Nuclear Power in Russia

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- **Despite major problems in the 1980s, Russia is now moving steadily forward with plans for much expanded role of nuclear energy.**
- **Efficiency of nuclear generation has increased dramatically over the last few years.**
- **Electrcity demand is rising 3% pa.**
- **Exports are a major policy and economic objective.**

Background

Russia's first two commercial-scale nuclear power plants started up in 1963-64, then in 1971-73 the first of today's production models were commissioned. By the mid 1980s Russia had 25 power reactors in operation.

At this time Russia seemed to be taking impressive steps to contest world leadership in civil development of nuclear energy. It had developed two major reactor designs, one from military plutonium production technology (the RBMK), and one from naval propulsion units, very much as in USA (the VVER series). An ambitious plant, Atommash, to mass produce the latter design was taking shape near Volgodonsk, construction of numerous nuclear plants was in hand and the country had many skilled nuclear engineers.

But a technological arrogance developed, in the context of an impatient Soviet establishment. Then Atommash sunk into the Volga sediments, Chernobyl tragically vindicated western reactor design criteria, and the political structure which was not up to the task of safely utilising such technology fell apart. Atommash produced a total of only three reactor pressure vessels, instead of the eight per year intended. Chernobyl became a byword for Soviet incompetence. Russia was disgraced technologically, and this was exacerbated by a series of incidents in its nuclear-propelled navy contrasting with a near-impeccable safety record in the US Navy.

After Chernobyl there was a significant change of culture in the Russian civil nuclear establishment, at least at the plant level, and this change was even more evident in the countries of eastern Europe who saw the opportunity for technological emancipation from Russia. By the early 1990s a number of western assistance programs were in place which addressed safety issues and helped to alter fundamentally the way things were done in the eastern bloc, including Russia itself. Design and operating deficiencies were tackled, and a safety culture started to emerge. At the same time some R&D programs were suspended.

Both the International Atomic Energy Agency and the World Association of Nuclear Operators were responsible for huge gains in safety and reliability of Soviet-era nuclear plants. In the first two years of WANO's existence, 1989-91, operating staff from every nuclear plant in the former Soviet Union visited plants in the west on technical exchange, and western personnel visited every FSU plant. A great deal of ongoing plant-to-plant cooperation, and subsequently a voluntary peer review program, grew out of these exchanges.

Between the 1986 Chernobyl accident and mid 1990s, only one nuclear power station was commissioned in Russia, the 4-unit Balakovo, with unit 3 being added to Smolensk. But by the late 1990s exports of reactors to Iran, China and India were negotiated and Russia's stalled domestic construction program was revived as far as funds allowed. Then Rostov-1 (now known as Volgodonsk-1), the first of the delayed units, started up in 2001, joining 21 GWe already on the grid. This greatly boosted morale in the Russian nuclear industry.

Electricity supply

Russia's electricity supply faces a number of acute constraints. First, demand is rising about 3% per year after more than a decade of stagnation, secondly some 50 GWe of generating plant (more than a quarter of it) in the European part of Russia comes to the end of its design life by 2010, and thirdly Gazprom cut back on natural gas supplies for electricity generation by 12% over two years because it can make about five times as much by exporting the gas to the west. (Also, by 2020, the Western Siberian gas fields will be so depleted that they supply only a tenth of current Russian output, compared with nearly three quarters now.) Also there are major regional grid constraints so that a significant proportion of the capacity of some plants cannot be used.

On the positive side, nuclear electricity output is rising strongly due simply to better performance of the nuclear plants, with capacity factors leaping from 56% to 75% 1998-2000 and 125 billion kWh being supplied in 2001 (15% of total). In gross terms, 135 billion kWh in 2001 is expected to grow to 175 in 2005, 212 in 2010, and 270 billion kWh or more by 2020.

Nuclear power is expected to increase from 15 to 25% of Russia's electricity by 2020 as the share from gas drops substantially to 28%.

Following proposals thrashed out over several years, a government order consolidating the country's nuclear utilities was signed in 2001. Rosenergoatom took over all civil reactors including those under construction and related infrastructure. Earlier, a decree integrated the country's fuel cycle enterprises, notably fuel production, with a view to exports.

Rosenergoatom operates very much within the context of state energy policy - currently that defined in 2000, and of state funding for new plants to meet policy goals. Currently Russian nuclear plants provide about 140 billion kWh per year from 22 GWe (20.8 GWe net), government policy is for this output to increase substantially. The growth is to come from lifetime extension of first-generation units, upgrading, increased availability to 85% average (and hopefully more), together with some new plant.

Unified electricity tariffs were planned to increase from 1.1 c/kWh in 2001 to 1.9 c/kWh in 2005 and 2.4 c/kWh in 2010. However, only much smaller increases have so far been approved by the government, and even these have attracted wide opposition. However, electricity supplied is now being fully paid for, in contrast to the situation in the mid 1990s.

