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Russia's Nuclear Energy Expansion

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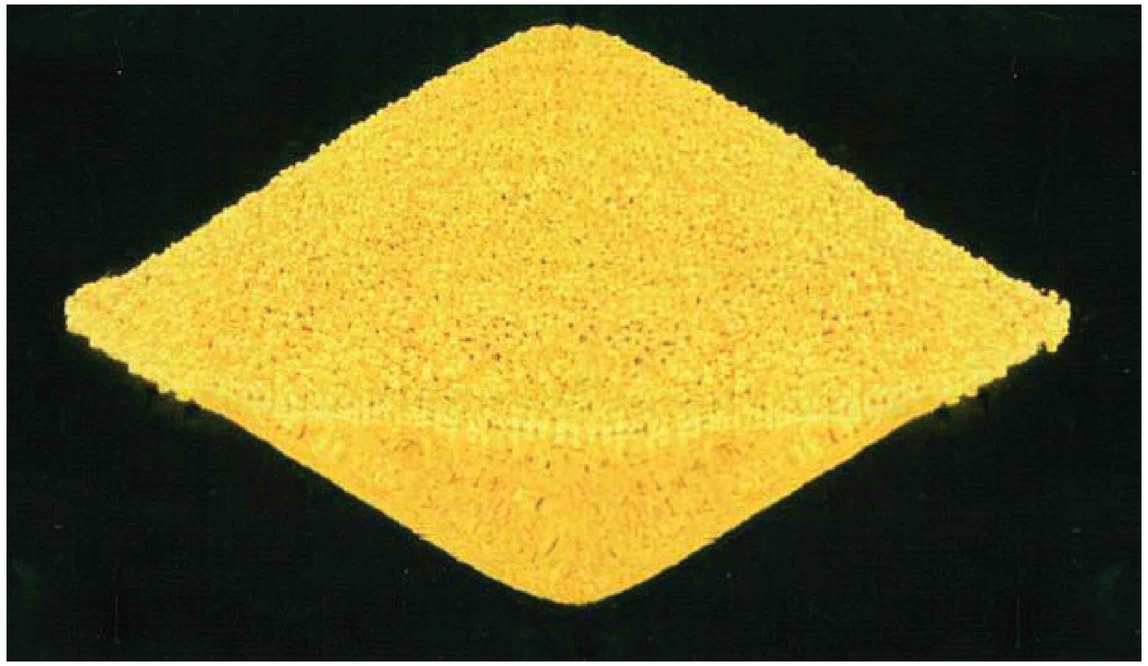

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Defence Analysis

Susanne Oxenstierna

Russia's Nuclear Energy Expansion

Cover: *Yellow cake* (an uranium concentrate powder). http://en.wikipedia.org/wiki/Yellowcake. Retrieved 2010-10-25.

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Sammanfattning

Ryssland är en internationell aktör på kärnkraftsområdet, vilket gjort det angeläget att undersöka vad den pågående expansionen inom detta område har för inhemska och internationella effekter. Studien ger en översikt av nuläget inom rysk kärnkraft och utvecklingsplanerna fram till 2030. Vid sidan av denna beskrivning undersöker studien följande frågeställningar:

- Vilken roll spelar kärnkraften i inhemsk och utländsk efterfrågan på ryska energiresurser?
- Vilka är resursrestriktionerna i kärnkraftsutvecklingen?
- Är Ryssland på väg att bli en civil kärnkraftssupermakt?
- Vilka är effekterna på säkerhet och spridning av mer kärnkraft i Ryssland?

Studien visar att kärnkraft kommer att spela en allt större roll i den ryska energiförsörjningen, men gas och kol kommer fortfarande vara de viktigaste bränslena i el-genereringen fram till 2030. Kärnkraften är speciellt viktig för elförsörjningen i Europeiska Ryssland och för att man ska kunna frigöra mer gas för export. Rysslands exporterar kärnkraftverk till bl a Indien, Iran, Kina och Turkiet där man varit framgångsrik i att få kontrakt i konkurrens med västliga tillverkare. Ett tiotal kärnkraftverk är kontrakterade och Ryssland förhandlar 2010 om ytterligare lika många. Ryssland försörjer alla de kärnkraftverk man har byggt utomlands med bränsle och tar även tillbaka det använda kärnbränslet för förvaring och återvinning. Anrikningsteknologi och anrikningsanläggningar, kan användas i militärt syfte, och genom att erbjuda färdigt kärnbränsle och återvinning minskar Ryssland spridningsriskerna. Ryssland har ansenliga urantillgångar i form av naturligt uran, stora lager av låg-anrikat och hög-anrikat uran och exporterar kärnbränsle över hela världen. Ryssland har också visat stort intresse för att köpa urangruvor och uran utomlands. Kärnkraftsindustrin har en hel del kapacitetsproblem, vilket kommer att orsaka förseningar, men det är sannolikt att dessa problem kommer att lösas under det närmaste decenniet.

Nyckelord: Ryssland, energi, kärnkraft, elektricitet, uran, anrikning,

Summary

The main purpose of this study is to provide an overview of the situation in the Russian civil nuclear energy industry in 2010 and the plans for the future up to 2030. This includes both the development of nuclear power plants at home and abroad and the Russian management of the nuclear fuel. Beside this descriptive purpose, the central issues that the study investigates are:

- What role does nuclear power play in domestic and foreign demand on Russia's energy resources?
- What are the resource constraints on the development of Russia's energy sector in general and of the nuclear energy sector specifically?
- Are the present expansion plans realistic and is Russia on the way to becoming a 'nuclear energy superpower'?
- What are the security implications of more nuclear power in Russia?

The results of the study are that nuclear power will play an increasing role in domestic electricity generation which will enable Russia increasingly to replace gas, which can be exported, with nuclear power at home. Russia is already a strong player in the nuclear export markets where it is constructing or negotiating contracts for about 20 reactors in competition with Western companies. Russia has almost half of the world's uranium enrichment facilities and is able to provide clients with nuclear fuel made from natural uranium, weapons-grade uranium, or spent fuel. Russia controls the fuel cycle of the nuclear plants that it exports, that is, it provides the fuel and repatriates it. In addition, the Russian state nuclear corporation Rosatom is buying stakes in uranium mines all over the world, which indicates that Russia intends to be a strong provider of the fuel for nuclear energy also in the future. The timetable of the present expansion plans is probably over-optimistic, but capacity problems and manning problems in the nuclear industry will most likely be overcome during the next decade.

Keywords: Russia, nuclear power, nuclear reactor, nuclear fuel cycle, uranium

Preface

The Russia project at FOI, *Russian Foreign and Security Policies* or RUFS, has traditionally devoted time and effort to Russian energy matters, mainly from the perspective that Russia is an energy power and that energy is central to Russia's foreign affairs and security policies. For natural reasons, gas and the geopolitics of pipelines were the focal point of the RUFS reports in this area during the 2000s. This study continues along the lines of this tradition, but also includes the economic and energy policy perspectives in the analysis in order to gain a deeper understanding of Russian policies in the energy field and their implications.

Nuclear energy was chosen as the object of the study because nuclear power is experiencing a renaissance worldwide and Russia is expanding rapidly in this sphere. The global expansion of nuclear energy has so far not attracted any substantial amount of attention among social scientists, and I believe it is time we started looking at its economic and political implications and not leaving the topic entirely to science and technical specialists. This study is a small contribution that may hopefully spur more discussion and further work.

I would like to thank Carolina Vendil Pallin, Mattias Waldenvik, Bengt Johansson, Stephen Fortescue, Julian Cooper, Fredrik Westerlund, Jakob Hedenskog and Margarita Balmaceda for valuable comments and suggestions on earlier drafts of the paper. Special thanks also to Waclaw Gudowski who arranged a very inspiring meeting with nuclear scientists at the ISTC (International Science and Technology Center) during my field mission in Moscow at the beginning of the project.

Stockholm 31 October 2010

Susanne Oxenstierna

Acronyms

ARMZ	Atomredmetzoloto, Russia's uranium production company
AST	*atomnaya stantsiya teplosnabzheniya* (atomic heat station)
bn	billion
BN	breeder reactor
ELF	French oil company
ES	Energy Strategy
EU	European Union
FBR	fast breeder reactor
GDP	gross domestic product
GW	gigawatt of electricity
HEU	highly enriched uranium
HR	human resources
IAEA	International Atomic Energy Agency
ICNND	International Commission on Nuclear Non-proliferation and Disarmament
IEA	International Energy Agency
INSC	International Nuclear Safety Center
IPFM	International Panel on Fissile Materials
ISAB	International Security Advisory Board
ISTC	International Science and Technology Center
kW	kilowatt
kWh	kilowatt hours
LEU	low-enriched uranium

LWGR	light-water graphic-cooled reactor
MIFI	Moscow Engineering and Physics Institute
MOX	mixed oxides, a blend of oxides of plutonium and natural uranium, reprocessed uranium, or depleted uranium
MW	megawatt of electricity
NRC	Nuclear Regulatory Commission
NTI	Nuclear Threat Initiative
PWR	pressurized-water reactor
RAO EES	the Russian State Electricity Company up to 2008.
RBMK	light-water graphite-cooled reactor
R&D	research and development
Rosatom	Russia's State Atomic Energy Corporation
RUR	Russian roubles
TEK	*Toplivno-energeticheskiy kompleks Rossii* (Fuel and Energy Complex of Russia)
TWh	terawatthours
U	Uranium
USD	United States dollar
USSR	Soviet Union
VVER	Russian pressurized-water reactor
WANO	World Association of Nuclear Operators
WNA	World Nuclear Association
WNN	World Nuclear News

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1 Introduction

The Russian State Atomic Energy Corporation *Rosatom* has launched an ambitious nuclear energy programme with the aim of building 24 new nuclear power reactors in Russia during the coming 10 years. By 2020, 23 percent of domestic electricity should be generated by nuclear power, and in 2030 the share will be 25 percent, according to Rosatom, which manages all Russian nuclear technology development, both military and civil. The tentative plans up to 2025 stipulate that Rosatom should be running over 50 reactors by then, compared to the total of 32 in operation in 2010. In addition to this domestic expansion, Rosatom intends to build around 20 reactors abroad over the next two decades.

Many questions arise around the Russian nuclear renaissance. Does Russia really require these reactors, that is, will demand for electricity increase so much, and can Russia build so many reactors in such a short time span, after a pause of 25 years in the development of the nuclear industry? Is nuclear power competitive compared to other fuels and is it possible for the country to deliver about three or four reactors per year, when at the height of nuclear power development in the Soviet Union, the industry only produced on average two per year? Is there capacity in the nuclear engineering industry to deliver the necessary machinery? Are there enough specialists in the pipeline to build and run the new facilities? Is there fuel for all these reactors? What are the security implications of the nuclear expansion and will Russian nuclear power be safe?

The boost currently being given to nuclear power, not only in Russia but in the whole world, is explained by concern to secure a sufficient energy supply for the future and to protect the environment at the same time. Hydrocarbons pollute the environment and will become scarcer and harder to extract in the future. Currently, the only alternative source of energy that can replace oil and gas in sufficient volumes and produce satisfactory amounts of electricity is nuclear power. Unlike traditional fuels, nuclear power produces almost no carbon dioxide emissions.

In November 2009, the Russian government approved the *Energy Strategy up to 2030*, which is a three-stage plan to develop the energy sector in the country.[1] This strategy gives a road map for the development of the energy sector and a focus on energy efficiency.

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[1] Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010.

1.1 Purpose of the study

The main purpose of this study is

- to provide an overview of the situation in the civil nuclear energy sector in Russia in 2010 and the plans for the future up to 2030.

This includes both the development of nuclear power plants and the Russian management of the nuclear fuel.

In addition to this descriptive objective, the central aspects that the study investigates and discusses are:

- What role does nuclear power play in domestic and foreign demand for Russia's energy resources?
- What are the resource constraints on the development of Russia's energy sector in general and of the nuclear energy sector specifically? Are the present expansion plans realistic?
- Is Russia aiming at becoming a major international player in this area? A sort of 'nuclear energy superpower'?
- What are the security implications of more nuclear power in Russia?

1.2 Method and limitations

The research takes its starting point in the stated objective and research questions. The work has been explorative. Official materials on Russian nuclear developments from Rosatom, the World Nuclear Association (WNA), the International Atomic Energy Agency (IAEA) and the new Russian Energy Strategy up to 2030 (ES) have been used in particular. In addition, articles and other literature by Russian and Western energy specialists and reports from international organizations such as the International Energy Agency (IEA) and World Association of Nuclear Operators (WANO) have been studied. Media cuttings and other Internet materials have been used to follow recent developments. In June 2010, the author made a fact-finding mission to Moscow and met and discussed issues relevant to this paper with several Russian energy specialists and international nuclear scientists.

The main limitation of the study is that it has been researched in a short time and that the author is an economist and not a technical specialist, which entails that the technical aspects of nuclear power development are not dealt with. Likewise, ecological aspects of the Russian energy development are beyond the scope of the study. The same is true for the environmental damage caused by past nuclear activities and accumulated nuclear waste. The issue is briefly touched upon in section 5, but this is a major problem in Russia and deserves its own study. Fact finding for the first draft of the paper ended on 30 August 2010, and subsequently data have been added only to finalise and clarify the analysis. A draft version of the report was discussed at a seminar at FOI on 7 October 2010.

1.3 Outline

The second section of the paper describes the development of nuclear power in the Soviet Union and Russia up to the time of the Chernobyl accident in 1986. The third section gives an overview of Rosatom's development plans. In Section 4 we discuss the main lines of the new Russian Energy Strategy up to 2030 and its implications for nuclear energy development. The fifth section discusses the situation in uranium production, nuclear fuels and Russia's fuel management. The sixth section discusses safety and proliferation issues. The seventh and last section draws the conclusions of the investigation.

2 From Soviet to Russian Peaceful Nuclear Power

The first Soviet atomic bomb was detonated in August 1949. It had been developed by Soviet nuclear physicists under the leadership of Igor Kurchatov at 'Laboratory 2' in Moscow, now the Kurchatov Institute. Research for military purposes was based on the advanced nuclear physics research that took place in the USSR as part of the war effort. The atomic bomb project started seriously in 1943. Before the bomb, the physicists had constructed an experimental 4-megawatt (MW)[2] reactor, F-1, on the October Field in Moscow, to study fission. The reactor came on line in December 1946.[3]

2.1 The communist 'Atoms for Peace'

Development of the peaceful nuclear industry did not take off in earnest until Khrushchev's 'Thaw'. Khrushchev abandoned Stalin's autarky in economics, politics and culture and once again opened up opportunities for Soviet scholars to exchange views with colleagues in the West, as had been possible before the 1930s. Khrushchev wanted the Soviet Union to compete with the West and show its superiority. Soviet physicists were thus allowed to compete openly with their Western colleagues. This entailed personal contacts and cooperation, and after two decades of complete isolation Soviet scientists were once again able to subscribe to foreign journals and share papers through the post and in meetings. Between 1954 and 1957, some 1 500 Soviet scientists travelled abroad.[4]

Russia's first nuclear power plant, and the first in the world to produce electricity to feed into an existing grid, was a 5-MW reactor, named *Atom mirnyi* – peaceful atom or AM – built in Obninsk, a town in the Kaluga region, 100 km south-west of Moscow, in 1954. The next step was the Kurchatov Beloyarsk Atomic Electric Power Station which was built in Zarechnyi, a village 60 km outside Sverdlovsk. The first Beloyarsk reactor of 100 MW of electricity was ready in February 1964. Additionally, the reactor produced thermal power of 285 MW which met the heating and other energy needs of the 15 000 persons living in the small town. The second block of 200 MW was ready in 1967.[5] These were reactors of the

[2] 1 megawatt – MW – is equal to 1 million watts. 1000 MW is equal to 1 GW. See Annex 1 'On Watts' for more help with energy measurements.
[3] Josephson, Paul R. (2000) *Red Atom* (Pittsburgh, PA, First University of Pittsburgh Press), pp. 16–17.
[4] *Ibid*., p. 10.
[5] *Ibid*., pp. 31–32.

same type as the one in Obninsk, so-called LWGRs – light-water graphite-cooled reactors.

Atomic communism

After these first tests, in 1971–73 the first large production models were commissioned. The first 1000-MW light-water graphite-cooled reactor RBMK[6] were installed at the Lenin Atomic Power Station in Sasnovyi Bor outside Leningrad on the Bay of Finland. The first block went on line late in 1973 and the second in 1975. The Soviet Union built similar nuclear stations in Smolensk, Kursk and Volgodonsk, and Chernobyl. The last RBMK plant to be built, the queen of these plants, was Ignalina in Lithuania. Each reactor was a 1 500-MW electric power and 4 800-MW thermal power unit. The first Ignalina RBMK-1 500 reactor came on line in 1983, and the second in 1987. At this point atomic communism saw no limit to its prospects. Two more 1 500-MW units were scheduled for 1990 but were not built. In 1986, the Soviet physicists were nurturing aspirations to build even larger RBMKs. A 2 000-MW RBMK was designed but would never see the light.[7]

No new RBMK reactors have been built since 1986. Russia has 11 RBMKs in use and they have all been given an extended service life up to around 2035. By then hopefully other types of reactors will be on line and able to deliver the necessary electricity (see Section 3).

Pressurized-water reactors

In parallel to the unique channel-graphite RBMK reactors, the Soviet Union developed *pressurized-water reactors* – in Russian abbreviated to VVER – a technology that was also developed in Western countries and is usually referred to by the acronym PWR. The first commercial VVER reactors were built in Novovoronezh about 40 km from Voronezh. The first reactor was a VVER 210 MW electric unit; it came on line 1964. The second block of VVER 365 MW of electricity was started in 1969 and the following units 3 and 4, each of VVER 440 MW of electricity, followed rapidly in 1971 and 1972. The fifth Novovoronezh unit, a VVER 1 000 MW of electricity, was turned on in 1980, 10 years after construction commenced. By then the Russian VVER industry had its own machine tool industry. In practice however, the central command system

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[6] See Annex 2 for a description of different reactor models.
[7] *Ibid*., pp. 34–36.

was not able to not make firms work well together and there were constant delays.

The VVER reactors were exported to the satellite states in Eastern Europe: Bulgaria, Hungary, East Germany and to Finland (Loviisa). Countries such as Poland, Hungary and Romania were able to tap into the *Mir* (peace) grid for power sharing that provided power mainly from the Soviet nuclear stations in southern Ukraine.[8] The VVER reactors are those that are used in the Russian nuclear energy programme up to 2020. They are also the reactors that Russia is exporting (see Section 3).

