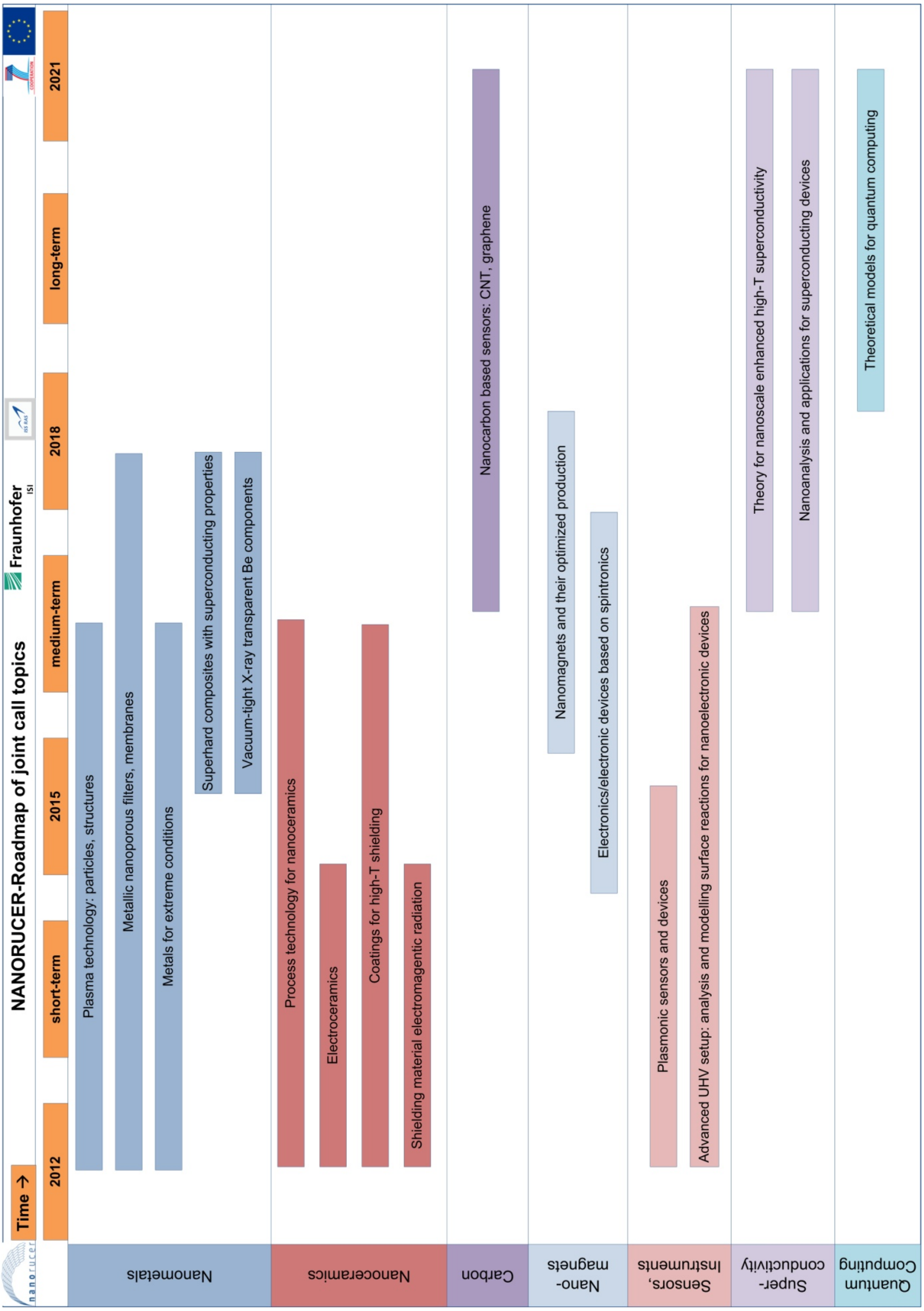
Profile of topics of interest between RF and EU

