A Bibliometric Study of Russian R&D on Nanotechnology

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Abstract
Russia has a tradition of high-quality basic research on nanotechnology. A bilbiometric study confirmed that Russian R&D in this field is still strong, but the trend is that its positon is weakening. A patent search, concentrating on two major nanomaterials topics, fullerenes and nanotubes, revealed that there is a substantial basis for innovative applications, but also cause for concern.

Introduction
Russia has a long history of basic research related to nanotechnology. In our view the Russian contribution to R&D in nanotechnology is undervalued due to a number of factors (Markusova et al., 2007). Unprecedented access to world information resources such as the SCOPUS, WOS, and US PTO databases and the creation of the national database of the Russian Foundation for Basic Research (RFBR) allowed monitoring and comparative analysis of nanotechnology development in Russia and other countries.
Nanotechnology has been the subject of several bibliometric studies (e.g. Braun et al., 1997; Terekhov et al., 2006; Bassecoulard et al., 2007; Igami M., 2007; Kostoff et al., 2007; Leydesdorff, 2007; Markusova et al., 2008). Although Russia's research output (RO) decreased during the last decade, Hebert (2007) points out that “Russia made a strong move forwards just in the last year”. In this research-in-progress paper we discuss the preliminary results of our study on the position of Russian R&D in the subfield of nanomaterials.

Background and purpose
This study, part of a Federal program funded through the Russian Academy of Sciences, analyzes the research field of nanomaterials, nanoscale “building blocks” (e.g. nanoparticles, fullerenes, quantum dots, nanotubes and dendrimers). Our goal is to provide recommendations for national and regional science policy. To this end we traced the global integration of Russian R&D in the different areas of nanomaterials as well as the changes in each area, and made comparisons with other countries; we evaluated the impact (citedness) of Russian research in this area, and we estimated patent activity in Russia and the USA.

Methodology
Data were obtained for the years 1991-2007 from searches in the Science Citation Index via Web of Science (WOS) and in the national database of the RFBR (Libkind, 2006), the second largest granting organisation in the world by number of research grants and grantees (The NSF, USA, being first). A terminology dictionary (vocabulary) was compiled as well as a

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frequency distribution of terms. Additional statistics were collected from the NSF, US PTO, and ROSPATENT (the Russian database on abstracts of applications and patents of innovation) databases. Variables used for analysis included: number of research grants, frequency of key words, research output (RO) by organization and by country, internationally collaborated papers (ICP); number of grantees by organization, number of nanomaterials patents obtained in Russia and the USA. The following key words were used to perform a search in various database: nanoparticles or nanosized particle; fullerene*; quantum dot*; nanotube*; dendrimer*. Files extracted from WOS included all types of publications (articles, reviews and etc) with the address “Russia”. Files were checked manually. We did not use the; “Research analysis” option in WOS to investigate international collaboration.

Findings

1878 projects on nanoscience funded by the RFBR in 1993-2006 were identified, in which 10,735 researchers (or 4,156 unique persons) participated. This community consists of 646 research teams working in 187 organizations. In 2005-2006, grants in Russia's civil sector nanotechnology R&D were distributed as follows: organizations affiliated with the RAS obtained 58.8%, higher education institutions 35.4% and research organizations affiliated with the industry 9.4 %. Grant titles were analysed for the frequency of specific words related to nanotechnology. The most frequent of which are presented in Table 1.

Table 1. Term frequency in grant titles.

Keyword	Frequency	Keyword	Frequency
Nanostructure	380	Nanocrystal	104
Fullerene	145	Nanosized	104
Nanoparticle	142	Nanocomposite	86
Quantum dot	125	Nanostructural	57
Quantum well	118	Nanotube	56

For the time period 1993-2006, a comparison of the distribution of grants by the RFBR and the NSF over various subfields of nanomaterials revealed the following: ratio for grants on fullerenes 1.88; quantum dots 1.02; dendrimers 0.57; nanoparticles 0.40; nanotubes 0.35. The distribution of grants by the RFBR and by the NSF on nanotubes and fullerenes are presented in Figure 1, showing a marked contrast in the grants distribution on those two closely related carbon nanostructures, the discovery of which speeded up developments in the field considerably. The impact of these discoveries was so significant that fullerenes and nanotubes continue to occupy high positions in internationally collaborated research.

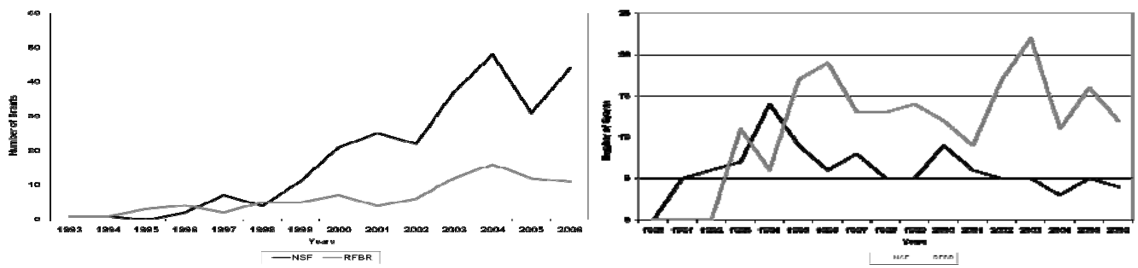

Figure 1. Grants by NSF and RFBR on nanotubes (left) and fullerenes (right)