Breeders

A third line in the development of Soviet nuclear energy is the breeder reactors. The Soviet breeder programme commenced in 1948 under the direction of Alexander Leipunskiy. The first prototypes came in the 1970s, and the first breeder reactor installed to the electricity grid was the BN 350 fast breeder reactor (FBR) in Shevchenko (now Aktau) in Kazakhstan on the Caspian Sea. In addition to power the BN 350 produced plutonium. It also provided energy for desalination to supply fresh water to the city of Shevchenko. This nuclear power station was closed in 1999. The first breeder nuclear station in Russia was built in Beloyarsk in Sverdlovsk region. Boris Yeltsin, who at this point was the first secretary of the Sverdlovsk regional Party Committee, supported the project by ordering local collective farmers to help in construction of the plant. The BN 600 with its 600 MW electric and 1 470 MW thermal energy was the largest breeder reactor in the world. It came on line in April 1980.[9]

Russia still has a strong breeder programme and is planning to have a BN 800 MW installed by 2014 (Table 3.2). Breeders have a superior fuel economy compared to the VVERs. There is no other breeder producer in Europe. (See also Annex 2 on fast reactors and fuels.)

AST nuclear heating

In the Soviet Union there were also plans to create special nuclear heating stations, called ASTs (*atomnaya stantsiya teplosnabzheniya*) or nuclear city heating station, GASTs. The idea of these was to distribute the heat produced at the nuclear heating plant directly to the population in nearby large cities such as Gorky, Voronezh, Minsk, Odessa, Kharkov and Volgograd. This required that these plants be located just a few kilometres away from the cities in question. According to Soviet engineers, a 1 000-MW AST would provide heat to 400 000 households and save 900 000 tons of coal or oil per year. After Chernobyl, public protests made it impossible for these ASTs to work, except in Voronezh. The

[8] Marple, David R. & Marilyn J. Young (1997) *Nuclear Energy and Security in Former Soviet Union* (Boulder, CO, Westview Press) p. 23

[9] *Ibid*., p. 74.

protests against the AST in Gorky were particularly serious. In the end it could not be constructed and had to be cancelled.[10]

Despite the problems with the ASTs in the past, the Energy Strategy up to 2030 indicates that thermal nuclear stations will be used to provide 5 GW of the yearly thermal capacity (see Section 4).

Hence, within 20 years the power standards of Soviet reactors increased 200-fold from 5 000 kilowatts to 1 GW electric power, and 100-fold from 30 000 kilowatts to 3 GW thermal power. By the mid-1980s the USSR had 25 nuclear power reactors in operation.[11]

2.2 Chernobyl – the end of atomic-powered communism

The Chernobyl accident on 26 April 1986 began with a safety experiment on 25 April. The operator wanted to see how long a spinning turbine could continue to provide electric power to the plant during an emergency reactor shutdown. The test went fatefully wrong and the reactor, Chernobyl's unit 4 reactor, became unstable.[12] In Ukraine, over 150 towns and villages, with a total of 3 million residents and over 40 000 hectares of arable land, were directly affected by Chernobyl. Soviet medical personnel concluded that over the next 70 years there would be 40 000 premature deaths in the European territory of the USSR caused by the accident.[13]

Reactors 1 and 3 were still in operation in Chernobyl up to 1996 and 2000 respectively. There were around 4 000 employees there running these reactors, with the only benefit of threefold salary premiums. The Ukrainian Parliament voted on several occasions to close the station permanently, but the demand for the electricity to power the distressed Ukrainian economy kept the plant open.[14] From 1991, Western nations pushed Ukraine to shut down the Chernobyl plant. After the fire at reactor 2 in 1991, it was closed and it was decided that the remaining two reactors would be taken out of service in two stages, with unit 1 being shut down by the year 1996 and unit 4 by the year 2000. To meet the year 2000 deadline, the last reactor was shut down on 15 December 2000.

Even after the last reactor was shut down, people continue to work at the Chernobyl plant and will continue doing so until reactor units 1, 2 and 3 are

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[10] *Ibid*., pp. 41–42.
[11] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, p. 1.
[12] Josephson, Paul R. (2000) *Red Atom* (Pittsburgh, PA, First University of Pittsburgh Press), p. 257.
[13] *Ibid*., p. 260.
[14] *Ibid*., p. 266.

totally decommissioned, which is expected to take years. The first stage of decommissioning is the removal of the highly radioactive spent nuclear fuel, which is placed in deep-water cooling ponds. However, these storage facilities are not suitable for long-term containment, and those on site do not have the capacity for all the spent fuel from units 1, 2 and 3. A second facility is planned that will be suitable for dry long-term storage and have the required capacity. Removal of uncontaminated equipment has begun at unit 1 and this work could be completed by 2020–2022. The isotope responsible for the greater part of the external gamma radiation dose at the site is caesium-137 which has a half-life of about 30 years. It is likely that with no further decontamination work the gamma-ray dosage at the site will return to background levels in about 300 years.

Chernobyl led to the Soviet authorities abandoning new nuclear plants under construction and in the pipeline. All in all about 100 000 MW (100 GW) in planned capacity was abandoned.[15] It was the end of atomic-powered communism. Table 2.1 shows that the Soviet nuclear power plants were crucial for the electricity supply in the post-Soviet republics, and especially so in Lithuania and Ukraine. In order to decommission the reactors at Ignalina and the remaining two reactors at Chernobyl, the countries had to seek other solutions to satisfy their electricity demand first, which explains why this was such a long process.

Table 2.1. Soviet nuclear energy legacy 1995

Country	Total number of reactors	% of total electricity production
Russia	29	13.1
Ukraine	15	43.8
Lithuania	2	85.8
Armenia	1	37.0

Source: International Nuclear Safety Center (INSC), *Soviet Book*, p. 1, http://www.insc.anl.gov/neisb/neisb5/3c_sb.pdf.

2.3 Reorganization of the industry

Despite difficulties in the 1990s, the authorities have managed to keep the civil and defence-related nuclear establishment together. The Ministry of Atomic Energy of the Russian Federation (Minatom) was established on the basis of the Ministry of Nuclear Power Industry of the USSR in January 1992. In September 1992 Boris Yeltsin, by a decree 'On the operating organization of nuclear power plants of Russia', established the Russian State Concern for Production of Electric and Thermal Energy at Nuclear Power Plants – Rosenergoatom. This

[15] INSC, *Soviet Book*, http://www.insc.anl.gov/neisb/neisb5/3c_sb.pdf. Retrieved 2010-08-10, p. 88.

decree resulted in all 10 Russian nuclear power stations being incorporated in Rosenergoatom by April 2002.[16] In March 2004, Rosenergoatom was replaced by the Federal Atomic Energy Agency. Thereafter the State Atomic Energy Corporation Rosatom was established by presidential decree in December 2007. In March 2008, the corporation took over the functions and authorities of the now abolished Federal Atomic Energy Agency.[17] Former Prime Minister Sergey Kirienko was appointed the Director General of the new corporation.[18]

Closed towns

The organization of the development of nuclear energy in the Soviet Union was closely linked to the military use of nuclear power and most research establishments had a dual purpose in their operations. The Soviet nuclear industry had under its control 10 closed cities,[19] known officially as ZATO – closed administrative territorial units. In these both nuclear weapons-related research and civil nuclear research and development (R&D) took place. After the dissolution of the Soviet Union, all these cities changed their names. All are still legally 'closed', though some have become accessible to persons from outside these cities and for foreign visitors with special permits. Currently around 2 million people live in the closed cities.[20] In July 1992, the 'Law on closed administrative territorial units' was adopted. The law specifies the legal status of closed administrative territorial units and the specifics of the local self-government and social security of people living there. (On the activities in these closed cities, see Annex 3, Closed Towns Involved in the Development of Nuclear Technology.)

The closed cities still play a major role in Russian nuclear developments and the management of nuclear waste. They house major research establishments, training institutions and design bureaux. The enrichment facilities that Russia uses for making nuclear fuel and for the downblending of highly enriched uranium (e.g. for the *Megatons to Megawatts* programme), as well as the interim storage of spent fuel, are located in these cities. (See further Section 5).

Licensing and monitoring

The Federal State Technical Inspection, Rostekhnadzor, is the supervisory body on ecological, technological and nuclear issues. Its functions include, for example, the passage of regulatory legal acts, supervision and oversight in the field of environmental protection with the aim of limiting harmful technogenic

[16] http://museum.rosenergoatom.ru/eng/archive/documents/index.wbp.
[17] One reason for the abolition of the agency and the introduction of a state corporation could have been the need to act as a commercial structure in export affairs.
[18] Mr Kirienko was Russian Prime Minister between March and August 1998.
[19] The Defence Ministry also has under its jurisdiction another 30 such closed zones.
[20] Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org. Retrieved 2010-08-20, p. 26.

impact, safety when working with the subsoil (e.g. mining), protection of the subsoil, industrial safety, the safety of electrical and thermal facilities and networks and atomic energy safety, but its functions do not include the development, preparation, testing, operation and use of nuclear weapons and military atomic facilities. Rostekhnadzor must grant Rosatom's nuclear constructions licences, but it does not seem that it actually inspects nuclear plants to see if safety routines are being followed. Russian Government Resolution No. 404 of 29 May 2008 transferred Rostekhnadzor to the Ministry of Natural Resources and the Environment; previously, the service had been directly subordinate to the government.[21] This transfer gives the inspectorate a weaker position vis-à-vis Rosatom.

Uranium mining and fuel fabrication

Uranium mining and fuel fabrication are managed by subsidiaries of Rosatom. These companies are presented in Section 5.

[21] Rostekhnadzor's website only says the basic functions of the federal service on ecological, technological and nuclear supervision and that it is the federal enforcement authority which is carrying out functions on acceptance of normative legal certificates, to the control and supervision over spheres: See further http://eng.fsetan.ru/about/. Last accessed 2010-12-06..

3 Revival of Nuclear Power

The use of nuclear power should be seen in relation to other sources of energy and the development of energy demand. A reasonable question is: Why would Russia, which is so richly endowed with hydrocarbons, start expanding electricity generation by nuclear power? Or, how much of the electricity-generating capacity should be nuclear? Many factors influence this choice and countries take different stands depending on, for example:

- *Political considerations*. In many countries there is no nuclear power or its development is restricted due to high risk aversion among the population to radioactive leaks or accidents and fears about the proliferation of nuclear fuel and waste. Alternatively, expanding nuclear power may be attractive for a country in order to make it more independent in electricity generation and less dependent on imported fuels like coal, oil and gas. Furthermore, nuclear power is a high-technology area and can be used to promote development in science and advanced technology. President Medvedev wants to promote Russia as an innovative economy and nuclear technology is one of the priority areas.

- *Environmental considerations*. Nuclear power gives clean electricity and is almost free of emissions. As the goals for diminishing carbon emissions have become tighter, nuclear power has become more attractive. Up to now, the major remaining problem is how to manage the radioactive waste resulting from nuclear electricity production. However, how to 'close the fuel cycle', that is, reprocess and reuse the spent fuel and waste, is a priority issue for R&D in the area. Russia has the advantage of public opinion being fairly positive towards nuclear power, even if there have been protests.

- *Cost competitiveness*. Nuclear power stations are expensive to build but do not have any major costs for fuel, unlike fossil fuel-fired power stations. In a nuclear power station fuel accounts for 20 percent of total costs while in gas-generated plants it is around 80-90 percent. With new high-capacity reactors with an expected service life of 40–60 years, nuclear power can compete with other fuel alternatives.

- *Technical advantage*. Nuclear technology is extremely complex and takes many years to develop. In Russia, as in some Western countries, civil nuclear technology was developed in parallel to its military exploitation. The Cold War left Russia with a considerable infrastructure for nuclear physics and design, uranium mining and, not least, fuel production. There is also a vast nuclear waste heritage of the Cold War that requires decommissioning and management. By expanding civil nuclear power, human and technical competence may be retained and developed.

The Russian boom in nuclear power coincides with the attempts to increase energy efficiency. Russia's energy intensity is two or three times higher than that of any other industrial country, and three times the world average (IEA, 2009). This is because of the outdated Soviet-era capital stock and the Soviet policy that increases in energy consumption were a sign of progress.[22] In June 2008, President Medvedev signed a decree calling for an overall reduction of the energy intensity of GDP by 40 percent by 2020 compared to 2007.[23]

3.1 International nuclear energy development

According to the WNA in 2010, there were 438 reactors operating in 30 countries. These provide 3 000 terawatt hours (TWh),[24] or 15 percent of the world's electricity. In addition, 52 reactors are under construction, 143 are being planned and 344 are proposed. The potential electricity generation of all these reactors is 7 000 TWh. The reactors currently in use are mainly so-called Generation III reactors. The next generation of Generation IV[25] reactors are expected to provide enhanced safety, minimal generation of waste, and reduced proliferation risks, and will produce hydrogen, heat and desalination of seawater.[26]

The IEA 2008 Blue Map[27] scenario assumes 1 300 nuclear power stations in the world by 2050. Additionally, to save the environment, in parallel to a gradual changeover to non-fossil fuel alternative energy sources, more efficient use of energy must be achieved.[28]

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[22] Charap, Samuel & Georgi V. Safonov (2010) 'Climate Change and Role of energy Efficiency', in A. Aslund, S Guriev & A. C. Kuchins (eds.), *Russia after the Global Economic Crisis*, Peterson Institute for International Economics, Center for Strategic and International Studies, New Economic School, New York, June, p. 140.

[23] Ministry of Economic Development of the Russian Federation (2010), http://www.economy.gov.ru/minec/activity/sections/efficiency/efficiency/. Retrieved 2010-04-05. Power and energy 10/12/09, http://www.ngpowereu.com/news/russian-energy-efficiency/. Retrieved 2010-08-20.

[24] 1 terawatt-hour (TWh) corresponds to 1 bn kilowatt-hours (kWh).

[25] Generation III reactors are a development of any of the Generation II nuclear reactor designs incorporating evolutionary improvements in design developed during the lifetime of the Generation II designs. These include improved fuel technology, superior thermal efficiency, passive safety systems and standardized design for reduced maintenance and capital costs. Generation IV refers to a set of theoretical nuclear reactor designs currently being researched. Most of these designs are not expected to be available for commercial construction before 2030.

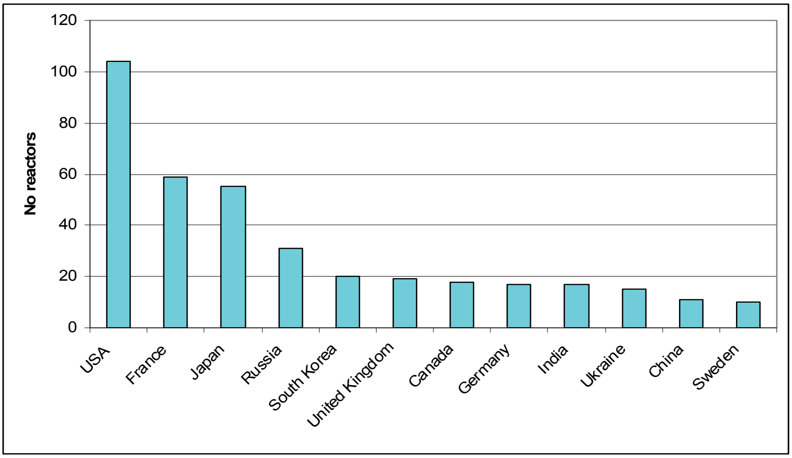
[26] KVA (2010) Royal Academy of Sciences, *Energy Resources and their Utilization in a 40-year Perspective up to 2050. A synthesis of the work done by the Energy Committee at the Royal Swedish Academy of Sciences*, May, p. 3.

[27] The Blue Map scenario entails halving the 2005 level of carbon dioxide emissions by 2050. The ACT Map scenario entails a return to the 2005 level by 2050.

[28] *Ibid.*, pp. 4–5.

Figure 1 depicts the number of reactors in selected countries. As can be seen, the USA has over 100 reactors and France and Japan 59 and 55 respectively. Russia follows after Japan. In the EU countries, 30 percent of electricity generation comes from nuclear power and about 18 percent of installed capacity in the EU area is nuclear.[29] There will not be any significant new nuclear capacity in the EU area until 2011, when the new Finnish nuclear station, Olkiluoto, is expected to come on line. Later, during the next decade a new French reactor currently under construction will come on line, and it is expected that some new reactors may be connected towards the end of the next decade in Great Britain.[30] In April 2010, Italy agreed on four reactors from the French company Areva, which is the dominant nuclear reactor constructor left in Western Europe.[31]

Figure 1. Number of reactors in selected countries 2007



Source: Table A1, Annex 4.

3.2 Nuclear power plants in operation

Russia's existing nuclear plants are mainly located in European Russia (Figure 2). There are 32 operating reactors totalling 23 GW (gigawatts of electrical power). As shown in Table 3.1, the oldest of these reactors are from the 1970s and 11 are of the RMBK type, that is, light-water graphite reactors, which

[29] IEA (2008) International Energy Agency *IEA Energy Policy Review. The European Union* (OECD/IEA, Paris)**,** p. 165.
[30] *Ibid*., p. 164.
[31] Announced on Areva's website, http://www.areva.com/EN/news-8330/areva-signs-three-major-agreements-with-partners-in-italy.html.

are unique to the Soviet Union. Russia has stopped producing these reactors, a half-built fifth RMBK reactor at Kursk was cancelled in 2010, and the main type that is now being produced and installed is the VVER or V reactors which correspond to Western PWRs, i.e. pressurized-water reactors.

Figure 2. Russian nuclear power plants

Source: IAEA (2009) *Russian Federation, Country Profiles*, http://www.pub.iaea.org/MTCD/publications/PDF/cnpp/cpuntryprofiles/Russia/.

However, the lifetime of the RBMK reactors has in most cases been prolonged from the original 30 years by 15 years, and these reactors will be on line until 2035 (Table 3.1). In 2009 they provided 45 percent of Russia's nuclear-generated electricity, which means that it is difficult just to close them down.[32] The extensions to their lifetime follow significant design modifications made after the Chernobyl accident. After these modifications a 45-year lifetime is seen as realistic for the 1 000-MW units.

[32] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, p. 4.