Topic No. 16	Nano-analysis and applications for superconducting devices
Area	Superconductivity (SC)
Characterisation	Superconducting devices are of interest due to their potential to lead to highly efficient and sensitive applications (no energy loss, no electric resistance). For example, superconducting (SC) tunnel junctions (e.g. SC-ferromagnet heterostructures or SC/metal/SC structures) using the proximity effect or Andreev reflection are of interest for spintronics and quantum computing, superconducting quantum interference devices (SQUIDS) may serve as sensor for magnetism (e.g. for medical devices, in geology for measuring the magnetic field of Earth, non-destructive measuring, etc.), superconductivity in graphene and other artificial nano-structured materials (with an increased set of properties) may enable further new electric devices, or superconducting nanostructures may be used to realise THz-sensors. On the other hand, analytical tools for analysing superconducting behaviour on the nanoscale are needed, in order to better understand the phenomenon and help developing new and advanced superconducting devices.
Relevance for grand challenges and potential impact	Superconducting devices are relevant to applications in the ICT-sector, in particular to spintronics and quantum computing (compare to the respective profiles). Also, superconducting materials with an increased set of properties, can lead to new or improved sensors and electrotechnical devices for medical, health, environmental, energy and further application fields.
Main R&D needs and barriers	R&D needs are identified for improving analytical tools as well as models and theories to understand the physical phenomena and being able to tailor new kinds of superconducting devices.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	The topic has a medium term to long term perspective for applications with slight to extreme importance, depending on the concrete subtopic and potential application addressed.
Synergies	Nanoelectronics with superconducting devices have been identified as a very important topic with a short term perspective for cooperation between Russia and the EU. Russia has strong competencies and interest, such that synergies with the EU (e.g. by combining theoretical work from Russia with experimental work from EU) may be exploited.
References	Some cooperations between Russian and European researchers are already established.

Profile of topics of interest between RF and EU

Topic No. 17	Theoretical models for Quantum Computing (QC)
Area	Quantum Computing (QC)
Characterisation	A quantum computer is a device for computation that makes direct use of quantum mechanical phenomena, such as superposition and entanglement, to perform operations on data. Various concepts exist to create such a quantum computer (e.g. based on trapped-ions, photons, superconductors with SQUBITS, quantum dots, graphene, nanodiamonds, etc.).
Relevance for grand challenges and potential impact	Quantum computers could be used e.g. for breaking computer security codes and are therefore of interest in the context of security and defence. Researchers believe quantum simulation to be one of the most important applications of quantum computing (e.g. to test quantum mechanics and explore new physical phenomena by studying problems in various fields including condensed-matter physics, high-energy physics, quantum chemistry, etc.
Main R&D needs and barriers	Besides the challenges of stabilising the decoherence-time or increasing the number of entangled qubits in such systems, also new theoretical models have to be developed, which can be applied to new promising concepts or candidate systems (e.g. currently graphene-based QC is under discussion) in order to realise quantum computers.
Time scale *(short: 2-4 y, medium: 4-6 y, long: 7-10 y)*	The topic has a long term perspective.
Synergies	Solid state Quantum Information Processing (QIP) and Quantum Computing (QC) have been identified as a very/extreme important topics with a short to medium term perspective for cooperation between Russia and the EU. Quantum computing (in particular with use of graphene but also nanodiamonds) is extremely important with a medium to long term perspective for cooperation (single cooperations between Russian and European researchers are already running). Furthermore, the study of quantum-coherent phenomena in superconducting nanostructures, implementing devices for quantum calculations based on superconducting nanoelectronics, implementing detectors for the conditions of quantum bits, interference effects and geometric phases in superconducting systems have been suggested as potential topics for cooperation by Russian experts. There are strong competences and interest from Russian researchers in the field (mainly in theory), providing synergy potentials with European research activities (e.g. on experiments).
References	-