It is worthwhile to underline that the RFBR began to fund research on dendrimers earlier than the NSF. Following president Bill Clinton's 2000 National Nanotechnology Initiative, the number of NSF grants on nanoscale “building blocks”, with the exception of fullerenes, increased. In the WOS data, the Russian share of research output (RO) in these nano-subfields was 5.6.%, i.e. twice as much as the general Russian share in global RO (S&E Indicators, 2008). In 1997-1998 Russian RO reached its highest share at about 10%. Since 1998 the

Russian share decreased. The average growth rate of world RO was about 20.8% with an upward trend, compared to l7.5% for Russia with a tendency to saturation. In our view, this negative trend must be partially attributed to the lack of attention from the Russian government for nanotechnology. Russia only introduced its national nanotechnology program in 2007, a few years later than other developed countries.

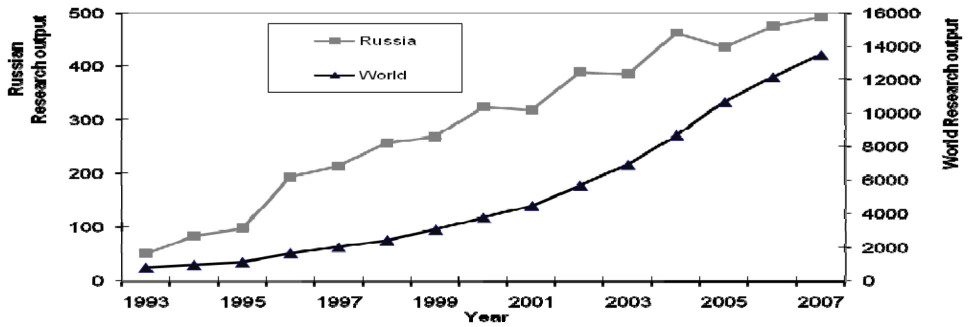

Figure 2. Research output on nanomaterials, WOS, 1993-2007

According to data extracted from WOS for 1993-2007, more than 75 countries were involved in fullerene research. Russia was in fourth position among the top ten by research output on fullerenes (third for 1993-2004). Other leaders include the USA, Japan, China, Germany, France, the UK, Italy, Switzerland and India. In Russia the research on new forms of carbon began at the A.N. Nesmeyanov Institute of Organo-elemental Chemistry of the USSR in the 1960s. However, full-scale research did not start until the 1990s, when it was stimulated by the State Program “Fullerenes and atomic clusters” funded by the Ministry of Science& Technology in 1993. About 26 % of the Russian RO in this field consists of internationally collaborated papers. We found that a community of researchers from Moscow, St-Petersburg, Nizhny-Novgorod, Novosibirsk, Krasnoyask, Ufa, Troitsk and Chernogolovka (the former two are science cities situated in the Moscow region) is working and publishing on an international level. Russia collaborates on fullerene research with all leading countries except China. The most internationally oriented are the research team from Moscow State University, the A.N.Nesmeyanov Institute of Organo-elemental Chemistry of the RAS, the Institute of Chemical Physics Problems, RAS (Chernogolovka), the A.F. Ioffe Physical-Technical Institute of the RAS (St-Petersburg), and the Institute of Solid State Physics, RAS (Chernogolovka). Research on fullerenes boomed worldwide and carbon nanotubes were discovered in 1991. As figure 3 shows, research interest in nanotubes has been larger than on fullerenes since 2002. In the field of nanotubes the percentage of internationally collaborated papers (ICP) in the Russian RO decreased from 22.2% in 1992-2002 to 18.6 % in 2003-2005.

Of 3390 papers published worldwide on nanotubes in the period 1992-2001, 88.8% were cited by 2003 with an average of 31.6 citations per paper. In comparison, for Russian RO on nanotubes in the same period the citedness was 80.2% with 14.5 citations per paper. We would like to emphasize that these numbers are very high for Russian publications. According to the National Science Indicators, Standard Version for 2000-2004, only 44.4% of the total Russian RO was cited with an average of 3.8 citations per paper.

We compared the citedness of papers on nanotubes with only Russian authors with that of Russian ICP. Our study revealed that international collaboration had a positive impact on the citedness of Russian papers: 78.7% with 8.7 citations per paper on average for exclusively Russian papers, 83.3% and 25.5 citations per paper for Russian ICP. In comparison, the citedness of US papers was 87.4%, with an average of 48.8 citations per paper. Among the papers which were cited one hundred times or more, 68.5% were published by US researchers. Among these highly cited papers 16.7% came from Japan, 8.3% from France, 5.5% from the Netherlands and the UK each, and 4.8% from Switzerland. Only one paper had

Russian co-authors. Among the ten most highly cited papers (675 to 1400 citations), US authors were involved in six, Dutch in three, French and Japanese in two, and Brazilian and Swiss in one. The USA, which shifted its priority from fullerenes to nanotubes in 2000, is now clearly leading in this subfield.