Table 3.1. Nuclear power reactors in operation in Russia 2010

Reactor	Type V=PWR	MW net, each	Commercial operation	Scheduled close	Life extension
Balakovo 1	V-320	950	May 1986	2015	
Balakalova 2	V-320	988	January 1988	2017	
Balakalova 3-4	V-320	950	April 1989, December 1993	2018 2023	
Beloyarsk	BN-600 FBR	560	November 1981	2010	Prepared for +15
Bilibino 1-4	LWGR EGP-6	11	April 1974- January 1977	2019-2021	+15 years to 2034-2036
Kalinin 1-2	V-338	950	June 1985, March 1987,	2014, 2016	
Kalinin 3	V-320	950	December 2004	2034	
Kola 1-2	V-230	411	December 1973, February 1975	2018, 2019	+ 15 years to 2033-2034
Kola 3-4	V-213	411	December 1982, December 1984	2011 2014	
Kursk 1-2	RBMK	925	October 1977 August 1979	2021 2024	Kursk 1 + 15 years to 2036
Kursk 3-4	RBMK	925	March 1984 February 1986	2013 2015	
Leningrad 1-2	RBMK	925	November 1974 February 1976	2019 2022	+15 years to 2039-2041
Leningrad 3-4	RBMK	925	June 1980 August 1981	2011	Len 3 + 15 to 2025 Len 4 prepared for +15
Novovoronezh 3-4	V-179	385	June 1972 March 1973	2016, 2017	+ 15 years to 2031
Novovoronezh 5	V-187	950	February 1981	2011	2035 after upgrade
Smolensk 1-3	RBMK	925	September 1983, July 1985, January 1990	2013, 2020	
Rostov 1	V-320	990	March 2001	2030	
Rostov 2	V 320	990	March 2010	2040	
Total: 32		**22 811 MW = 23 GW**			**+ 5 700 MW**

Source: WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, pp. 4-5.

3.3 Expansion of nuclear power plants

In 2006 Rosatom announced a target of nuclear plants providing 23 percent of Russia's electricity by 2020 and 25 percent by 2030, but the 2007 plans approved by the government have scaled this ambition back a little, and in 2009 it was pruned back even more.[33] Over 20 reactors are to be built during the next 10 years, which implies between two and four per year (tables 3.2 and 3.3). In addition, Russia's ambition is to export 10-20 reactors during the same period (table 3.4).

Table 3.2. Nuclear reactors under construction in Russia 2010

Plant	Reactor Type	MW	Status, start of construction	Commercial operation	Contractor and estimated cost
Kalinin 4 Tver region	V-320	1000	Under construction	October 2011	
Vilyuchinsk. Kamchatka region. Floating NPP - *Academician Lomonosov*	KLT-40S	40x2	Start const May 2009	2012	St Petersburg Baltiysky Zavod, RUR 9.98 bn. Public-private partnership between Rosatom and En+ (associate of EuroSibEnergo and majority owner of Rusal)
Beloyarsk 4	BN-800 FBR	880	Under construction	2014	OKBM Afrikantov RUR 64 bn (USD 2.05)
Novovoronezh II-1	VVER 1200/V-392	1200	Start constr. June 2008	2012-2013	Moscow AtomEnergoProekt USD 5 bn
Novovoronezh II-2	VVER 1200-392M	1200	Start costr. July 2009	2015	
Leningrad II-1	VVER/V-392M	1200	Start constr. October 2008	October 2013	St. Petersburg AtomEnergoProekt Len II-1 & 2 USD 6.6 bn
Subtotal of 7 reactors under construction		**5 600 MW**			

Source: WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, pp. 9-10; 11-14.

[33] *Ibid*.

Table 3.3. Reactors officially proposed in Russia, 2010

Plant	Reactor Type	MW	Status, start of construction	Commercial operation	Contractor and estimated cost
Rostov/Volgodonsk 3	VVER 1000/V-320	1100	Planned 2010	2014	Nizhnyi Novgorod Atomenergoproekt (NN AEP) RUR 146 bn (USD 5 bn)
Rostov/Volgodonsk 4	VVER 1000/V-320	1100	Planned 2011	2016	
Leningrad II-2	VVER 1200	1200	Planned 2011	2016	St. Petersburg AtomEnergoProekt Len II-1 & 2 USD 6.6 bn
Leningrad II-3	VVER 1200	1200	Planned 2011	2016	St. Petersburg AtomEnergoProekt
Leningrad II-4	VVER 1200	1200	Planned 2014	2019	
Obninsk, Pilot project	SVBR-100	100	Planned 2011	2015	AKME Engineering (owned by Rosatom) and EN+. RUR 16 bn
Baltic 1 (Kaliningrad)	VVER 1200	1200	Planned 2011	2016	49% equity from the EU. St Petersburg AEP, Baltic 1 & 2 RUR 194 bn, USD 6.6 bn. CEZ, Iberdrola, Siemens
Baltic 2 (Kaliningrad)	VVER 1200	1200	Planned 2014	2018	
Seversk 1	VVER 1200	1200	Planned 2010	2016	Moscow Atomenergoproekt RUR 134 bn, USD 4.4. Alstrom atomenergomash
Seversk 2	VVER 1200	1200	Planned 2012	2017	
Nizhegorod 1	VVER 1200	1200	Planned 2012	2017	NN AEP 4 units RUR 269 bn, USD 49.4
Nizhegorod 2	VVER 1200	1200	Planned 2013	2018	
Tver 1	VVER 1200	1200	Planned 2012	2017	NN AEP
Tver 2	VVER 1200	1200	Planned 2013	2017	
Tsentral 1 Kostroma region	VVER 1200	1200	Planned 2014	2019	Moscow AEP, RUR 130 bn; USD 5 bn.
Tsentral 2	VVER 1200	1200	Planned 2014	2019	
Beloyarsk 5	BREST (lead-cooled fast reactor)	300	Planned 2016	2020	Federal Target Programme RUR 140 bn (USD 3 bn)
Subtotal of 17 planned units		18 300			

Source: WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, pp. 9-10; 11-14.

Further power reactors have been proposed in the Leningrad region, in the north-west of Russia and in the Tatar Republic of a combined capacity of 6.6 GW, and also in the regions of Yaroslav, Chelyabinsk and Vladimir, but their status remains unclear.[34]

Electricity exports

The Baltic plant in Kaliningrad will serve as a replacement for the closed Ignalina RBMK plant in Lithuania, which provided over 85 percent of Lithuania's electricity. (Since 2000, Ignalina's former clients have been served by gas-generated electricity from Kaliningrad.) The Russian plant competes with the Lithuanian proposed unit at Visaginas (near Ignalina). The Baltic plant is intended to be integrated with the EU grid and export two-thirds of its power to the Baltic states, Germany and Poland. Rosatom expects its Western partners to contribute 49 percent of the equity.[35]

Aluminium and nuclear power

Aluminium smelting is energy-intensive and requires reliable low-cost electricity to be competitive. Since 2007, RUSAL, the world's largest aluminium producer, and Rosatom have investigated the possibility of nuclear power generation and an aluminium smelter at Primorye in Russia's Far East. The cost of the project is estimated at USD 10 billion (bn), involving four reactors of 1 000 MW, resulting in a total capacity of 4 GW. The aluminium production would require about one-third of the output from the nuclear plant and electricity exports to China and North and South Korea are envisaged. This project seems to have replaced an earlier initiative between the Siberian-Urals Aluminium Company SUAL and Rosatom for a joint project at Kola.[36] Furthermore, in 2010 RUSAL announced that it would build its own 2 000-MW nuclear power station in Balakovo (where there is already a 4-GW plant) on the Volga River 800 km south-east of Moscow. Rosatom planned to expand the Balakovo plant for some time but the two planned units were dropped from the 2008 plan as they were low priority for the united electricity grid supply.[37]

Transition to fast reactors

In January 2010, the government approved the federal target programme 'New-generation nuclear energy technologies for the period 2010–2015 and up to 2020', designed to bring a new technology platform for the nuclear power industry based on fast neutron reactors. There are three types, the BREST, SVBR and sodium-cooled types. It is hoped that the federal target programme will enable commercialization of new fast neutron reactors for Russia to build in 2020–2030. Rosatom's long-term strategy up to 2050 involves moving to

[34] *Ibid.*, p. 13.
[35] *Ibid.*, p. 12.
[36] *Ibid.*, p. 14.
[37] *Ibid.*, p. 15.

inherently safe nuclear plants using fast reactors with a closed fuel cycle and mixed oxides – MOX- fuel.[38]

The Russians plan to have technical designs for Generation IV reactors working in closed fuel cycles by 2020. Detailed designs for a multi-purpose fast neutron research reactor MBIR should be ready by 2014.[39] Relative to current nuclear power plant technology, the claimed benefits for Generation IV reactors include:

- Nuclear waste that lasts decades instead of millennia
- 100–300 times more energy yield from the same amount of nuclear fuel
- The ability to consume existing nuclear waste in the production of electricity.

3.4 Floating nuclear power plants

Russia has built nuclear icebreakers since 1959 when the icebreaker *Lenin* was launched. Since then the Arctic fleet has grown and nuclear icebreakers have proved technically and economically essential in the Russian Arctic where operating conditions are beyond the capability of conventional icebreakers.

In the 2010s, Rosatom is using the experience gained from building the icebreakers in the planning and construction of seven or eight mini floating nuclear power plants by 2015. The stations are designed to have a 70-MW capacity and are based on the reactor type used in Soviet icebreakers. The floating nuclear power plants are intended for places that are difficult to reach, e.g. near the coast. The first of them is the *Academician Lomonosov*, with intended completion in 2010. It is designated for Vilyuchinsk, Kamchatka. Each floating nuclear power plant has two 35-MW KLT-40S reactors.[40] In August 2008, Rosatom transferred the contract from Sevmash in Severodvinsk to the Baltiysky Zavod shipyard at St. Petersburg, which has experience in building nuclear icebreakers. The *Alexander Lomonosov* was launched in St Petersburg in June 2010.[41]

The second floating nuclear power plant is planned for Pevek on the Chukotka Peninsula in the far north-east, near Bilibino. The third is for Cherski research station in Yakutia, the two sites comprising the Chaun-Bilibino energy hub. Up to eight further floating nuclear power plants are on the drawing board. Four floating plants are designated for northern Yakutia in connection with the Elkon uranium mining project in southern Yakutia. Five are intended for use by

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[38] See Annex 2 for more description of reactors and fuels.
[39] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, p. 14.
[40] *Ibid*., p. 16.
[41] The Voice of Russia, 30 June 2010, http://english.ruvr.ru/2010/06/30/11101839.html. Retrieved 2010-07-10.

Gazprom for offshore oil and gas field development and for operations on the Kola Peninsula near Finland and the Yamal Peninsula in central Siberia (see Figure 3).[42]

Figure 3. Locations for the deployment of floating nuclear power plans

Source: WNA, http://www.world-nuclear.org/info/inf45.htm. Retrieved 2010-10-19.

3.5 Russia's exports of nuclear power plants

Economic reforms following the collapse of the Soviet Union resulted in an acute shortage of funds for nuclear development and a number of projects were stalled. However, by the late 1990s exports of reactors to Iran, China and India were negotiated and thanks to these exports it was also possible to revive Russia's domestic construction programme as far as funds allowed.[43] The Tianwan Nuclear Power Plant is the largest economic cooperation project between the People's Republic of China and the Russian Federation. The first phase of the Tianwan Nuclear Power Plant (two VVER 1000-MW units) was constructed as part of an Intergovernmental Agreement on cooperation in construction of nuclear plants in the People's Republic of China, and was concluded on 18 December 1992. On 30 December 1997, China and Russia signed a contract

[42] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, p. 16.

[43] Oxenstierna, Susanne (2009) *Russia in Perspective. Scenarios of Russia's Economic Future 10 to 20 Years Ahead*. FOI-R--2774--SE, p. 33.

to build the Tianwan Nuclear Power Plant jointly. The original cost of the project was estimated at USD 2.5 bn, but has now reached over USD 3.2 bn.[44]

Table 3.4. Russian planned exports of nuclear power plants 2010

Country	Name of station	No. and type of reactors	Time
India	Kudankulam 1-2, 3-4, 5-6	6 VVER-1000	2011 2012-2017
India	Haripur, West Bengal	6 VVER 1000 10 000 MW	
Bulgaria	Belene 1-2	VVER-1000/V-446B 2000 megawatts	2013, 2014
Iran	Bushehr 1-3	3 VVER-1000/V-446 1000 MW	1-opening 2010 2-start constr. 2011 3-constr start 2012
China	Tianwan 1-2	2 VVER-1000	April 2010. delayed
China	Tianwan 3	VVER	
Turkey	Akkuyu	4	Start constr. 2014

Source: RIA Novosti, 10 March 2010, http://en.rian.ru/analysis/20100310/158148685-print.html. http://www.atomstroyexport.ru/project/eng. Retrieved 2010-08-24; http://www.csmonitor.com/World/Europe/2010/0512/Russian-deal-puts-Turkey. Retrieved 2010-06-28.

India has cooperation on nuclear plants with all the major reactor constructors in the world (Russia, the UK, France, and the USA). In March 2010, India and Russia agreed on a road map for Russian reactors in India. Apart from the already agreed four reactors in Kudankulam, two more are planned for the same station and two at Haripur.[45] India has also signed a USD 700 million deal with Russia for the supply of 2 000 tons of nuclear fuel.[46]

Thailand and Indonesia have demonstrated a keen interest in floating nuclear power plants. The financing of the project might come from a USD 150 million loan from China. In October 2003, Rosatom signed a Protocol of Cooperation with South Korea for the potential purchase of a floating nuclear power plant. The fuel used for floating nuclear power plants is uranium enriched to 40 percent uranium-235. According to engineering standards, some 960 kilograms of uranium will be stored at each floating plant.[47]

[44] NTI, http://www.nti.org/db/china/jiangsu.htm.
[45] India Juris (2010) *Nuclear Energy in India & Foreign Investment*, http://www.india.juris.com. Retrieved 2010-09-07.
[46] http://www.world-nuclear.org/info/inf53.html. Retrieved 2010-09-07.
[47] http://www.bellona.org/english_import_area/international/russia/nuke_industry/co-operation/39015/2010-08-24.

4 The Energy Strategy up to 2030

In November 2009, the Russian government adopted a new Energy Strategy (ES) for the period up to 2030.[48] This strategy shows that Russia intends to expand and profit from all its different energy resources and also to try to modernize its energy sector and improve the efficiency of energy production and energy use over the next 20 years. According to the ES, the use of nuclear energy is to be expanded substantially up to 2030. The ES is to be implemented in parallel with the attempts to modernize the Russian economy and lower its energy intensity .

The changes envisaged in the energy sector will demand capital, R&D, and human resources. The technology now available in the Russian energy industry was developed during the Soviet period and its specialists were trained during that time. Considerable capital resources are needed to revive the sector. Although there is considerable state involvement in the energy sector, parts of it are deregulated and a large part is organized in the form of state companies, for example, the giants Gazprom and Rosatom. It follows that there will be competition for resources and lobbying will play a role in accessing state support for more investment. The possible, and probably necessary, cooperation with Western partners with superior technology will also be an interesting marker in this process.

Russia is extremely rich in energy resources. In 2008, it was endowed with around 6 percent of world oil reserves, 23 percent of total gas reserves (first place in the world), and 19 percent of world coal reserves (second place in the world), and it produces over 5 percent of the world's electricity.[49] Furthermore, Russia came third in the consumption of energy in the world, after the USA and China, with 6.1 percent of world energy consumption in 2008.[50] In 2008, Russia produced energy equivalent to nearly 1 800 million tons of conditional fuel[51] and

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[48] Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), Ministry of Energy RF, http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010.

[49] TEK (2009) *Toplivno-energeticheskiy kompleks Rossii 2000-2008* (Russia's Heat and Energy Complex 2000-2008) (Moscow, Ministry of Energy of the Russian Federation, Institute of the Energy Strategy), pp. 14; 19; 24; 29.

[50] *Ibid*., p. 10.

[51] Conditional fuel is a standard measure in the Russian energy literature used to compare different energy types. 1 ton of conditional fuel is equal to 7 Gkal; 873 square metres of natural gas; 27.8 British thermal units (BTU); and 0.7 tons of oil equivalent (MacKinsey, 2009, p. 5). In the Western literature, the term 'short tons' of coal is often used in comparisons between fuels. 1 short ton of coal is equal to 907.2 kg (2 000 pounds).

used 990 million tons domestically. The difference, 813 million tons of conditional fuel, almost half of production, is exports.[52]

According to the base scenario of the Energy Strategy, the production of energy will increase to 2 300–2 500 million tons of conditional fuel up to 2030,[53] that is, an increase of 28–29 percent. Domestic consumption of energy will be at 1 380–1 570 in 2030, an increase of 39–59 percent compared to 2008.[54] Exports are estimated to rise to 974–985 million tons of conditional fuel in 2030, which corresponds to an increase of 19–21 percent between 2008 and 2030.[55] Thus, domestic consumption is expected to rise faster than export.

4.1 Electricity production and capacity

It is as a source of electricity that nuclear power is of primary interest. As seen in Figure 4, total production of electricity in Russia is expected to double up to 2030 and will be between 1 800 and 2 200 TWh. This is a high estimate if we compare it with the IEA reference scenario for Russia, which shows a much more modest trend, up to 1 424 TWh in 2030 (Figure 4).

All types of power generation will increase, but the proportions accounted for by different fuels will change in such a way that nuclear power will deliver 20 percent of power in 2030 instead of 16 percent in 2008. According to the ES, the share of electricity from thermal power stations should be reduced. These run mainly on coal and oil, which means that electricity generation should become cleaner (Figure 5).

How much capacity does Russia need to install?

The Energy Strategy assumes almost a doubling of capacity up to the year 2030, from the present 225 GW to 355–445 GW, a change of up to 220 GW. As can be seen in Figure 6, this is considerably higher than the IEA reference scenario for Russia, and one of the reasons why the IEA assumes much lower production of electricity in 2030. Up to 2020 the planned increase in the ES is between 50 and 60 GW. The capacity in nuclear power should be increased by 4–9 GW up to 2015, by 13–17 GW up to the 2020s, and in all by 28–38 GW up to 2030 (Figure 6).