NANORUCER-Roadmap of joint call topics
Fraunhofer ISI
Time →
2012
short-term
2015
medium-term
2018
long-term
2021
Nanometals
Plasma technology: particles, structures
Metallic nanoporous filters, membranes
Metals for extreme conditions
Superhard composites with superconducting properties
Vacuum-tight X-ray transparent Be components
Nanoceramics
Process technology for nanoceramics
Electroceramics
Coatings for high-T shielding
Shielding material electromagentic radiation
Carbon
Nanocarbon based sensors: CNT, graphene
Nano-magnets
Nanomagnets and their optimized production
Electronics/electronic devices based on spintronics
Sensors, Instruments
Plasmonic sensors and devices
Advanced UHV setup: analysis and modelling surface reactions for nanoelectronic devices
Super-conductivity
Theory for nanoscale enhanced high-T superconductivity
Nanoanalysis and applications for superconducting devices
Quantum Computing
Theoretical models for quantum computing

3.6 Conclusions

The **performance** analysis carried out within NANORUCER indicates that scientific activities in nanotechnology as measured by publication output increased very rapidly worldwide during the last ten years. We observe an average growth rate of nanotechnology publications of 3.5 compared to an average growth rate of 1.3 over all scientific disciplines. The dynamics of nanotechnology publications is mainly driven by Asian countries (Japan, South Korea, China, India and Singapore) and the United States, while in terms of overall publishing activities EU15 is the second most active region with a share of 30 per cent of all publications compared to 41 per cent for Asia and 25 per cent for the USA. Russia is an important player in the world-wide scientific nanotechnology community. With respect to scientific activities, we observe a clear specialisation of Russia in two subfields of nanotechnology, namely nanooptics and nanophysics. On the other hand, the intersection between nanotechnology and life sciences is a field were we observe lower intensities of scientific activities in Russia. Thus, the analysis of scientific performance using bibliometric indicators gives some first ideas about potential nanotechnology subfields for future cooperation between Russia and European countries. The fields of nanooptics and nanophysics, where we observe a clear specialisation of Russia are also areas where most European countries present rather intensive activities. Accordingly, we would expect a number of interesting opportunities for cooperation within these larger subfields.

The patent analyses reveal only low numbers of international patents from Russia. We propose two different explanations for this situation. Firstly, if we assume that publications reflect scientific activities and patent applications indicate activities concerned with applied research, technology transfer and commercialisation, we would conclude that nanotechnology activities in Russia currently are mainly focussed on basic research. Secondly, we could also assume that the low number of patents does not reflect adequately the application- and commercialisation activities in Russia. Rather, it mainly would indicate a low prospensity to protecting inventions with international patents. This could be due to lacking awareness of the role of patents, to language biases, to constraints in financing patent applications or to other reasons. In both cases we would argue for future policy support activities, however, different strategies would be needed in each case. In the first case (low intensity of applied research and commercialisation activities), the task would be to support building up applied research and commercialisation activities. In the second case (low propensity to patenting), supporting activities should focus more on providing information, racing the awareness of the role and significance of patent protection, providing advice in legal issues related to patenting, and finally supporting patenting activities financially.

The **analysis of the Russian SIS in NN** reveals the following strong points: the level of education in particular in the disciplines mathematics, physics, chemistry and material sciences is high in the international context. We also observe a broad science base in nanotechnology-related research based on physical sciences. These include nanooptics, nanomaterials and nanophysics. The institutional set up of R&D organisations is well developed. There are more than 700 organisations with activities in nanotechnology. Most of these belong to the Russian Academy of Sciences. Also infrastructures for nanotechnology-related research are well in place. Not least since the recent initiative on nanotechnology of the Russian presidency there is a growing policy support for nanotechnology in terms of funding and in terms of new initiatives for innovation. Another important driving force of nanotechnology in Russia is the corporation RUSNANO which has been established during the last years as a global player aiming at supporting the commercialisation of nanotechnology. Finally, the geopolitical orientation of Russia is mostly towards the European Union which forms another positive condition for future cooperation in NN.

On the other hand, we also observe a number of weak points of the Russian SIS in NN. These include fragmentation and misbalances between the different constituents of the innovation system. In particular, there is a strong imbalance between activities related to R&D and activities related to innovation, the latter still being rather weak. Concerning different areas of nanotechnology, nanotechnology research related to life sciences has only been emerging recently. Science-industry interaction is rather weak. The private sector provides only low contribution to knowledge generation. In particular, we observe only a low level of in-house R&D activities. Also with respect to innovation activities, the private sector presents a rather weak performance as measured, for example, in the number of patent applications or the number of innovative products. Systems for technical regulations and also the financial infrastructure are developed rather weakly in Russia.