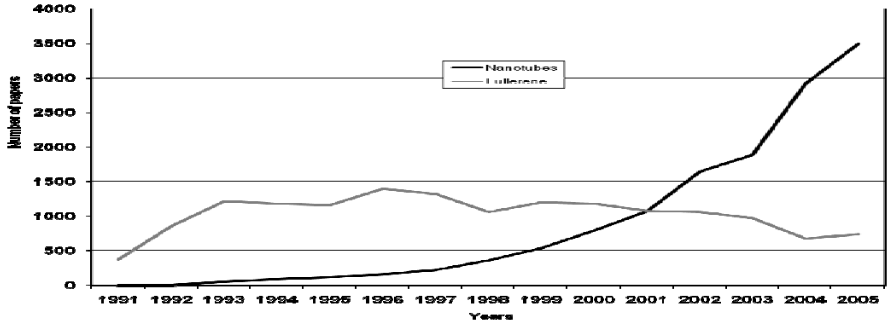

Figure 3. Research output on fullerenes and nanotubes, WOS, 1991-2005

Nanotubes' high potential for applications was an impetus for researchers around the world to seek patents. A search in the US PTO database shows that the US Patent Office has issued 953 patents on inventions related to the creation or usage of nanotubes (11 % of the total number of patents in nanotechnology). The Russian government not only funds R&D in Russia, but also pays significant attention to the patenting activity. The Russian national patent database ROSPATENT contains information on 630684 patent applications and patents for the period 1994-2008. Figure 4 shows the result of a search in this database, looking at the occurrence of the words nanotubes and fullerenes in patent titles and abstracts.

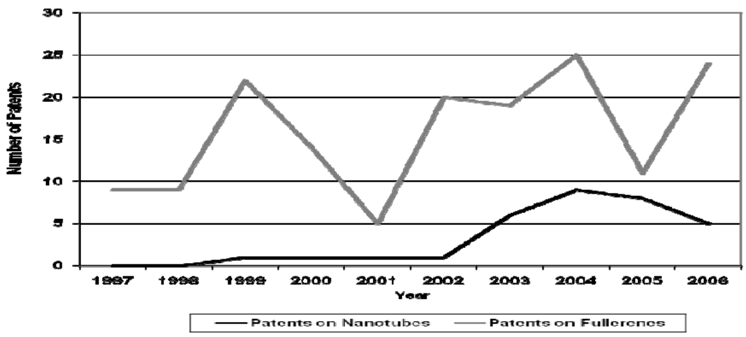

Figure 4. Russian patents on nanotubes and fullerenes, ROSPATENT, 1997-2006

In Russia only 50 patents were issued on nanotubes in the period 1999-2007, compared to three times that number on fullerenes. We suspect that, at least in some cases, Russian inventors may not have sufficient financial means to maintain a patent over a longer period of time. Of course, in that case the inventor loses his rights.

There is a basis for industrial development of fullerenes in St-Petersburg and Nizhny-Novgorod. The commercialization of nanotubes has proved to be more difficult. There was an attempt to develop multiwall nanotubes in Tambov city. Single wall nanotubes, which could be used in high-tech applications, are very expensive and were produced by only a few labs. Nanotubes were included in the “List of critical technologies” signed by President V. Putin in 2006. Researchers from the Institute of Chemical Physics Problems of the RAS developed a new method for their synthesis, but this development did not reach large scale production. The potential of the Russian market attracts foreign companies. Two Russian patents on nanotubes were given to the Hyperion Catalysis International (USA) and the Rosetter Holdings (Cyprus).

Areas, in which Russian R&D on nanomaterials is strong and could lead to successful technological breakthroughs, include:

- The development at the Institute of Spectroscopy of the RAS of ultra-hard and super-hard fullerene C60, which obtained one US and four Russian patents;
- The invention of a fullerene-oxygen-iodine laser by researchers from the Research Institute of Laser Physics (St-Petersburg);
- The discovery of ferromagnetic properties of polymerized fullerene C60; an internationally collaborated paper published in Nature in 2001 by authors from the A.F. Ioffe Physical-Technical Institute of the RAS (St-Petersburg) was highly cited (more than 200 times), in particular in view of possible application opportunities.

Conclusions

Russia continues to play an significant role in research on nanomaterials, the most important of which so far have been fullerenes and nanotubes. The number of RFBR research grants and of patents awarded by ROSPATENT on fullerenes exceed those on nanotubes. Russian R&D did not shift its focus from fullerenes to nanotubes when most other researchers worldwide did. Russia ranks eighth in research on nanotubes, third on fullerenes. The citedness of Russian papers on nanotubes was 80.2% (twice the average value for Russians papers in general), with an average of 14.5 citations per paper (3.5 times as many as the average Russian research paper). However, the trend is that these numbers are decreasing, so this promising area of Russian research seems to be under pressure. If the goal set by V. Putin of achieving global leadership in nanotechnology is to be reached, sufficient investments in both basic research and applications on the basis of research results are necessary, and budget reservations for these activities should be ensured.

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