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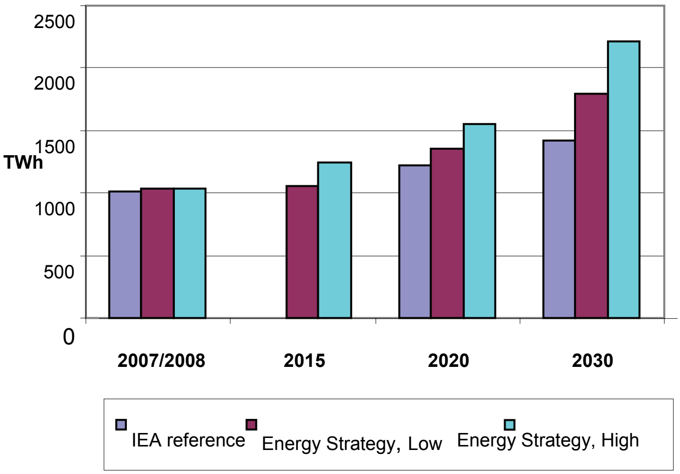
[52] *Ibid.*, pp. 46–48.

[53] Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 164.

[54] *Ibid.,* p. 138.

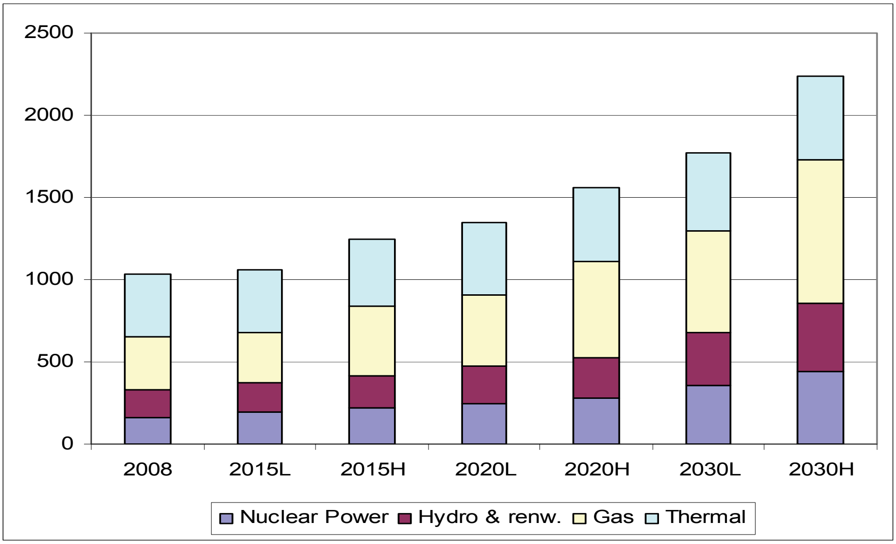
[55] *Ibid.*, p. 139.

Figure 4. Forecast of electricity generation according to the IEA reference scenario and Energy Strategy low (L) and high (H) scenarios



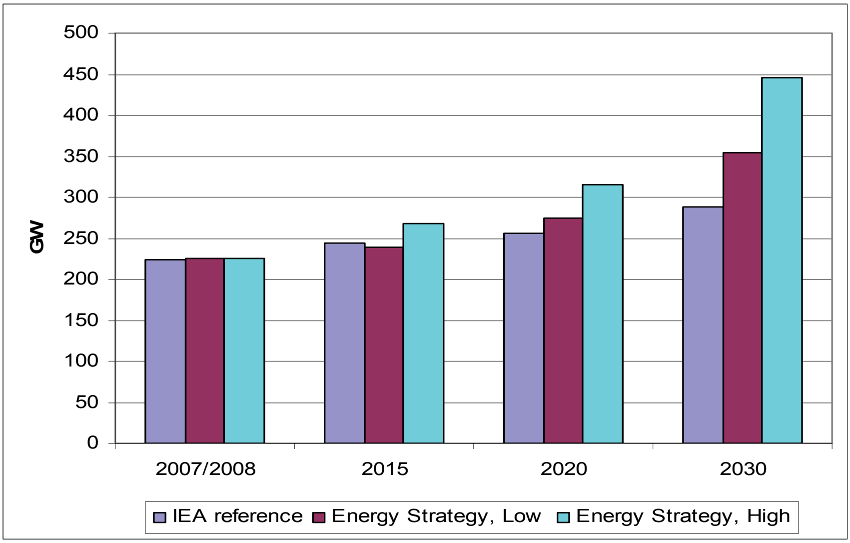
Source: Table A2; IEA (2009) *IEA World Energy Outlook 2009* (IEA, Paris), p. 643.

Figure 5. Proportion of different fuels in electricity generation according to the energy strategy low (L) scenario and the high (H) scenario, TWh



Source: Table A2, Annex 4.

Figure 6. Forecast of Russia's electricity capacity expansion 2008–2030, GW



Source: Table A3, Annex 4; IEA (2009) *IEA World Energy Outlook 2009* (IEA, Paris), p. 643.

The Energy strategy's estimates of how much electricity production and capacity is needed are based on the forecasts of the growth of the economy by the Ministry of Economic Development - 'Russia 2020'. Even though the ES forecast is much higher than the one presented by IEA, it is much lower than that in the forecasts presented by the Russian monopoly electricity corporation RAO EES in 2008, and the electricity demand assumed in Rosatom's plans.[56]

However, some observers claim that even the ES assumed increase of capacity is too high when estimated growth of GDP after the economic crisis is taken into account. Furthermore, according to a former deputy minister of the Ministry of Atomic Energy, Bulat Nigmatulin, 1 percent growth in GDP results in 0.33 percent growth in electricity demand. This is without taking into account energy-saving measures that will follow from the 'Law on energy saving and energy efficiency' and other measures.[57] According to Nigmatulin, Russia needs an

[56] RAO EES stated that 3 000 bn kWh will be needed in 2030.Accordingly, capacity was to grow by 70–100 GW between 2005 and 2030. For nuclear capacity as well, the RAO EES figures are higher, stipulating 32 additional GW in 2020 and 62 in 2030.56 The ES also assumes a lower installed capacity of nuclear power compared to Rosatom's plans (cf. tables 3.1; 3.2; 3.3 above). *Elektroenergetika Rossii 2030* (2008) (Moscow).

[57] Nigmatulin, B.I. (2010) 'Otlichat porozhenie ot pobedy', *Proatom*, 29 March, http://www.proatom.ru. Retrieved 2010-06-11.

increase in capacity of a maximum of 40 GW up to 2020 compared to 50–60 GW according to the ES.[58]

4.2 How competitive is nuclear power?

Globally the economic competitiveness of nuclear power has increased in the 21st century due to cost reductions at all stages of development, for instance:[59]

- Construction costs per kilowatt have fallen thanks to standardized design, shorter construction times and more efficient technologies. Further gains are expected as nuclear technology becomes more standardized around a few globally accepted designs.
- Financial costs fall if risks and uncertainties in construction and development are decreased.
- Operating costs of nuclear plants have fallen steadily because nuclear power has high fixed costs and virtually no running costs. Efficiency in generation has also increased and reactors have been granted extensions of their operating licence (for the same investment (fixed) cost).
- Waste and decommissioning costs represent only a tiny fraction of operational costs.

Furthermore, concern about carbon dioxide emission, targets to reduce these emissions and emission quotas have made fossil fuels more expensive and nuclear energy relatively less expensive.

The overnight cost[60] of USD 1 000–1 500 per kilowatt is achievable if design is standardized, and especially if several reactors can be built at the same plant. Some studies show that in France industrial organization and the standardization of series of reactors have reduced construction costs, construction time and operating and maintenance costs. In the French PWR programme, average overnight cost was less than 1 300 Euro (2004) per kilowatt. Other studies of the competitiveness of nuclear power say overnight costs of USD 2 000 per kilowatt and above.[61]

In some instances, largely because of the Chernobyl interlude when skills and working practices vanished, costs have increased substantially during construction. In Olkiuloto, Finland, installation of Areva's reactors (originally

[58] *Ibid*.

[59] WNA (2005) *The New Economics of Nuclear Power*, December, http://www.world-nuclear.com/Reference/pdf/economics.pdf. Retrieved 2010-07-15, p. 7.

[60] *Ibid*., p. 18. Overnight cost is the cost of a nuclear plant if it could be built overnight, i.e. without interest payments and other financial costs. This measure is often used for comparisons.

[61] *Ibid*.

budgeted for at USD 2 000 per kW, and total contract value of USD 3.3 bn) has been delayed for three years at an extra cost of over 75 percent. In Loganville, France, ELF has experienced a delay of 1–1.5 years at an extra cost of 20 percent.[62]

Given that reactors develop all the time and producers attempt to improve them and increase the effect, it is difficult to see that nuclear plants can profit from 'standardization' for longer periods in the future. Each reactor type needs a long testing period and it is important, especially for winning export contracts, that there are 'reference plants' at home, that is, plants where the reactors have run for a while and have been thoroughly tested.

In Russia, the cost comparison is done with gas-fired plants since that is the main alternative to nuclear power in Russia. According to critics, nuclear power stations should have an overnight cost of USD 2 500 per kilowatt at the most and be built in a maximum of five years in order to be competitive with gas-fired plants.[63] One problem with recent construction of nuclear plants so far (which in Russia is based on constructions started in the 1980s in the USSR) is that it takes longer, apparently at six to seven years. This way, according to the same source, the plants cost approaching USD 4 600 per kilowatt, which is much more than gas-fired plants for the same amount of electricity. Another contributing factor is that Rosatom has cut its construction staff by 90 percent and hires foreign low-qualified labour, which leads to mistakes and longer construction times.[64]

4.3 Investment and manpower

Investment

Figure 7 shows that for nuclear energy, hydro and the grid, investments into the electricity sector will to a great extent be undertaken during the last part of the strategy, that is after 2022. The Energy Strategy estimates that the cumulative investment cost of the whole strategy is USD 2 400–2 800 bn in 2007 prices.[65] This is equivalent to around twice the Russian GDP in 2007.[66] Of the total

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[62] Marttyshev, Stanislav (2009) 'Ritmichnost vypolneniya investprogrammy nailuchshiy sposob ukrepleniya privlekatelnosti Rosatom' (The rhythm in the investment programme increases the attractiveness of Rosatom), *Atomkon*, No. 1, p. 34.

[63] Nigmatulin, B.I. (2010) 'Otlichat porozhenie ot pobedy', *Proatom*, 29 March, http://www.proatom.ru. Retrieved 2010-06-11, p. 14.

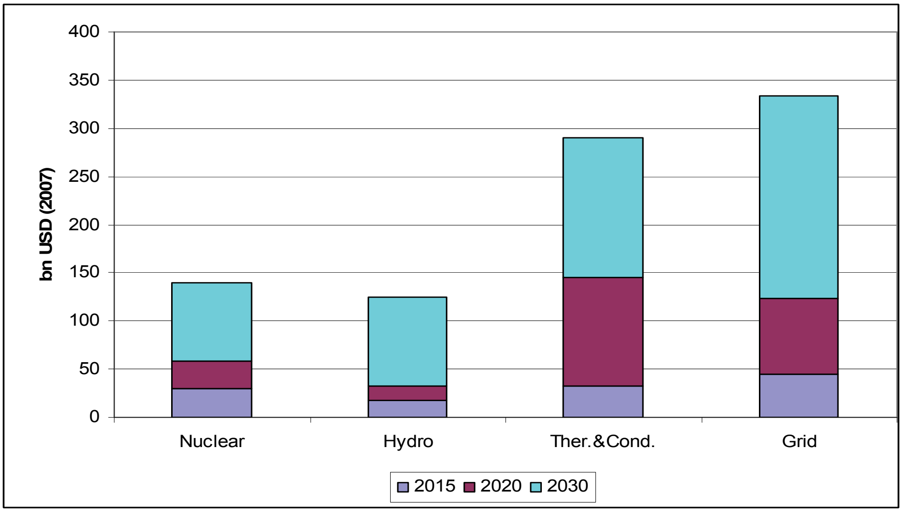
[64] *Ibid*., p. 16.

[65] Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Energy strategy up to 2030) (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 162.

[66] http://www.imf.org/external/pubs/ft/weo/2008/01/weodata/weorept.aspx?sy=2006&ey=2013&scs

amount, 77–79 percent is needed in the traditional energy industries and the rest would be used to develop alternative sources of energy and energy saving.[67]

Figure 7. Forecast of necessary investment for the development of electricity sector in Russia up to 2030, in billion 2007 USD



Source: Table A4, Annex 4.

If we look at just the first stage, up to 2015, and use the accumulated GDP for the years 2009–2015 forecast by the IMF, we can calculate the investment share in the economy implied by the ES figures. Such a calculation shows that the energy sector's demand for investment corresponds to 5.8–9.0 percent of (accumulated) GDP over that period,[68] which is a substantial share bearing in mind that Russia needs many other infrastructural investments over the next few years. The

m=1&ssd=1&sort=country&ds=.&br=1&c=922&s=NGDP_R%2CNGDPD%2CNGDP_D&grp=0&a=&pr1.x=36&pr1.y=8. Retrieved 2010-04-05.

[67] Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Energy strategy up to 2030) (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 162.

[68] Calculated by using IMF figures for actual Russian GDP in 2007 USD and estimated growth rates in constant prices up to 2015. http://www.imf.org/external/pubs/ft/weo/2010/01/weodata/weoselser.aspx?c=922&t=1. Retrieved 2010-08-20.

investment required in electrical power generation in the first stage is USD 122–126 bn (Table A4) which corresponds to 1.2–1.3 percent of GDP, and for nuclear power the investments will amount to 0.1 percent of GDP. Investment in the electricity sector should be both public and private.

Human resources

Nowhere in the materials on the Russian nuclear renaissance is there any comprehensive information on how the Russians are reviving education and training for the people who are to construct these nuclear power plants and run them. Russia has a high reputation in science and engineering, but the expansion described here calls for a whole new generation of nuclear engineers to be attracted to the sector, and the industry will have to compete for the best manpower with other domestic and foreign employers. This was not an issue in the USSR. A new generation of nuclear specialists also needs to embrace a new safety culture and thinking if Russian nuclear plants are to be safe.

The long break in nuclear development has created a deficit of human resources in the nuclear industry in all nuclear states. In the USA, the nuclear industry foresees difficulties with an ageing work force; a large percentage of the nation's nuclear employees will be eligible for retirement in five to 10 years. In addition, the plant designs for the new Generation III and Generation III+ reactors feature updated technologies, such as digital instrumentation and control systems, which are not present in the operating plants.[69]

In Russia, the famous Moscow scientific nuclear physics institute MIFI was reorganized into the *National Research Nuclear University MIFI* by presidential decree in October 2008. In 2009, the MIFI umbrella was extended to include 10 other higher educational establishments and 15 professional training facilities.[70] Several of the additional training establishments are found in the closed towns where nuclear development and waste management take place.[71]

From an IAEA report we learn that in 2007, about 40 000 persons worked in the nuclear power stations and of these about 35 000 worked directly with electricity generation.[72] This means that about 1 000 persons are required per reactor, or 1 500 persons per installed GW. Rosatom's plans indicate a doubling of the capacity installed up to 2020 (see tables 3.2 and 3.3), which means that a doubling of the number of nuclear professionals is required. According to a Russian country report to the IAEA in 2009, there is a human reources policy to keep and attract personnel to the nuclear industry. The nuclear sector has six

[69] http://www.window.state.tx.us/specialrpt/energy/nonrenewable/nuke.php. Retrieved 2010-09-02.
[70] Interview with the Rector of MIFI, Mikhail Strikhanov, http://www.rosatom.ru/wps/wcm/connect/rosatom/journalist/interview/b5f56780434090a7e6bfde508f3ca4. Retrieved 2010-09-02.
[71] http://www.mephi.ru/entrant/entrant2010/terobdpod.php. Retrieved 2010-09-02.
[72] http://www-ns.iaea.org/conventions/nuclear-safety.htm.

centers and institutes for Advanced Professional Training of managers and engineers and up to 10 000 persons are trained here annually. Basic training can also be acquired in 20 higher educational establishments, including seven industrial ones, in technical colleges, and in professional and technical schools. The reports states that all in all over 18 500 persons were being trained in the industry educational institutions, including over 6 000 students in higher education institutions.[73]

It is impossible to say whether these numbers are sufficient to provide the booming nuclear industry with enough competent personnel. According to a nuclear specialist, the Russian nuclear industry needs 3 500 engineers and scientists per year, and there are only around 2 000 graduates available.[74] Also, it takes a long time, at least 10 years, to prepare qualified personnel for the industry. In addition, the competition from other sectors will demand that the industry can offer attractive salary and benefit packages.

[73] http://www-pub.iaea.org/MTCD/publications/PDF/cnpp2009/countryprofiles/Russia/Russian2008.html.

[74] Grigory Zinovyev (2009) 'Atomic industry of Russia: status, issues, prospects', presentation, CNS Visiting Fellow, Monterey.

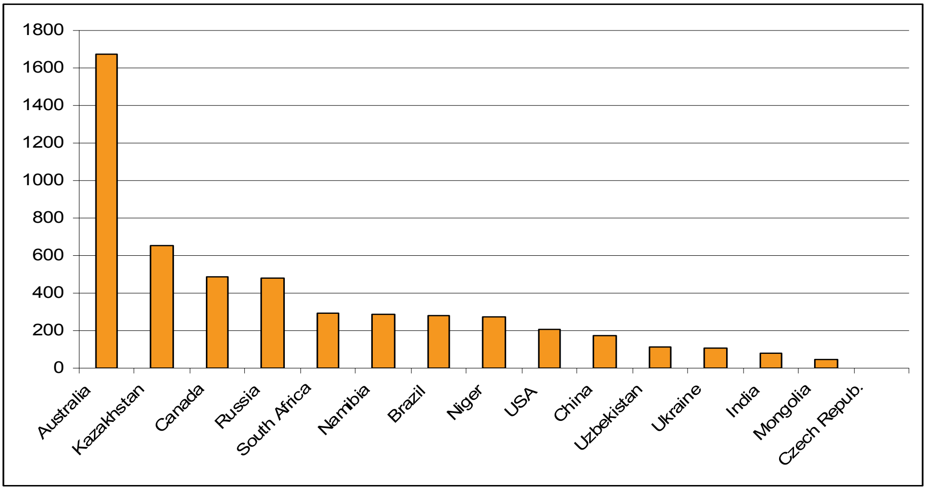
5 Uranium and Fuel Production

The primary supply of fuel for nuclear reactors has so far been uranium. For most reactors, natural uranium needs to be enriched to LEU – low-enriched uranium – in order for it to be used in nuclear power stations, which is done at special enrichment facilities. There has been some concern about whether the world's reserves of uranium will be enough to provide the expanding nuclear power industry with enough fuel. However, currently information on uranium reserves indicates that there will not be a shortage during the next 100 years. The reasons for this are, first, expanding reserves of natural uranium and, second, the abundant secondary supplies of fuel such as spent fuel that can be enriched and HEU - highly enriched uranium - that can be downblended for use in nuclear energy plants.