Strong points of the **European SIS in NN** include public funding, not least by the European Union and the available research infrastructures. Also the research base in particular in nanooptics-, nanophysics-, biotechnology- and biomedicine-related nanotechnology can be considered as strong. The institutional framework is well developed. This includes legislation, activities related to environmental, health and safety (EHS) issues, risk assessment activities and joint activities towards standardisation. Since nanotechnology at a first hand will be mainly used in industrial sectors, it is also important to note that those sectors were nanotechnology is expected to exert strongest influence are very well-developed in Europe. These include the automotive industry, energy, chemistry, materials and manufacturing. Compared to the USA and also to the main

Asian competitors, a number of weak points of the European SIS in NN need to be mentioned. These include private investment, in particular venture capital, and a fragmentation of R&D and innovation activities and support, commercial performance and, also an increasing lack of highly qualified human resources.

With respect to future **cooperation between Russia and the EU in NN** results of the NANORUCER project allow the following conclusions. A win-win situation can be generated via cooperation if complementary science bases and research infrastructures are combined. This requires that common goals need to be identified. We suggest that these could be oriented best at the grand challenges (including health, environment, energy and communication) as identified by various international organisations. Mutual benefit could be generated best if Russian competences and capacities in basic and theoretical research activities are combined with the innovation perspective and experience of European R&D actors. Complementary skills could be linked up and further developed also via exchange of personnel between the two regions. In addition, further developing institutional frameworks for nanotechnology in joint activities and in a global context could be a beneficial field of action in the NN context. This includes standards, the EHS framework and regulation.

Starting from these principle considerations we suggest nanomaterials, in particular metals and ceramics, sensors and instruments as fields opening opportunities for cooperation in a short term. Nanomagnets- and nanocarbon-based applications offer mid-term opportunities. Finally, superconductivity and quantum computing provide a number of topics for mid- to long-term cooperation.

As **follow-up activities** of the NANORUCER project a refinement and implementation of the suggested topics into future calls of the European Union would be necessary. In addition, we also strongly propose to monitor the further development of cooperations between the European Union and the Russian Federation in NN. This could in particular contribute to mutual learning from good or best practices.

4 Potential impact and main dissemination activities and exploitation results

The expected impact of the NANORUCER project as described in Annex 1 (description of work) includes the following:

- Improvement of knowledge of the Russian research capacities in nanotechnology and nano-structured materials (NN),
- Provision of reliable information to pave the way for future EU-Russia cooperation in NN,
- Contribution to increasing the cooperation between European and Russian research organisations in the area of NN.

The **improvement of knowledge of Russian research capacity in nanotechnology** was at the heart of the NANORUCER support activity. We considered as not being sufficient just to collect and map information in a systematic way. Rather an assessment of the obtained information along predefined criteria was seen as crucial. For that purpose within the NANORUCER activity a set of indicators and assessment tools was developed in the very beginning and used in the following work packages. The final assessment itself was a combination of desk research, including science and technology indicators and expert assessments.

The key results which are relevant for improving the knowledge of the Russian research capacities in NN are documented in two databases. The first database contains detailed information of more than 80 research organisations active in NN. The second database summarises information of more than 50 companies being active in nanotechnology in Russia and providing also research capacities. Both databases are available on the NANORUCER website (www.nanorucer.eu). Search functions allow detailed searches for specific topics and research activities. Feedback from the research communities and also from representatives of industry indicates that both databases are used intensively in Russia and also in European countries.

In addition to these main databases also databases of other important actors of the Russian nanotechnology SIS were elaborated. These include a database of research infrastructure centres (128 entries), a database of business incubators (33 entries), a database of technology transfer centres (102 entries), and a database of venture funds (14 entries).