5.1 Reserves and production

In 2009, the reserves of uranium accessible at a cost of USD 130 per kg amounted to over 5 million tons. Australia is the country with largest known reserves – 31 percent of world reserves; thereafter come Kazakhstan with 12 percent and Canada and Russia with 9 percent each of the reserves. Thus Russia's uranium reserveves amount to 500 000 tons of uranium (Figure 8).

Figure 8. Uranium (U) reserves 2009, 1 000 tons

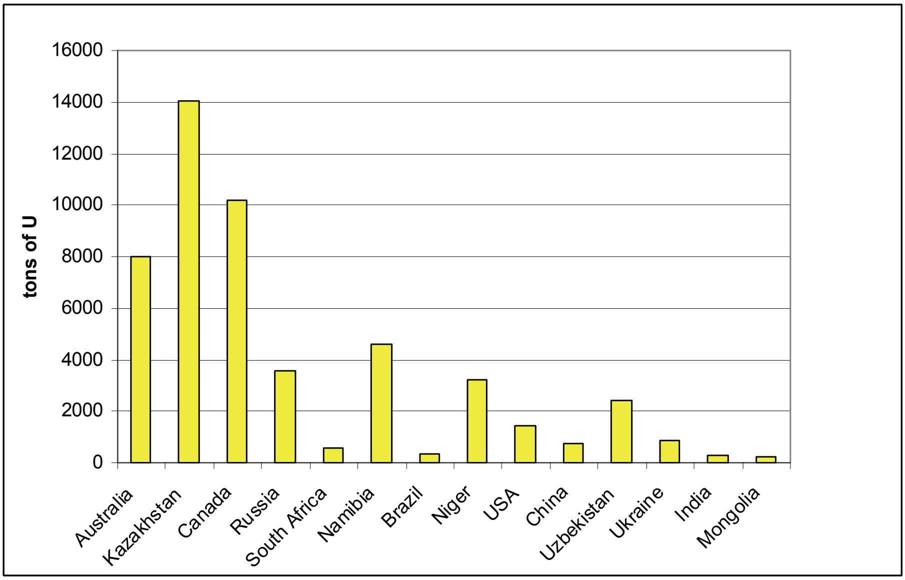


Source: Table A5, Annex 4.

The yearly worldwide production of uranium is less than 1 percent of reserves. In 2009, it amounted to 50 772 tons, of which 27 percent was mined in Kazakhstan.

Other important uranium mining countries are Canada (20 percent of world production), Australia (16 percent), Namibia (9 percent), Russia (7 percent), and Niger (6 percent) (Figure 9). As can be seen in Table A5, many countries that have uranium do not have nuclear energy, for example, Australia. The extent to which countries are dependent on nuclear power in their electricity generation thus varies and is not directly dependent on whether they have uranium or not.

Figure 9. Uranium production 2009, tons



Source: Table A5, Annex 4.

Russian uranium mining

In 2009, Russia produced 3 564 tons of uranium, which is 1.8 times more than in 2000, when production was 2 000 tons.[75] However, Russia uses much more uranium than it mines annually. In August 2010, Russia's nuclear reactors required 4 135 tons of uranium.[76]

The ARMZ Uranium Holding Co. (Atomredmetzoloto) is the successor to the world's largest uranium production complex built by the Soviet Union. All uranium mines in Russia, as well as a number of uranium joint ventures in the Commonwealth of Independent States and abroad, were brought together under ARMZ in 2008, after the restructuring of Russia's nuclear industry had been completed. As part of the nuclear industry restructuring, ARMZ gained control

[75] Table A5.

[76] WNA, http://world-nuclear.org/reference/position_statements/uranium.html. Retrieved October 2010.

over the following domestic uranium mining companies: Priargunsky, Dalur and Khiagda, which had formerly been owned by TVEL, the manufacturer of nuclear fuel for utilities. Further, Tenex, Russia's exporter of uranium and uranium enrichment services, transferred to ARMZ its shares in foreign uranium exploration and mining joint ventures, first of all, in Kazakhstan – at Zarechnoe and Akbastau. Tenex' licences for the stand-by uranium deposits, including those of Elkon, the world's largest uranium deposit, were reissued to ARMZ. In 2009, natural uranium output grew by more than 25 percent to reach 4 624 tons.[77]

ARMZ is one of the leaders in the world uranium mining industry. It is among the top five uranium mining companies by uranium output and ranks second in the world in terms of reserves with 546 000 tons as of 1 January 2009. ARMZ is the primary supplier of uranium feedstock to the Russian nuclear industry. Rosatom has a majority stake in ARMZ's shares. ARMZ together with its affiliates and subsidiaries employs over 10 000 people.[78]

Foreign acquisitions

Besides its close cooperation with Kazakhstan on uranium mining, Russia is buying stakes in other uranium mining companies abroad. In August 2010, ARMZ acquired the controlling stake, 51 percent, in Canada's *Uranium One*, using a 50 percent stake in the Akbastau mine and 49.7 percent of the stock in the Zarechnoe mine as a part of the payment.[79] Apparently, this deal has upset Republican members of the House of Representatives in the USA because *Uranium One* operates a Wyoming-based uranium mine in the USA. The Republicans are trying to block the sale of the Wyoming-based mine. According to American politicians the sale could give Moscow control of up to 20 percent of the US national uranium extraction capability and a controlling interest in one of the country's largest uranium mines.[80]

Russia also buys natural uranium. In 2007, Australia agreed a deal to sell uranium to Russia, on condition that the substance is not passed on to Iran or India. Australia, has a similar agreement with China.[81]

5.2 Nuclear fuel fabrication

Natural uranium must be enriched up to 3.75 percent of U-235 before it can be used in most energy producing reactors. Russia owns about half of the world's uranium enrichment capacity and is therefore already a major international

[77] http://www.armz.ru/eng/company/history. Retrieved 2010-08-12.
[78] http://www.armz.ru/eng/company/history. Retrieved 2010-08-12.
[79] http://en.rian.ru/business/20100907/160498531.html. Retrieved 2010-10-24.
[80] http://www.alipac.us/ftopict-214528.html. Retrieved 2010-10-24.
[81] http://news.bbc.co.uk/2/hi/business/6983340.stm.

provider in enrichment services.[82] Around 40 percent of installed uranium-enrichment capacity is used to provide LEU for existing reactors of Russian design, in Russia and abroad. Another 20–25 percent is used to produce LEU from weapon-grade uranium for use as power-reactor fuel in the United States (see below, Section 5.4). The remaining 40 percent of Russia's enrichment capacity is used to enrich natural uranium and to re-enrich reprocessed uranium for European customers, and to extract the equivalent of 'natural' uranium from depleted uranium.[83]

Russia has four uranium enrichment plants, in the Sverdlovsk, Krasnoyarsk, Irkutsk and Tomsk regions (Table 5.1). The locations are all in the closed cities where nuclear weapon and civil nuclear development took place in the USSR (cf. Annex 3).

Table 5.1. Russian uranium enrichment plants and their capacity, end of 2006

Plant	Location	Capacity Million SWU*/year	Enrichment limits
Urals Electrochemical Combine	Novouralsk, Sverdlovsk region	12.45	30
Electrochemical plant	Zelenogorsk, Krasnoyarsk region	7.39	5
Angarsk Electrolyzing Chemical combine	Angarsk, Irkutsk region	2.5	5
Siberian Chemical Combine	Seversk, Tomsk region	3.65	5
Total capacity		25.99	

Source: IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06, p. 95.

*Separative work unit (SWU) is a measurement. A large nuclear power station with a net electrical capacity of 1300 MW requires about 25 tons per year of LEU with a U-235 concentration of 3.75. This quantity is produced from about 210 t of new uranium using about 1.2 million SWU. An enrichment plant with a capacity of 1 million SWU per year is able to enrich the uranium needed to fuel about eight large nuclear power stations.

TVEL is the Russian holding company that manages all nuclear fuel production. It also exports nuclear fuel to countries that have Russian reactors (Ukraine, Armenia, Bulgaria and Slovakia), but also to other countries such as the USA, China, Finland and Sweden. In 2010, TVEL contributed 17 percent to global

[82] IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06, p. 100.

[83] *Ibid.,* p. 97.

nuclear fuel production.[84] TVEL provides fuel for one in every six power reactors in the world.[85]

TVEL was founded in 1996. It combined all manufacturers[86] of fuel assemblies and components into one holding company. Along with the finished fuel assemblies, TVEL exports nuclear fuel components. It also works on creating essentially new types of mixed oxide uranium-plutonium fuel, MOX fuel (see Annex 2), which would alleviate the problem of feed material availability in nuclear power and significantly reduce nuclear waste generation.[87]

5.3 Stockpiles and secondary supplies

Secondary supplies fulfil an important function in fuelling the nuclear power stations. These include stockpiles of natural and enriched uranium, decommissioned nuclear weapons, the reprocessing of natural and enriched uranium and the re-enrichment of depleted uranium tails.[88] Secondary supplies of uranium from military and civilian stockpiles became important in the period after 1985 as East–West arms control began to entail substantial dismantling of nuclear warheads, yielding commercially usable fissile material. During the Cold War, large uranium inventories accumulated and until the mid-1980s the Western uranium industry was producing material much faster than nuclear power plants and military programmes were consuming it. Uranium prices fell throughout the 1980s. Hence, the enormous stockpiles had the effect of depressing prices and thus delaying the next exploration cycle, as there was little economic incentive to invest in new development. It is believed that as secondary supplies are depleted, primary uranium production will pick up.[89]

In the early 2000s, Russia's stockpiles were equivalent to 500 000 tons of LEU. This figure takes into account 1 400 tons of HEU, which is equivalent to 420 000 tons of LEU, added to 80 000 tons of uranium that has been stockpiled over the years.[90]

[84] URALSIB, 9 March 2010.
[85] http://www.rosatom.ru/en/energy_complex/nuclear_fuel/, 19 May 2010.
[86] Elektrostal, Moscow Region, Novosibirsk Chemical Concentrates Plant, Chepetsky Mechanical Plant (Glazov, Udmurt Republic), Moscow Composite Metal Plant.
[87] http://www.rosatom.ru/en/energy_complex/nuclear_fuel/. Retrieved 2010-05-19.
[88] Depleted uranium tails are a by-product of the U-235 enrichment process. The tails contain normally between 0.25 and 0.35% of U-235, or about one-third of the 0.71% contained in natural uranium. http://europe.theoildrum.com/node/5677. Retrieved 2010-10-12.
[89] WNA (2005), http://www.world-nuclear.org/reference/position_statements/uranium.html.
[90] NTI (2002).

Future additional sources of nuclear fuel

There is reason to believe that adequate and affordable supplies of uranium can be found to fuel the nuclear industry, even at greatly expanded levels of activity, using current technology. Already well-known nuclear technologies offer a wide range of possibilities for stretching uranium supplies to a considerable extent, as market forces render these options economically attractive:[91]

- *Reprocessing*. Used nuclear fuel can be reprocessed to recover unburned fissile material. Depending on reactor core management, the efficiency of uranium utilization increases by up to 30 percent. Today, while accounting for a minor part of world nuclear fuel supply, reprocessing is already occurring on a substantial scale and could well become increasingly attractive as market conditions evolve.

- *Increased enrichment*. Most reactor types require enriched uranium fuel. If uranium becomes relatively more expensive compared with enrichment (through price changes in either), increasing the input of enrichment services to optimize fuel cost can save on uranium use in reactors.

- *Thorium.* The element thorium, which is four times more abundant in the earth's crust than uranium, constitutes an additional source of nuclear fuel. Although thorium is not fissile, it is 'fertile', that is, capable of being converted into fissile U-233, and technologies for making the conversion are already well advanced in some places, notably in India.

- *Enhanced reactor efficiency*. Evolutionary light-water reactor designs, which are all more fuel-efficient than their predecessors, will be the mainstay of nuclear programmes over the next decades. However, in the period beyond 2030, advanced reactor designs such as those included in current multinational research programmes represent a further step forward in fuel efficiency.

- *Breeder reactors*. Some advanced reactor designs are fast-neutron types, which can utilize the U-238 component of natural uranium (as well as the 1.2 million tons of depleted uranium now stockpiled as a result of enrichment activities). When such designs are run as breeder reactors, with the specific purpose of converting non-fissile U-238 to fissile plutonium, they offer the prospect of multiplying uranium resources 50-fold and thereby extending them far into the future. The technology is well proven, with some 300 reactor-years of experience, and breeder reactors are already firmly emplaced in the long-range energy plans of such nations as Russia, Japan and India.

[91] WNA, http://world-nuclear.org/reference/position_statements/uranium.html. Retrieved 2010-08-19.

The Russians are conducting research aiming at closing the fuel cycle and, as far as possible, utilizing recycled uranium and plutonium in MOX fuel. So far, used fuel from the RBMK reactors and from the VVER-1000 reactors has been stored at reactor sites and is not reprocessed.

The international fuel bank at Angarsk

In November 2009, the IAEA approved an international nuclear fuel bank at Angarsk, Irkutsk region, Russia, under IAEA auspices. The Angarsk fuel bank, first proposed by Russia in September 2007, is meant to ensure the supply of LEU to participating states in the event of a political disruption in the international uranium enrichment services market. The fuel bank will be hosted by the already existing *International Uranium Enrichment Center* at Angarsk. Proponents of the fuel bank concept argue that, by guaranteeing fuel supply to states that do not have their own industry, the reserve reduces the incentive for such states to develop their own indigenous uranium enrichment facilities.[92]

Economic or political rationale?

From its acquisitions and policies in the nuclear fuel area, it is clear that Russia is interested in controlling a substantial share of the uranium resources and nuclear fuel in the world. From an economic point of view this makes sense since uranium prices will surge as the nuclear industry expands during the next decades. Also, specializing in nuclear fuel enables Russia to make use of its Cold War-sized enrichment industry and keep specialists in this area busy. Profiting from this comparative advantage is certainly rational from an economic standpoint. Yet the political motives are probably just as strong. Concentrating uranium assets and enrichment and fuel production in countries that already have the technology is believed to restrain the proliferation of fissile materials and enrichment technology. It certainly gives the nuclear weapon states an opportunity to keep up and even expand their nuclear industry capacity and the R&D in the area.

5.4 Exports of uranium and fuel

Russia began exporting uranium in the mid-1970s to France, Spain, the United Kingdom, Belgium, and Germany. In the late 1980s and early 1990s, exports to South Korea and the United States began. Russian uranium exports come from three sources: uranium that is mined, uranium from stockpiles, and LEU that is downblended from HEU under the US–Russia HEU deal. Statistics on Russian uranium exports are scarce but in 1996 approximately 16 000 tons was exported. In December 2000, the export volume remained at 16 000 tons.[93]

[92] http://www.nti.org/e_research/e3_low_enriched_uranium_angarsk.html. Retrieved 2010-10-24.
[93] NTI (2002).

In the early 2000s Russia exported 16 000 tons of uranium each year, and used 8 000–8 500 tons to produce nuclear fuel.[94] As of December 2000, it was estimated that Russian nuclear power plants used between 3 000 tons and 4 500 tons of uranium annually with an additional 2 200 tons committed to fuel Soviet-built reactors in the former USSR and Eastern Europe. Approximately 1 000 tons is used to produce submarine fuel. Russia relies heavily on its large uranium stockpile to make up the difference between the uranium it exports and uses domestically each year (24 000–24 500 tons) and the uranium it mines annually.[95]

The annual average demand for uranium in the EU area is estimated at 20 000 tons of uranium up to around 2015, when more reactors may come on line. In 2006, 21 000 tons of uranium were loaded into EU countries' reactors.[96] Russia supplied 19 percent of the uranium to the EU 27 in 2006.[97]

Megatons to megawatts

Surplus weapons-grade HEU resulting from the various disarmament agreements led in 1993 to an agreement between the US and Russian governments. Starting in 1995, Russian nuclear warheads were to be recycled into LEU fuel for US nuclear power plants. Up to 2009, this programme has eliminated the equivalent of 15 000 nuclear warheads. The *Megatons to Megawatts* government-to-government programme goal of eliminating 500 metric tons of warhead material, the equivalent of 20 000 nuclear warheads, is scheduled to be completed in 2013.[98]

Under the terms of the agreement, both the United States and Russia created government-owned corporations to act as the deal's executors: the American United States Enrichment Corporation (USEC) and Russian Tenex. The original deal called for Tenex to downblend its HEU to LEU at its facilities. USEC would then buy an intermediate component of the resulting LEU over a 20-year period. By September 2009 a total of 375 tons of HEU had produced nearly 10 868 tons of low-enriched fuel, for which Tenex had received over USD 8.5 bn. The 375 tons of HEU is equivalent to 15 000 nuclear warheads, according to USEC.[99] The LEU is equivalent to about 137 000 tons of natural uranium from mines. The fuel purchased by USEC had been used in many of America's commercial nuclear power plants to produce electricity. Approximately 20 percent of America's electricity is generated by nuclear energy. Nuclear warheads that were once

[94] *Ibid*.
[95] *Ibid*.
[96] IEA (2008) International Energy Agency *IEA Energy Policy Review. The European Union* (OECD/IEA, Paris), p. 65.
[97] *Ibid*., p. 66.
[98] http://www.USEC.com/megatons to megawatts, http://nnsa.energy.gov/news/2592.htm, http://www.usec.com/megatonstomegawatts.htm.
[99] http://www.world-nuclear.org/info/inf13.html.

aimed at American cities now provide 50 percent of the nuclear energy produced in the United States, which corresponds to one-tenth of America's overall electric power production.[100]

Continuing and increased exports to the USA

Completion of the Megatons to Megawatts agreement will leave a considerable gap in the supply of uranium fuel at a time when the global use of nuclear power is increasing. The US nuclear programme anticipates over 30 new reactors in the next few decades. Continued use of Russian downblended HEU is therefore of interest. In February 2010, Reuters reported that American nuclear power plants will be able to obtain more supplies of Russian enriched uranium for fuel under a new trade deal. The agreement will provide US utilities with a reliable supply of nuclear fuel by allowing Russia to boost exports to the United States while minimizing any disruption to the American enrichment industry. The new trade deal may correspond to 20 percent of the American market, so one in every five atomic stations in the US will be working thanks to the import of Russian uranium enrichment services.[101]

5.5 Nuclear waste management

Nuclear waste in Russia does not come only from nuclear energy plants. Russia has inherited a major nuclear waste problem from Soviet military activities and there are also many research reactors in operation that produce plutonium and waste. In 2003, there were 500 million cubic metres of liquid radioactive waste in Russian nuclear establishments. In addition, there were 180 million tons of solid radioactive waste at storage sites such as Mayak at Chelyabinsk, the Siberian Chemical Combine at Tomsk, and the Mining and Chemical Combine in Zheleznogorsk.[102]

There is still no comprehensive legal framework for the management of radioactive waste.[103] Nor does Russia have a final solution to the problem of how

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[100] See USEC's homepage, http://www.usec.com/megatonstomegawatts.htm.

[101] Under the deal, Russian uranium exports to the United States would increase slowly over a 10-year period, beginning in 2011, when shipments would be allowed to reach 16 559 tons. Exports would then increase by about 50 percent annually over the next two years and increase more than tenfold from 41 398 tons in 2013, when the current Megatons to Megawatts programme expires, to 485 279 tons the next year. Shipments would increase at much slower rates in each of the following six years, until reaching 514 754 tons in 2020. http://uk.reuters.com/article/idUKN0146993820080202. Retrieved 2010-08-22.

[102] Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org. Retrieved 2010-08-20, p. 42.

[103] A draft law 'On Management of Radioactive Waste' has been under preparation by the Russian legislators for over 10 years. In July 2010, the draft law went through its second reading at the lower house of the Russian parliament, the State Duma. According to the requirements set out by the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of

to store radioactive waste from its nuclear power plants. No waste repository is yet available, though sites on the Kola Peninsula and in the Nizhnekansky Rock mass in Krasnoyarsk region have been put forward. The Russians are opting first of all for a facility that can hold 20 000 tons of intermediate- and high-level waste that will be retrieved.[104] So far, spent nuclear fuel is kept in cooling ponds on the premises of the nuclear plants. These ponds were dimensioned to store three years'-worth of spent fuel and a reserve corresponding to a full load of the reactor core.[105] Spent fuel needs to be cooled down (for around five years) before it is transported for reprocessing. A problem now is that some of these ponds are overfull, and this complicates further production at the plants. Spent fuel from the RBMK plants is exclusively stored in ponds at the plants.[106]

Spent fuel from the VVER-440 reactors and the BN-600 reactor plus the HEU from the naval and research reactors is reprocessed at the Mayak reprocessing facility at Chelyabinsk.[107] In reprocessing, 95 percent of spent fuel can be recycled to be returned to use in nuclear power plants. Fuel from the VVER-1000 is transported to the storage facility at the Mining and Chemical Combine in Zheleznogorsk.

Repatriation of fuel used abroad

The Soviet Union repatriated all spent fuel from Soviet-built reactors in other Soviet republics and Eastern Europe. Spent fuel from VVER-440 reactors in Bulgaria, the Czech Republic, Finland, East Germany, Hungary and the Slovak Republic was shipped back to the Soviet Union. Russia continues this policy and takes back spent fuel of Soviet/Russian origin. In the early 2000s, however, only Ukraine[108] and Bulgaria still shipped spent fuel to Russia.[109]

Radioactive Waste Management, which Russia signed in Vienna in 1999 and ratified in 2005, countries that employ nuclear energy must have a regulatory and legal framework in place to ensure safe management of spent nuclear fuel and radioactive waste. http://www.bellona.org. Retrieved 2010-09-07.

[104] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, pp. 30–31.

[105] Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org. Retrieved 2010-08-20, p. 38.

[106] IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06, p. 96.

[107] *Ibid*.

[108] At the end of the 1990s Ukraine had five nuclear plants that produced over one-third of Ukraine's electrical energy. All aspects of the fuel cycle remained under Russian control. The waste and spent fuel from the Rovenskaya station in Kuznetsov belong to Chelyabinsk-40, and the waste of

The building of the nuclear power plant at Bushehr in Iran was severely delayed, one reason for this being the Iranians' reluctance to agree to return used fuel to Russia. In 2005, however, the parties signed two agreements implying that Iran would get all its fresh fuel from Russia and all the spent fuel would be returned to Russia after use for reprocessing and storage. Russia completed the transport of fuel assemblies for Bushehr in January 2008 and in August 2010 the process of loading fuel into the first unit of the Bushehr nuclear power station began under the supervision of inspectors from the IAEA.[110]

In the late 1990s, Evgeniy Adamov, at the time Minister of Atomic Energy, proposed that Russia would take on spent nuclear fuel of non-Russian origin for storage. The nuclear sector was short of money and it was estimated that importing 10 000 tons of spent fuel could bring in USD 20 bn. Public opinion in Russia at that time was very strongly against this. Nevertheless the Duma passed a law in 2001 allowing the import of foreign spent fuel for temporary storage or reprocessing. Despite this enabling legislation, neither Minatom nor Rosatom has taken advantage of this opportunity. First, it is strongly opposed by various organizations and the public, and, second, spent fuel is a hot topic in foreign affairs, and other countries such as the USA have legislation and 'consent rights' that make it complicated for Russia to design such a scheme.[111] Rosatom's head, Sergey Kirienko, stated in 2006 that Russia did not import foreign fuel and would not do so in the future.[112]

the 10 reactors in South Ukraine (the Zaporozhskaya and Khmelniskaya stations) goes to Krasnoyarsk-26 (Josephson, 2000, p. 270).

[109] Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org. Retrieved 2010-08-20.

[110] WNN (2010-08-23) 'Fuel loading starts at Bushehr 1', *World Nuclear News*, 23 August, http://www.world-nuclear-news.org/NN-Fuel_loading_starts_at Bushehr_1-2308104. Retrieved 2010-08-26.

[111] IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06, p. 99.

[112] *Ibid*.

6 Security and Proliferation

If it is to expand nuclear power, it is imperative that Russia improve its safety culture well beyond what it was on 26 April 1986, the date of the Chernobyl accident. The Russians assure the world that safety thinking has changed and that the remaining 11 RBMK reactors[113] that it is still using were substantially improved before they were granted 15–25 years of increased service life. Yet the major accident at Russia's Sayano-Shushinskaya hydroelectric station in September 2009 shows that there is still a culture in Russia of highly trained engineers breaking vital safety rules and causing lethal damage. In addition, the recent militant attack of 21 July 2010 on the hydropower station in Kabardino-Balkariya raises concerns regarding the security against attacks of nuclear power stations as well. The possibility of terror attacks is an issue in Western nuclear development. Moreover, it is a major challenge is to secure nuclear plants and radioactive waste from methods of sabotage that are still unknown.

6.1 The IAEA Convention

The IAEA Convention on Nuclear Safety was adopted in Vienna on 17 June 1994. The convention was the result of a great deal of work by governments, national nuclear safety authorities and the IAEA's Secretariat between 1992 and 1994. Its aim is to legally commit participating states operating land-based nuclear power plants to maintain a high level of safety by setting international benchmarks. Russia signed this convention in September 1994 and it came into force in October 1996.[114] It entails monitoring and safeguarding nuclear developments in the member states. There are several safety aspects monitored by the Convention, for instance:

- National nuclear safety infrastructure
- Regulatory effectiveness and independence
- Long-term management of radioactive sources
- Management of spent fuel and radioactive waste
- Education and training
- Exposure to releases from radioactive substances
- Decommissioning

[113] See Annex 2 below for a detailed explanations of different reactor types.
[114] http://www-ns.iaea.org/conventions/nuclear-safety.htm. Retrieved 2010-08-02.

- Safety of transport of radioactive material.

It follows that the safety issues around nuclear energy are extremely complex. Several aspects concern the hard-core technical safety of the reactors, transport, and spent fuel storage. Others concern broader security issues that encompass outside threats to nuclear facilities such as cyber sabotage and terrorist attacks. The IAEA distinguishes between safety issues and security issues in its work in the following way:

> *In the safety area, they cover nuclear installations, radioactive sources, radioactive materials in transport, and radioactive waste. A core element is setting and promoting the application of international safety standards for the management and regulation of activities involving nuclear and radioactive materials.*
>
> *In the security area, they include nuclear and radioactive materials, as well as nuclear installations. The focus is on helping states and companies prevent, detect, and respond to terrorist or other malicious acts - such as illegal possession, use, transfer, and trafficking - and to protect nuclear installations and transport against sabotage.*[115]

Hence, *safety* refers to mainly technical aspects of making nuclear power safe, while *security* refers to a broader family of threats.

6.2 Safety

Chernobyl drew attention to the importance of safety culture and the impact of managerial and human factors on safety performance. The term 'safety culture' was first used in the International Nuclear Safety Group (INSAG) *Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident*.[116] This concept was introduced as a means of explaining how the lack of knowledge and understanding of risk and safety on the part of the employees and the organization contributed to the outcome of the disaster.

Some reports, mostly referring to the 1990s and early 2000s, claim that the Russian safety and security culture still has its deficiencies. According to Khripunov and Holmes, in the 1990s there were successful and attempted diversions of nuclear material from Russian nuclear facilities.[117] In particular, such incidents occurred when the personnel failed to recognize how important it

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[115] http://www.iaea.org/OurWork/SS/index.html.

[116] INSAG (1988) International Nuclear Safety Advisory Group. *Basic Safety Principles for Nuclear Power Plants* (IAEA, Vienna).

[117] Khripunov, Igor & James Holmes (2004) *Nuclear Security Culture: The Case of Russia* (Center for International Trade and Security, University of Georgia, December), p. 2.

is to follow all procedures to the letter and to actually use systems available for protecting nuclear materials. For example, foreign visitors noted that Russian security personnel often made ‘exceptions’ to security procedures in order to speed up procedures and access to security areas. Reports indicate that guards deactivated security and monitoring systems when they lost patience with false alarms.[118]

By the early 1990s a number of Western assistance programmes were in place, which addressed safety issues and helped to alter fundamentally the way things were done in the USSR and later Russia. Design and operating deficiencies were tackled, and a safety culture started to emerge. The IAEA and WANO contributed greatly to improving the safety and reliability of Soviet-era nuclear plants. WANO came into existence as a result of Chernobyl. In the first two years of its existence, 1989–91, operating staff from every nuclear plant in the former Soviet Union visited plants in the West on technical exchanges, and Western personnel visited every Soviet plant. A great deal of ongoing plant-to-plant cooperation, and subsequently a voluntary peer review programme, grew out of these exchanges.[119]

The generally better economic situation in Russia in the 2010s compared to the 1990s and the fact that the nuclear sector is experiencing a renaissance probably diminish the incentives for individuals to divert nuclear materials and sell them. How well Western assistance has worked to encourage a different safety culture to penetrate the Russian nuclear establishment is not quite clear. A safety culture in any area is to some degree correlated with the safety culture in the society as a whole, and the common ‘exceptions’ made to any kind of procedures in any area are well known to any long-term visitor to Russia.

6.3 Security

We have not found any references to how the Russians deal with broader threats to their nuclear installations. In the West, security around nuclear plants has increased after 9/11 and in particular nuclear power plants’ vulnerability to deliberate aircraft crashes has been a continuing issue. After much consideration the US Nuclear Regulatory Commission (NRC) decided in 2009 that all new nuclear plants should incorporate design features that should ensure that the reactor core would remain cooled and the reactor containment would remain

[118] *Ibid*.
[119] WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01, p. 41.

intact in the event of a crash of a large commercial aircraft, and also that the spent fuel cooling or spent fuel pond integrity would be maintained.[120]

The use of insiders in sabotage operations is widely known. For instance, in 2001 the Tamil Tigers managed to force themselves into Sri Lanka's international airport and an adjoining airbase and destroy a large number of commercial and military aeroplanes. The assault had been planned with the help of insider information on hard safety and security routines.[121]

Another area that has been receiving increased attention is cyber security. Computer systems that help operate the reactors and safety equipment must be isolated from the Internet to protect against outside intrusion. In the USA, the 2009 rule requires nuclear plants to have comprehensive cyber-security programmes and response procedures to address a threat posed by e.g. the loss of large areas of the facility because of explosions and fire.[122]

The 2010 wildfires around Sarov,[123] formerly Arzamas-16, one of the main nuclear facilities in the Soviet Union, have probably made Russian nuclear safety experts think more about fire protection and whether nuclear facilities should be located deep in forests. A problem with safety and security set-ups is that we can only prepare and defend ourselves against risks that are known. After 9/11, threats from the sky have been a high priority. However, the problem is that terrorists are creative and will think up something new that the people responsible for security have not thought of.[124]

Hence, it is important to combine hard security with routines and creative approaches to security threats. In Sweden, the security surrounding (for example) the drawings of nuclear plants has been stepped up. The use of 'red teams'[125] to

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[120] Holt, Mark & Anthony Andrews (2009) *Nuclear Power Plant Security and Vulnerabilities*, Congressional Research Service, http://www.crs.gov, RL34331. Retrieved 2010-09-02.

[121] *Ibid*.

[121] NEI, (2009) Nuclear Energy Institute, Fact sheet, August.

[121] RIA Novosti, 14 August 2010, http://en.rian.ru/russia/20100814/160201171.htlm. Retrieved 2010-08-30.

[121] Westin, Jonas & Eric Sjöberg (2007) *Kreativitet som hot och möjlighet i kärnverksamheten*, (Creativity as a threat and an opportunity in the core business), June, FOI-R--2288--SE, p. 31.

[122] NEI (2009). Nuclear Energy Institute, Fact sheet, August.

[123] RIA Novosti, 14 August 2010, http://en.rian.ru/russia/20100814/160201171.htlm. Retrieved 2010-08-30.

[124] Westin, Jonas & Eric Sjöberg (2007) *Kreativitet som hot och möjlighet i kärnverksamheten*, (Creativity as a threat and an opportunity in the core business), June, FOI-R--2288--SE, p. 31.

[125] A red team activity is any set of activities that involve an unannounced assessment of security and readiness by an unfamiliar (to the target) team of operators with no awareness or support from the assessed target. The function of individuals engaged in this activity is to provide a unique understanding from a threat actor's point of view in less contrived circumstances than through exercises, role playing, or announced assessments. Red team activities may involve interactions that trigger active controls and countermeasures in effect within a given operational environment.

test different threat scenarios to nuclear establishments is common in the USA and Europe.[126]

6.4 Proliferation implications

What are the consequences of civil nuclear expansion for proliferation and non-proliferation of fissile materials? The nuclear renaissance has stirred experts in the non-proliferation and disarmament area since the expansion of nuclear energy changes the whole setting in these areas.

The basic international document regulating the proliferation of nuclear materials is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). It came into force on 5 March 1970, and currently 189 states are parties. Five of these are recognized as nuclear weapon states – the USA, Russia, the UK, France and China, the five permanent members of the United Nations Security Council. The NPT allows for the transfer of nuclear technology and materials to NPT signatory countries for the development of civilian nuclear energy programmes in those countries as long as they can demonstrate that their nuclear programmes are not being used for the development of nuclear weapons.[127]

However, the NPT is not considered enough to offset the risks of proliferation of fissile materials that is implied by the current expansion of civil nuclear power. It is the open fuel cycle in civil nuclear generation that is the problem. The former Director General of the IAEA, Mohamed ElBaradei, has called the spread of enrichment and reprocessing capabilities the 'Achilles' heel' of the nuclear non-proliferation regime. As of 2007, 13 states had an enrichment capability.[128] As the commercial reactors use enriched uranium fuel, it follows that states must be able either to enrich uranium themselves or to purchase enriched uranium on the international market.

Several international actors have addressed the question and come forward with recommendations. According to ISAB, the International Security Advisory Board of the US Department of State, strengthening proliferation protection under present conditions demands concrete measures at the level of those countries that supply and use nuclear power.[129] In particular, it is recommended

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[126] See for instance '"Red Team" Penetrates Nuke Lab's Security, Reaches "Superblock"', http://www.globalresearch.ca/index.php?context=va&aid=9043.

[127] http://en.wikipedia.org/wiki/Nuclear_Non-Proliferation_Treaty#Third_pillar:_peaceful_use_of_nuclear_energy.

[128] http://en.wikipedia.org/wiki/Nuclear_Non-Proliferation_Treaty#Third_pillar:_peaceful_use_of_nuclear_energy.

[129] ISAB (2008) *Report on Proliferations of the Global Expansion of Civil Nuclear Power*, Washington, DC, April.

that the spread of enrichment and reprocessing capabilities to nations that do not have these technologies be restricted. ISAB additionally recommends that:[130]

- Nations without their own enrichment capabilities should be guaranteed reliable and economic supplies of nuclear fuel. Fuel banks are one element in this 'attractive offer'.
- States supplying nuclear technologies should work together to establish guidelines and sanctions for recipients who must forgo the opportunity to develop their own enrichment and reprocessing capability.
- The suppliers of nuclear technology should be given greater responsibility in non-proliferation efforts and should be backed by states.

The ICNND, International Commission on Nuclear Non-proliferation and Disarmament, has similar ideas. It commissioned a paper that was presented in 2009 and put forward the following conclusions:[131]

- The development of internationally agreed arrangements for effective control of sensitive nuclear technology, such as enrichment and reprocessing, is of the outmost importance.
- The development of mechanisms for ensuring long-term supply for nuclear fuel and fuel management services, so that states will not feel compelled to develop national fuel-cycle capabilities, is essential.
- The nuclear industry should develop a comprehensive Code of Conduct ranging from responsible uranium supply to support for the development of proliferation-resistant fuel-cycle technologies.

To involve industry in the development of guidelines and a code of conduct appears to be necessary. Yet governments have tended to manage proliferation as a political issue with virtually no industry involvement other than an expectation that it will comply with directives – which themselves can be difficult to follow or implement. The ICNND considers that industry should be an active partner with governments in the drafting of regulations and treaties that affect their activities.[132]

On the one hand, Russia by its present policy of providing the fuel to its nuclear plants abroad and reptriating spent fuel, as well as hosting one of the international fuel banks outside Irkutsk, appears to support non-proliferation along the lines of these recommendations. On the other hand, Russia is building

[130] *Ibid*.
[131] Letts, Martin & Fiona Cunningham (2009) 'The role of the civil nuclear industry in preventing proliferation and in managing the second nuclear age'. Paper prepared for the Second Meeting of the ICNNPD, Washington, 13–15 February 2009.
[132] *Ibid.,* p. 5.

nuclear plants in countries that have not signed the NPT, and in others there have been clandestine uranium enrichment efforts. There has also been some concern about the export of the floating nuclear power plants that can be moved and are more vulnerable to attack than ordinary stations.