All these databases have been described in detail in various reports which have been submitted as deliverables no. 15 and 16 and which are also available on the NANORUCER website.

Based on this information but also using external sources, a careful analysis of the Russian SIS in NN has been carried out. The results of this analysis are documented in an analytical paper - Russian nanotech innovation systems: the key trends, barriers and opportunities -, which has been submitted as deliverable no. 17 and which is also available on the NANORUCER website.

In order to provide **reliable information to pave the way for future EU-Russia cooperation**, the work packages of NANORUCER have been designed in a way that allowed a continuous interplay between data gathering and data evaluation. In particular the same analytical framework developed in work package 1 turned out to be very useful for analysing the situation in Russia as well as in Europe. In addition, specific workshops were carried out to validate the results of the project team by external experts.

The information about the Russian SIS in NN as elaborated during work packages 3 and 4 was complemented by information on the European situation in NN using mainly existing literature. In addition, performance indicators relying on publications and patent applications have been gathered allowing an objective assessment of the performance of various European and other countries compared to Russia in terms of scientific activities and also in terms of activities related to technology development and commercial orientation. The results of the assessment of the European situation have been summarised in deliverable 12 - Thesis paper on European strengths and weaknesses in NN R&D. The assessment has been discussed and validated during a workshop on March 25th, 2011 in Brussels with 14 experts from scientific communities, industry and policy-making representing the countries France, United Kingdom, Belgium, Italy, Switzerland, Germany and Russia. Results of the validation workshop have been submitted as deliverable 13.

Finally, both the situation in Europe and the situation in Russia in terms of nanotechnology-related research have been summarised in a SWOT analysis providing a comprehensive assessment of both sectoral innovation systems.

The NANORUCER activity will **contribute to increasing cooperation between EU and Russian** organisations in several ways. Firstly, the information basis about the Russian SIS in NN allows research groups from Europe and other countries to obtain a better picture of the whole NN-related SIS in Russia and also to identify possible partners for cooperation. In particular the databases developed within NANORUCER are useful tools serving that purpose. Secondly, a main activity within NANORUCER was the identification of possible topics for future cooperation between research groups of Russia and the EU. Within work package 6 a total of 17 core topics for future cooperation were identified which have been classified into the 7 fields nanometals, nanoceramics, carbon-based materials, nanomagnets, sensors and instruments, superconductivity, and quantum-computing. These topics were presented to the research and industrial communities during the final workshop of NANORUCER organised on October 25th, 2011 in Brussels. 31 representatives from research organisations, industrial enterprises and policy-making from European countries and Russia intensively discussed and finally validated the proposed topics. The validated topics for future cooperation including a roadmap indicating the time perspective for the individual topics were summarised and submitted in deliverable no. 13.

Additional important dissemination activities include two project workshops organised in Moscow on January 13th, 2011 and April 15th, 2011. These workshops provided an opportunity to present the results of NANORUCER to key representatives of the Russian SIS in NN. In addition, opportunities for future cooperation were discussed intensively during these workshops. The final NANORUCER workshop on October 25th, 2011 in Brussels provided another forum for disseminating NANORUCER results among the scientific and industrial communities.

In addition, the NANORUER activity was presented at the following meetings:

- Information workshop "Supporting participation of Russian organisations in FP7-NMP projects", June 18th, 2010, Moscow,
- Conference "Industrial technologies 2010", September 8th, 2010, Brussels.

As an additional dissemination activity the results of the performance analysis have been published as a scientific paper in Nanotechnology Law and Business: Reiss, T. and Thielmann, A. (2010): Nanotechnology research in Russia - an analysis of scientific publications and patent applications. In: Nanotechnology Law and Business 7 (4), pp. 387-404.

Finally, the NANORUCER website was used as an important dissemination channel of results of the NANORUCER activity: www.nanorucer.eu. In addition, the NANORUCER website is linked to the Nanofutures platform (www.nanofutures.eu). In order to disseminate results of NANORUCER among the Russian communities in addition to the NANORUCER website main results are also presented on the website of the Russian partner of NANORUCER, ISS RAS: http://issras.ru/eng/.