7 Conclusions

The main purpose of this study was to provide an overview of the situation in the civil nuclear energy sector in Russia in 2010 and the plans for the future up to 2030. This included both the development of nuclear power plants and the Russian management of the nuclear fuel. Beside this descriptive purpose, we set out to investigate a number of questions: a) What role does nuclear power play in domestic and foreign demand for Russia's energy resources? b) Are the present expansion plans realistic and what are the resource constraints? c) Is Russia on the way to becoming a nuclear energy superpower? d) What are the security implications of more nuclear power in Russia?

a) What role does nuclear power play in domestic and foreign demand for Russia's energy resources?

The overview of Russian plans shows that nuclear-generated electricity will play an increasing role in Russia, with a projected increase in capacity of over 50 additional reactors by 2030. The role of fossil fuel-generated electricity will decrease. However, coal and gas will still provide 60–70 percent of Russian electricity in 2030, while nuclear power will provide 20 percent. Yet nuclear power will play an important role, particularly in European Russia, in replacing gas in domestic electricity generation. More nuclear power means that more gas can be exported, which is obviously a central aim of this strategy.

A main feature in Russia's nuclear expansion is its exports of nuclear plants to other countries. On the international market Russia competes with the leading Western suppliers for contracts to build nuclear power plants in, for example, India, China, Turkey and Iran. In 2010, Russia had secured contracts for over 10 reactors abroad, and there are several more in the pipeline. Furthermore, Russia has started a series of mini floating nuclear power plants for power generation in geographical areas that are difficult to reach, and these have also attracted interest abroad.

Apart from nuclear plants, Russia exports enrichment services as well as fabricated nuclear fuel. It has around half of the world's uranium enrichment capacity and will remain a major provider of these services on the international market. On the whole, it appears that Russia is exceedingly interested in expanding this line of industry: Russia controls the fuel cycle of the nuclear plants it builds abroad, and recently it became the host of an international fuel bank.

The Russian nuclear renaissance is well in line with President Medvedev's drive to modernize the Russian economy, making it more innovative. The nuclear sector is one of the priority sectors in this initiative and at the same time one of the few sectors where Russia has considerable advantages.

It follows that, although nuclear energy will only provide up to 20 percent of Russian electricity in 2030, its role is considerable. Nuclear power will provide a replacement for gas, reference plants at home to attract export customers, and a base for the enrichment and fuel reprocessing industry as well as for research.

b) What are the resource constraints on the development of Russia's energy sector in general and on the nuclear energy sector specifically? Are the plans realistic?

The findings with regards to the constraints on the nuclear energy expansion are inconclusive because information on investment resources, capacity constraints in the nuclear engineering sector and manpower is scarce. Also, there does not seem to be a serious economic discussion in Russia on how investments should be allocated between different infrastructural needs or within the energy sector. The Energy Sector is a technical document that does not take into account relative prices of different fuels or the bargaining power of different economic actors. Thus, conclusions are very tentative.

In order for the whole energy sector to deliver, according to the Energy Strategy, the investments required to modernize it and raise its efficiency are quite substantial. Under the first step of the Energy Strategy alone, the period up to 2015, 6–9 percent of GDP would be required for the necessary modernization, of which investment in electricity would account for about 1 percent. Investment in the energy sector competes with investment in other infrastructure in Russia and in production enterprises. Investment during the last phase of the strategy will be even more substantial.

The expansion plans as presented do not seem realistic. Russia has not built any nuclear reactors from scratch since the mid-1980s and the break means that the industry does not have the necessary capacity. The lack of modern technology and management, inputs and practice leads to delays in the construction of nuclear stations and makes them more expensive. Even the slower expansion envisaged in the Energy Strategy, compared to Rosatom's plans, is quite steep, but it may be assumed that start-up and capacity problems in the nuclear construction industry will be overcome within the next decade.

Moreover, the availability of manpower that has the training for constructing and running nuclear plants is uncertain, to say the least, and specialists are probably in short supply. Rosatom is supporting training for nuclear engineers, and the sector has become more popular again, but it will take time to turn the trend of bright people choosing business schools instead of the sciences and technical subjects when making their choice of profession. Hence it will take time to surmount the 25 years of nuclear silence, but the demand for more and cleaner electricity from diversified sources is a strong support for the nuclear energy expansion and thereby sustainable demand for specialists in this sector.

Uranium supplies appear to be adequate to fuel the foreseeable expansion of nuclear power, and an abundant fuel resource will remain a crucial advantage of nuclear power. In Russia, there are additionally abundant secondary supplies of fuel to support the expanded electricity generation by nuclear plants. Spent fuel may be reprocessed and used again. The Megatons to Megawatts project between Russia and the USA is an extraordinary example of how lethal weapons can be used for peaceful means. The project proves that the Russians have the technology to downblend weapons-grade uranium and deliver it safely, and hopefully this technology will be applied further.

c) Is Russia on the way to becoming a nuclear energy super power?

Russia has several advantages when choosing to expand nuclear power. First, its public opinion is fairly unconcerned about the risks associated with nuclear energy. Second, even after a pause of 25 years, Russia has competence in the nuclear area, largely thanks to the fact that military nuclear expansion was a first priority for so many years. Russian nuclear scientists are respected worldwide, and in some fields Russia is at the forefront, for example, it is the only country in Europe that is pursuing the development of breeder reactors. Third, Russia has a long-standing tradition in nuclear physics and an impressive infrastructure of research institutes and production companies that are able to generate reactor designs, construct plants, and undertake transport, storage, fuel fabrication and so on. Hence, Russia has strong comparative advantages in the nuclear energy area, even if the infrastructure and many facilities need to be modernized.

The Energy Strategy anticipates that Russia will continue to be the most important energy provider in Europe and the fourth most important country in electricity generating in the world during the coming decades. To maintain this position the oil and gas sector must be modernized to be able to maintain its role in exports, and at the same time substantial emphasis must be put on projects that enhance the substitution of nuclear power for gas in domestic electricity consumption. Oil will remain Russia’s most important export product and Russia plans to increase its gas exports.

Nuclear power is high-tech and Russia is competing with other nuclear nations for contracts to build nuclear plants abroad. Success in these projects is important for the national prestige and the image of being a country with a high level of R&D. Russian research in nuclear physics and new nuclear technologies is well respected internationally. Russian nuclear scientists have been integrated into the world science community again and they are taking part in cooperation projects trying to make nuclear power more efficient and safer. Russia is well advanced in the design of fast neutron reactors and Generation IV reactors, and other research that aims, for example, at closing the fuel cycle.

From uranium acquisition and policies in the nuclear fuel area, it is clear that Russia is interested in controlling a substantial share of the uranium resources and nuclear fuel in the world. Concentrating uranium assets and enrichment and fuel production on countries that already have the technology is believed to restrain the proliferation of fissile materials and enrichment technology. It also gives the nuclear weapon states an opportunity to keep up and expand their nuclear R&D and capacity.

Russia's ambitions in the nuclear energy area are high and, so long as no further serious accident occurs, this expansion trend will continue. Resource constraints will delay the development but not stop it. Russia has several strong advantages in its nuclear energy development, such as steady, strong government financial support for expansion and relatively positive support from the general public. Russia is already a big player on the international nuclear power plant market and on the nuclear fuel market and has all the opportunities to become a 'nuclear energy superpower'.

d) What are the safety and security implications of more nuclear power in Russia?

More nuclear power naturally means more chances of accidents occurring, as well as more opportunities to divert fissile materials. In the world as a whole, safety and security systems at nuclear facilities have been updated since Chernobyl and 9/11, but there will never be a guarantee that no new type of accident or sabotage will occur. The wildfires around the nuclear facilities in the closed city of Sarov in Nizhnyi Novgorod region in August 2010 have probably forced Russian nuclear safety experts to think more about fire protection. However, the fact remains that they will only be able to limit the risks of known threats, never completely eliminate all risks.

Russia's safety and security culture around nuclear power and fissile materials appears to have improved since the Chernobyl accident. Russia has adopted the safety conventions of the IAEA and is participating in cooperation that enhances security in different international organs. Still, many problems remain. Russia has a huge Soviet legacy of radioactive waste from primarily military operations but also from civil and research activities. The practice of storing waste at nuclear plants is widespread even if waste is eventually moved for temporary storage and reprocessing at special facilities. No final repository has been decided on and Russia has primarily opted for an intermediate repository from which spent fuel can be retrieved. This is a natural continuation of the Russian solution for spent fuel, where fuel is reprocessed. Decommissioning of research reactors and commercial reactors will take years. It is important that these objects are kept safe during the process.

Concerns have been raised regarding the proliferation implications of the global nuclear expansion. The 'Achilles' heel' of non-proliferation of fissile materials is the open fuel cycle. The NPT states focus on deterring new nuclear technology states from acquiring enrichment and reprocessing facilities. Russia's policies of providing the fuel to its nuclear plants abroad and repatriating spent fuel, and also hosting one of the international fuel banks, are in line with recommendations to support non-proliferation.

Expansion of civil nuclear power is one way of keeping and developing competence on how to handle the massive Soviet legacy of nuclear waste. Warheads and other weapons containing fissile materials need to be taken care of, and attention needs to be given to the environmental damage, which demands monitoring and policies. Nuclear technology is extremely complex and Russia must keep its long-standing competence in the field.

The strong expansion of nuclear power plants at home and abroad will to a great degree ensure that there will be people who have the education, training and experience to maintain the nuclear infrastructure and run both the civil and military facilities. Trained personnel are a first prerequisite for keeping nuclear plants and waste management safe. Obviously, this is also a way of keeping the base competence for the military applications of nuclear power in the future.

References

Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org. Retrieved 2010-08-20.

Charap, Samuel & Georgi V. Safonov (2010), 'Climate Change and Role of Energy Efficiency', in A. Aslund, S. Guriev, A. C. Kuchins (eds.), *Russia after the Global Economic Crisis*, Peterson Institute for International Economics, Center for Strategic and International Studies, New Economic School, New York, June.

Elektroenergetika Rossii 2030 (2008) (Moscow).

Government of the Russian Federation (2009), *Energeticheskaya strategiya do 2030 godu* (Energy strategy up to 2030) (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010.

Holt, Mark & Anthony Andrews (2009) *Nuclear Power Plant Security and Vulnerabilities*, Congressional Research Service, http://www.crs.gov, RL34331. Retrieved 2010-09-02.

IAEA (1986) Report INSAG-1 International Nuclear Safety Advisory Group. *Summary Report on the Post-Accident Review on the Chernobyl Accident*. Safety Series No. 75-INSAG-1 (Vienna, IAEA).

IAEA (2009) *Russian Federation, Country Profiles*, http://www.pub.iaea.org/MTCD/publications/PDF/cnpp/cpuntryprofiles/Russia/. Retrieved 2010-08-16.

IAEA (2010) *Nuclear Safety Review for the Year 2009* (IAEA, July). Retrieved 2010-08-09.

IEA (2008) *IEA Energy Policy Review. The European Union* (Paris, OECD/IEA).

IEA (2009) *IEA World Energy Outlook 2009* (Paris, IEA).

INSAG (1988) International Nuclear Safety Advisory Group. *Basic Safety Principles for Nuclear Power Plants* (Vienna, IAEA, 1988)

INSC*, Soviet Book*, http://www.insc.anl.gov/neisb/neisb5/3c_sb.pdf. Retrieved 2010-08-10.

IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06.

ISAB (2008) *Report on Proliferations of the Global Expansion of Civil Nuclear Power*, Washington, April.

Josephson, Paul R. (2000) *Red Atom* (Pittsburgh, PA, First University of Pittsburgh Press).

Khripunov, Igor & James Holmes (2004) *Nuclear Security Culture: The Case of Russia* (Center for International Trade and Security, University of Georgia, December).

KVA (2010) Royal Academy of Sciences, *Energy Resources and Their Utilization in a 40-year Perspective up to 2050. A synthesis of the work done by the Energy Committee at the Royal Swedish Academy of Sciences*, May.

Letts, Martin & Fiona Cunningham (2009) The role of the civil nuclear industry in preventing proliferation and in managing the second nuclear age. Paper prepared for the Second Meeting of the ICNND, Washington, 13–15 February 2009.

Marple, David R. & Marilyn J. Young (1997) *Nuclear Energy and Security in Former Soviet Union* (Boulder, CO, Westview Press).

Matrtyshev, Stanislav (2009) 'Ritmichnost vypolneniya investprogrammy nailushchiy sposob ukrepleniya prvlekatelnosti Rosaatom' (The rhythm in the investment programme increases the attractiveness of Rosatom), *Atomkon*, No. 1.

McKinsey&Company (2009) *Energoeffektivnaya Rossiya* (Energy efficient Russia), www.mckinsey.com, December.

MacKinsey & Company (2010) *Energoeffektivnaya Rossiya*, http://www.mckinsey.com/clientservice/sustainability/pdf/CO2_Russia_RUS_final.pdf. Retrieved 2010-10-18.

NEI (2009) Nuclear Energy Institute, Fact sheet, August

Nigmatulin, B.I. (2010) 'Otlichat porozhenie ot pobedy', *Proatom*, 29 March, http://www.proatom.ru. Retrieved 2010-06-11.

NTI (2002) Nuclear Threat Initiative, *Russia: Uranium Mining and Milling Overview*, http://www.nti.org/db/nisprofs/russia/fissmat/minemill/overview.htm. Retrieved 2010-08-06.

Oxenstierna, Susanne (2009) *Russia in Perspective. Scenarios of Russia's Economic Future 10 to 20 Years Ahead.* FOI-R--2774--SE (Stockholm, FOI).

TEK (2009) *Toplivno-energeticheskiy kompleks Rossii 2000-2008* (Russia's Heat and Energy Complex 2000-2008) (Moscow, Ministry of Energy of the Russian Federation, Institute of the Energy Strategy).

Westin, Jonas & Eric Sjöberg (2007) *Kreativitet som hot och möjlighet i kärnverksamheten* (Creativity as a threat and an opportunity in the core business), June, FOI-R--2288--SE (Stockholm, FOI).

WNA (2005) *The New Economics of Nuclear Power*, December, http://www.world-nuclear.com/Reference/pdf/economics.pdf. Retrieved 2010-07-15.

WNA (2010) *Nuclear Power in Russia*, http://www.world-nuclear.org/info/inf45.htlm. Retrieved 2010-05-01.

WNN (2010) 'Fuel loading starts at Bushehr 1', *World Nuclear News*, 23 August, http://www.world-nuclear-news.org/NN-Fuel_loading_starts_at Bushehr_1-2308104. Retrieved 2010-10-14.

Annex 1. On Watts

Watts and watt hours

The watt is a derived unit of power in the International System of Units, named after the Scottish engineer James Watt (1736–1819). The unit measures the rate of energy conversion. When we talk about kilowatts, megawatts, gigawatts and so on we refer to the *capacity of power installed in an engine, power plant* etc.

When we talk about kilowatt hours we refer to *the number of watts produced or consumed multiplied by the number of hours*. The kilowatt hour (kWh) is most commonly known as a billing unit for energy delivered to consumers by electricity utilities.

Kilowatt

The kilowatt (kW) is equal to 1 000 watts. This unit is typically used to express the output power of engines and the power consumption of tools and machines. It is also a common unit used to express the electromagnetic power output of radio transmitters. One kilowatt of power is approximately equal to 1.34 horsepower. A small electric heater with one heating element can use 1.0 kW. The average annual electrical energy consumption of a household in the United States is about 8 900 kWh, equivalent to a steady power consumption of about 1 kW for an entire year.

Megawatt

The megawatt (MW) is equal to 1 million watts. Many events or machines produce or sustain the conversion of energy on this scale, for example, lightning strikes, large electric motors, large warships, such as aircraft carriers, cruisers, and submarines, engineering hardware, and some scientific research equipment. A large residential or commercial building may consume several megawatts in electric power and heat. The productive capacity of electrical generators operated by a utility company is often measured in MW. Nuclear power plants have capacities between about 500 and 4 000 MW.

Gigawatt

The gigawatt (GW) is equal to 1 billion watts. This unit is used for large power plants or power grids. It is also a common unit for a country's installed capacity.

Terawatt

The terawatt (TW) is equal to 1 trillion watts. The total power used by humans worldwide – about 16 TW in 2006 – is commonly measured in this unit.

Annex 2. Reactors and Fuels Developed

RBMK is an acronym for the Russian *Reaktor Bolshoy Moshchnosti Kanalniy* which means 'high power channel-type reactor', and describes a class of graphite-moderated nuclear power reactor which was built in the Soviet Union. The RBMK was the culmination of the Soviet programme to produce a water-cooled power reactor based on their graphite-moderated plutonium production military reactors.[133]

The advantages of the RMBK were clear for the Soviet leadership. The unit of equipment was made at existing plants in the country and did not require the establishment of a new machine building industry. It was a significant advantage for the RBMK that planners did not to have to worry about manufacture at some outside, distant manufacturer. These reactors were primarily designed for making plutonium for nuclear weapons, with electric power as a by-product.

VVER, *Vodo-Vodyanoi Energetichesky Reactor*, stands for 'water-cooled, water-moderated energy reactor'. This describes the pressurized-water reactor design, in the West abbreviated to PWR. The VVERs were developed by the Soviet Union and used by Armenia, Bulgaria, China, the Czech Republic, Finland, the former East Germany, Hungary, India, Iran, Slovakia, Ukraine, and the Russian Federation. VVER series nuclear reactors were also scaled down in size and used by the Soviet nuclear submarine fleet as well as by surface warships. The VVERs are currently the standard reactor type being developed and are used in all Russia's international projects.[134]

BN – A breeder reactor is a nuclear reactor that generates new fissile material at a greater rate than it consumes such material. In the 1940s and 1960s, these reactors were attractive because their superior fuel economy. A normal reactor is able to consume less than 1 percent of the natural uranium that begins the fuel cycle, whereas a breeder can utilize a much greater percentage of the initial fissionable material, and with reprocessing can use almost all of the initial fissionable material. Breeders can be designed to utilize thorium, which is more abundant than uranium. Currently, there is renewed interest in breeders because they would consume less natural uranium (less than 3 percent compared to conventional light-water reactors), and generate less waste, for equal amounts of energy. The first USSR commercial breeder reactor was put into action in Beloyarsk in 1960s. The Russians are currently developing a BN-800.[135]

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133 http://en.wikipedia.org/wiki/RBMK. Retrieved 2010-10-21.
134 http://en.wikipedia.org/wiki/VVER. Retrieved 2010-10-21.
135 http://en.wikipedia.org/wiki/Breeder_reactor. Retrieved 2010-10-21.

- FBR – **fast breeder reactor**. The superior neutron economy of a fast neutron reactor makes it possible to build a reactor that, after its initial fuel charge of plutonium, requires only natural (or even depleted) uranium feedstock as input to its fuel cycle. This fuel cycle has been termed 'the plutonium economy'.[136]
- TBR – **thermal breeder reactor**. The neutron capture characteristics of fissile uranium-233 make it possible to build a moderated reactor that, after its initial fuel charge of enriched uranium, plutonium or mixed oxide (MOX) (see below), requires only thorium as input to its fuel cycle. Thorium is a naturally occurring, slightly radioactive metal. It is estimated to be about three to four times more abundant than uranium in the Earth's crust. It has been considered a waste product in mining rare earths, so its abundance is high and its cost low (see further below).[137]

MOX fuel is nuclear fuel containing more than one oxide of fissile or fertile materials. Specifically, it usually refers to a blend of oxides of plutonium and natural uranium, reprocessed uranium, or depleted uranium which behaves similarly to the low-enriched uranium oxide fuel for which most nuclear reactors were designed. MOX fuel is an alternative to the LEU fuel used in the light-water reactors that predominate in nuclear power generation. One attraction of MOX fuel is that it is a way of disposing of surplus weapons-grade plutonium, which otherwise would have to be disposed of as nuclear waste, and would remain a proliferation risk. However, there have been fears that normalizing the global commercial use of MOX fuel and the associated expansion of reprocessing will itself lead to greater proliferation risks.[138]

Thorium was successfully used as a breeding (fertile) source for nuclear fuel – uranium-233 – in the molten-salt reactor experiment from 1964 to 1969 (producing thermal energy for heat exchange to air or liquids), as well as in several light-water reactors using solid fuel composed of a mixture of ^{232}Th and ^{233}U. Currently, the Japanese Fuji project and officials in India are advocating a thorium-based nuclear programme, and a seed-and-blanket fuel utilizing thorium is undergoing irradiation testing at the Kurchatov Institute in Moscow. Advocates of the use of thorium as the fuel source for nuclear reactors state that they can be built to operate in a way that is significantly cleaner than uranium-based power plants as the waste products are much easier to handle.[139]

[136] *Ibid*.
[137] *Ibid*.
[138] http://en.wikipedia.org/wiki/MOX_fuel. Retrieved 2010-10-21.
[139] http://en.wikipedia.org/wiki/Thorium. Retrieved 2010-10-21.

Annex 3. Closed Towns

The Russian nuclear industry has under its control 10 closed cities, known officially as closed administrative territorial formations (ZATO). The Defence Ministry ahas another 30 such closed zones under its jurisdiction about.[140] The organization of the development of nuclear energy in the Soviet Union was closely linked to the military use of nuclear power and many research establishments had a dual purpose in their operations. The Soviet Union created at least 10 closed nuclear cities, known as *atomgrads*, in which both nuclear weapons-related research and civil nuclear R&D took place. After the dissolution of the Soviet Union, all of the cities changed their names (most of the original code names were simply the oblast and a number). All are still legally 'closed', though some have become accessible to persons outside these cities and to foreign visitors with special permits. Around 2 million people currently live in the closed cities.[141]

Sarov is a closed town in Nizhnyi Novgorod Oblast, Russia. Until 1995 it was known as Kremlev, while from 1946 to 1991 it was called Arzamas-16. The city is still considered a closed town and is off limits to foreigners. It is one of the main centers of Russian nuclear research. Its population is around 88 000. The town is located mostly on the territory of Nizhny Novgorod Oblast, but a part of it extends into the Republic of Mordovia. In 1946, the *All-Union Scientific Research Institute of Experimental Physics* – a nuclear weapons design facility that would become known in the West under the acronym *VNIIEF* – was built in Arzamas. Warheads were also assembled here. In 1954, Arzamas-16 was given the status of a town. Much of the town was built by German prisoners of war. Currently, in 2010, Sarov is home to the *Russian Federation Nuclear Center*.[142] In 1993, the town became a sister city to Los Alamos, New Mexico, the home of the US nuclear weapons design laboratory. Boris Yeltsin changed the town's name back to Sarov at the request of the residents in August 1995. Today the Russian Federal Nuclear Center is responsible for important decisions concerning the development, production, storage and utilization of nuclear weapons; the recycling of radioactive and other materials; and research in fundamental and applied physics.

Snezhinsk is a closed town in Chelyabinsk Oblast, Russia. It was founded in 1957, and was known as Chelyabinsk-70 until 1991. Town status was granted in 1993 and it has a population of around 50 000. Snezhinsk is also a sister city of

[140] Bellona (2004) *The Russian Nuclear Industry. The Need for Reform*. Bellona Foundation, http://www.bellona.org, Retrieved 2010-08-20, p. 26.
[141] *Ibid.,* p. 26.
[142] http://en.wikipedia.org/wiki/Sarov. Retrieved 2010-10-21.

Livermore, CA, United States. It is one of two main centers of the Russian nuclear programme (the other is Sarov; see above) and is built around a major scientific institute – the *All-Russian Scientific Research Center of Technical Physics/Federal Nuclear Center* – which was used for weapons design and research.[143]

Seversk is a closed city in Tomsk Oblast, Russia, located 15 km north-west of Tomsk on the right bank of the Tom River. The population is around 110 000. Founded in 1949, it was known as Pyaty Pochtovy until 1954 and as Tomsk-7 until 1992. Seversk is the site of the *Siberian Group of Chemical Enterprises* (SGCE), founded in 1954. It comprises several nuclear reactors and chemical plants for the separation, enrichment and reprocessing of uranium and plutonium. Following an agreement in March 2003 between Russia and the United States to shut down Russia's three remaining plutonium-producing reactors, two of the three (the two that are sited at Seversk) have now been shut down. Nuclear warheads are produced and stored on the premises. One of the most serious nuclear accidents at SGCE occurred on 6 April 1993, when a tank containing a highly radioactive solution exploded.[144]

Ozersk is a closed town in Chelyabinsk Oblast, Russia. It was founded on the shore of the Irtyash Lake in 1945 and called Chelyabinsk-40 and then, until 1994, Chelyabinsk-65. Ozersk was and remains a closed town because of its proximity to the **Mayak** plant, located 150 km south-east of Ekaterinburg. Mayak produced plutonium and is a main facility for processing nuclear waste and recycling nuclear material from decommissioned nuclear weapons and from nuclear plants. The Mayak plant itself covers an area of approximately 90 km^2 and employs about 15 000 people. Mayak is also known for the *Kyshtym disaster*, a radiation contamination incident that occurred on 29 September 1957 in Mayak. It measured as a Level 6 disaster on the International Nuclear Event Scale, making it the second-most serious nuclear accident ever recorded (after Chernobyl). Nowadays, the Mayak plant is primarily engaged in reprocessing of spent nuclear fuel from the nuclear submarines and icebreakers and from nuclear power plants.[145]

Zelenogorsk is a closed town in Krasnoyarsk region (Krai), Russia. It was formerly known as Krasnoyarsk-45 and was involved in enriching uranium for the Soviet nuclear programme. The city is located on the left bank of the Kan River 180 km above its confluence with the Yenisei River in Siberia. It is engaged in uranium enrichment.[146]

143 http://en.wikipedia.org/wiki/Snezhinsk.
144 http://en.wikipedia.org/wiki/Seversk.
145 http://en.wikipedia.org/wiki/Ozersk.
146 http://en.wikipedia.org/wiki/Zelenogorsk.

Zarechnyi, called Penza-19 between 1962 and 1992, is a closed town in Penza Oblast, Russia, located 12 km east of Penza. The town of Zarechny was formed in 1958 on the territory of Penza's Zarechny City District. It was closed and renamed Penza-19 in 1962, and renamed Zarechny in 1992. Zarechny's main employer is Rosatom and the manufacture of nuclear weapon components is a major industry. Other industries include electronics and software.[147]

Lesnoy is a closed town in Sverdlovsk Oblast, Russia, located 254 km north of Ekaterinburg. The town was founded in 1947 when Plant 418 was constructed to produce HEU for the production of nuclear weapons. Nuclear weapons were also assembled here. In 1954 it was incorporated by the former Soviet Union as the closed city of Sverdlovsk-45 to support production of nuclear weapons, uranium enrichment and warhead assembly.[148]

Novouralsk is a closed town in Sverdlovsk Oblast, Russia. The city of Novouralsk, formerly known as Sverdlovsk-44, is situated on the eastern side of Ural mountain range, about 70 km north of Ekaterinburg. Although it came into being during World War II, and was named Novouralsk in 1954, it was kept secret until 1994, and has since retained closed city status. The Ural Electro Chemical Plant (UECP)'s main activities are uranium enrichment and the development of centrifuge technology, as well as the manufacture of instruments and industrial systems for the nuclear industry. The plant began operating in 1949 and was the site of the Soviet Union's first gaseous diffusion enrichment plant. It leads the development of Russian centrifuge technology, has used seventh-generation gas centrifuges since 1996, and has developed eighth-generation centrifuges. UECP now produces LEU using centrifuge technology.[149]

Trekhgorny is a closed town in Chelyabinsk Oblast, Russia, founded in 1952, and earlier known under the name Zlatoust-36. The name 'Trekhgorny' means 'a town of three mountains'. The town is located in the western part of Chelyabinsk Oblast, as far as 200 km from Chelyabinsk. It is closed because it was used for warhead assembly and a plant producing parts of atomic reactors is located there.[150]

Zheleznogorsk (Krasnoyarsk-26). In 1950, the former Soviet Union created the closed city of Krasnoyarsk-26 for the production of weapons plutonium. The histories of the town and the associated defence complex are intertwined. Defence plants included nuclear facilities built within caverns excavated in the granite mountain on the northern edge of the city as well as space research enterprises.[151]

[147] http://en.wikipedia.org/wiki/Zarechny.
[148] *Ibid.*/Lesnoy.
[149] *Ibid.*/Novouralsk.
[150] *Ibid.*/Trekhgorny.
[151] *Ibid.*/Zheleznogorsk.

Annex 4. Tables

Table A1. Operating reactors and nuclear capacities in selected countries in 2007

Country	**Units**	**Total GW**
Total world		**372**
Selected countries:		
USA	104	100.3
France	59	63.3
Japan	55	47.6
Russia	31	21.7
South Korea	20	17.4
United Kingdom	19	10.2
Canada	18	12.6
Germany	17	20.3
India	17	3.8
Ukraine	15	13.1
China	11	8.6
Sweden	10	9.0

Source: IPFM (2007) *Global Fissile Material Report 2007*, http://www.fissilematerials.org. Retrieved 2010-04-06, p. 83; UNESCO (2009) *Global Energy and Sustainable Development* (Moscow, ISEDEC), p. 164.

Table A2. Forecast of production of electricity in Russia, 2008–2030, bn kilowatt per hour (bn kWh)

	2008	2013-15	2020-22	-2030	2008	2030
Domestic demand for electricity, bn kWh	1021	1041-1218	1315-1518	1740-2164	*% of total*	*% of total*
Export, bn kWh	16	18-25	35	45-60		
Production, bn kWh	1037	1059-1245	1350-1555	1800-2210		
Of which:						
Nuclear power plants	163	194-220	247-282	356-437	*16*	*20*
Hydro power stations & renewable energy	167,5	181-199	224-240	319-422	*16*	*18-19*
Condensing power stations	322	299-423	432-592	620-873	*31*	*34-40*
Thermal power stations	385	385-403	441-447	478-505	*37*	*22-28*

Source: Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 158.

Table A3. Forecast of electricity generation capacity expansion in Russia, 2008–2030, million kilowatt

	2008	2013-15	2020-22	-2030	Change 2008-2030	Change %
Total generating capacity	225	239-267	275-315	355-445	220	*49*
Of which:						
Nuclear power plants	24	28-33	37-41	52-62	38	*61*
Hydro and renewable energy	47	55-59	66-73	91-129	82	*64*
Condensing power stations	68	67-83	73-103	100-148	80	*54*
Thermal power stations	85	89-92	98-99	106-112	27	*24*

Source: Government of the Russian Federation (2009), *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 158.

Table A4. Forecast of necessary investments for the development of electrical energy in Russia up to 2030, in billion 2007 USD

	1st stage 2013–2015	2nd stage 2020–2022	3rd stage –2030	Total 2009–2030
Total	122–126	110–233	340–529	572–888
Nuclear Power	29–30	13–28	58–81	100–149
Hydro	17–18	8–15	30–92	55–125
Heat	32–33	46–112	122–145	200–290
Grid	44–45	43–78	130–211	217–334

Source: Government of the Russian Federation (2009) *Energeticheskaya strategiya do 2030 godu* (Directive No. 1751, adopted by the government 13 November), http://minenergo.gov.ru/activity/energostrategy/Strategiya/Energostrategiya-2030.doc. Retrieved February 2010, p. 160.

Table A5. Known recoverable resources of uranium (U), production of U, and share of nuclear power in electricity production 2009

	Reserves (tons U)	% of world reserves	Production (tons U)	% of world production	% of nuclear power in electricity production
Australia	1,673,000	31	7982	16	0
Kazakhstan	651	12	14020	28	0
Canada	485	9	10173	20	14.8
Russia	**480**	**9**	**3564**	**7**	**17.8**
South Africa	295	5	563	1	4.8
Namibia	284	5	4626	9	0
Brazil	279	5	345	1	3.0
Niger	272	5	3243	6	0
USA	207	4	1453	3	20.2
China	171	3	750	1	1.9
Jordan	112	2	na	na	na
Uzbekistan	111	2	2429	5	0
Ukraine	105	2	840	2	48.6
India	80	1.5	290	1	2.2
Mongolia	49	1	258	1	0
Other	150	3	229	0,4	
World total	**5 404 000**	**98**	**50 772**	**100**	**14**

Source: Reasonably Assured Resources plus Inferred Resources, to USD 130/kg U, 1/1/09, from OECD NEA & IAEA, *Uranium 2009: Resources, Production and Demand* ('Red Book'), http://www.world-nuclear.org/info/inf75.html; WNA, http://www.world-nuclear.org/info/inf23.html, 2010-08-13. World Nuclear Power Reactors & Uranium Requirements ! August 2010, http://www.world-nuclear.org/info/reactors.htlm. Retrieved 2010-08-24.

About the author

Susanne Oxenstierna is a senior social scientist who has specialized on the Russian economy for 25 years. After finishing her PhD in Economics at Stockholm University in 1991, she worked in numerous technical assistance projects of the Swedish Ministry of Finance, the Swedish International Development Cooperation Agency (Sida), DFID and the European Union to Russia and Eastern Europe. For several years in the 1990s and early 2000s she was a resident advisor to the Russian Ministry of Finance and Ministry of Economic Development in Moscow. She is currently working at the Swedish Defence Research Agency, FOI, in Stockholm.

Her research areas are the Russian economy, its military economy and its energy sector. Her most recent publications are 'Russia's Nuclear Renaissance', *Baltic Rim Economics*, No. 4, August 2010; 'Ryssland: råvaruexportör eller innovationsdriven granne i öst?' (Russia: commodity exporter or innovative neighbour?), together with Carolina Vendil Pallin, in Granholm and Lindström (eds.) *Strategisk utblick 2010: Säkerhetspolitisk nattorientering?* FOI-R--2975--SE, June 2010, pp. 29–34; and 'Modernisering eller fortsatt oljeberoende? Den ryska ekonomin efter krisen' (Modernization or continued commodity dependence? The Russian economy after the crisis), *Ekonomisk Debatt,* No. 7, November 2010.

RUFS reports 2008-2010

2010

Oxenstierna, Susanne (2010) *Russia's Nucler Energy Expansion*. FOI-R—3049--SE, December.

Ekström, Markus (2010) *Rysk operativ-strategisk övningsverksamhet under 2009 och 2010*. FOI-R--3022--SE, November.

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Roffey, Roger (2010) *Biotechnology in Russia: Why is it not a Success Story?*, FOI-R--2986--SE, April.

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Vendil Pallin, Carolina; Westerlund, Fredrik (2010) *Rysslands militärdoktrin 2010*, FOI Memo 3097, February.

2009

Oxenstierna, Susanne (2009) *The Russian Economy in 2009: Steep Decline Despite Crisis Management*, FOI-R--2853--SE, December.

Westerlund, Fredrik (2009) *Rustningskontroll i det 21 århundradet*, FOI Memo 2905, December.

Westerlund, Fredrik (2009) *Övergripande ledning och organisation av den ryska försvarsindustrin 2008*, FOI Memo 2903, November.

Westerlund, Fredrik (2009) *Rysk Försvarsmaterielproduktion 2006-2007*, FOI Memo 2731, October.

Oxenstierna, Susanne (2009) *Russia in Perspective: Scenarios of Russia's Economic Future 10 to 20 Years Ahead*, FOI-R--2774--SE, June.

Kölstad, Henrik (2009) *White Russia – Xenophobia, Extreme Nationalism and Race Radicalism as Threats to Society*, FOI-R--2592--SE, April.

Leijonhielm, Jan et al. (2009) *Russian Military Capability in a Ten-Year Perspective: Ambitions and Challenges in 2008 – Summary and Conclusions from a Study for the Swedish Ministry of Defence*, FOI-R--2759--SE, February.

Leijonhielm, Jan et al. (2009) *Rysk militär förmåga i ett tioårsperspektiv – ambitioner och utmaningar 2008,* FOI-R--2707--SE, January.

2008

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Bladel, Joris van (2008) *The Dual Structure and Mentality of Vladimir Putin Power Coalition: A Legacy for Medvedev*, FOI-R--2519--SE, May.

Löfstrand, Maria (2008) *Rysk identitet: Ryska medborgares syn på hot, sitt land och sin omvärld*, FOI-R--2503--SE, April.

Niklasson, Charlotte (2008) *Russian Leverage in Central Asia*, FOI-R--2484--SE, April.

Konnander, Vilhelm (2008) *Ryssland – en suverän demokrati?*, FOI-R--2501--SE, April.

Holmberg, Carl (2008) *The Struggle for Bureaucratic and Economic Control in Russia*, FOI-R--2504--SE, April.

Roffey, Roger (2008) *EU-Russian Partnership to Reduce Bio-Threats and Fight Disease Outbreaks*, FOI-R--2493--SE, March.

Holmberg, Carl (2008) *Managing Elections in Russia – Mechanisms and Problems*, FOI-R--2474--SE, February 2008.

Larsson, Robert L. (2008) *Energikontroll: Kreml, Gazprom och rysk energipolitik*, FOI-R-2445--SE, January.

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