Extending nuclear capacity

Russia's nuclear plants, with [30 operating reactors] totalling 20,793 MWe, comprise:

- 4 first generation VVER-440/230 or similar pressurised water reactors which have serious design deficiencies,
- 2 second generation VVER-440/213 pressurised water reactors with some major design deficiencies which have been partly remedied.
- 8 third generation VVER-1000 pressurised water reactors with a full containment structure. These have some instrumentation and control system deficiencies, but come closest to Western standards.
- 11 RBMK light water graphite reactors now unique to Russia (apart from 2 larger units in Lithuania). The four oldest of these were commissioned in the 1970s at Kursk and Leningrad and are of some concern. A further Kursk unit is under construction.
- 4 small graphite-moderated BWR reactors in eastern Siberia, constructed in the 1970s (EGP-6 models on linked map).
- One BN-600 fast-breeder reactor.

Generally, reactors are licensed for 30 years. Late in 2000, plans were announced for lifetime extensions of twelve first-generation reactors* totalling 5.7 GWe, and the extension period envisaged is now 15 years, necessitating major investment in refurbishing them by 2006. So far three 15-year extensions have been issued, for Novovoronezh-3, Kursk-1&2 and Kola-1. Leningrad-1 was upgraded in 2004 to prepare for licence renewal. Replacement of all these twelve units after 2015 is planned.

* Leningrad 1&2, Kursk 1&2, Kola 1&2, Bilibino 1-4, Novovoronezh 3&4.

Power Reactors in Operation

Reactor	Type V=PWR	MWe net, each	Commercial operation
Balakovo 1-4	V-320	950	5/86-12/93
Beloyarsk 3	BN600 FBR	560	11/81
Bilibino 1-4	LWGR	11	4/74-1/77
Kalinin 1-2	V-338	950	6/85, 3/87
Kola 1-2	V-230	411	12/73, 2/75
Kola 3-4	V-213	411	12/82, 12/84
Kursk 1-4	RBMK	925	10/77-2/86
Leningrad 1-4	RBMK	925	11/74-8/81
Novovoronezh 3-4	V-179	385	6/72, 3/73
Novovoronezh 5	V-187	950	2/81
Smolensk 1-3	RBMK	925	9/83-1/90
Volgodonsk 1	V-320	950	3/01
Total: 30		20,793 MWe	

With the exception of Kursk-5, financing for the next six reactors (5.5 GWe) appears to be secure, and beyond that a further 3.5 GWe of capacity remains partially complete.

Power Reactors Under Construction

Operate*	unit	type V=PWR	MWe net
2004	Kalinin 3	V-320	950

2006	Kursk 5	RBMK	925
2007	Volgodonsk-2	V-320	950
2008	Balakovo 5	V-320	950
2010	Beloyarsk-4	FBR (BN-800)	750
2011	Balakovo 6	V-320	950
Total: 6		5475 MWe	

* proposed commercial operation.
Construction of Kursk-5 is halted, perhaps aborted.

The investment program amounts to 450 billion roubles (US$ 15 billion) in 2002 currency, 290 billion roubles (US$ 9.7 billion) by 2010. Some 35% of this is for upgrading and replacement capacity, 56% of it for new capacity (@ US$ 650/kW), including 90 billion roubles (US$ 3 billion) for growth after 2010.

The BN-800 Beloyarsk-4 fast reactor is designed to replace the BN-600 unit 3 and the US$ 1.22 billion project may become international, with Japanese and Chinese involvement.

Power Reactors Planned or On Order

unit	type	MWe*	start-up
replacement capacity:			
Leningrad NPP-2 1&2	PWR	1500	2012,15
Novovoronezh 6	PWR	950	2016
Kursk NPP-2 1&2	PWR	1500	2016,19
new capacity:			
Kalinin 4	PWR	950	2009
Kursk 6	RBMK	925	2010
Bashkira 1	PWR	950	2012
North-west 1	VK	300	2011
Smolensk 4	RBMK	925	2012
North-west 2	VK	300	2013
Bashkira 2	PWR	950	2014
Volgodonsk 3	PWR	950	2015
Volgodonsk 4	PWR	950	2017
Tatar 1	PWR	950	2016
Smolensk NPP-2 1&2	PWR	950	2017,19
Tatar 2	PWR	950	2018
South Ural 1, 2	PWR	950	2016,19
Novovoronezh 7	PWR	950	2016
Bashkir 3&4	PWR	1500	2018,20
Tatar 3	PWR	1500	2020

* each, (1500 & 300 are gross capacity)
VVER-1000 may replace RBMK at Smolensk & Kursk
South Urals was to be BN-800, and may revert.
BWR is VK-300.

All this is designed to provide growth to 49.3 GWe by 2020 in the high-growth scenario, or 35 GWe in the low-growth alternative, or perhaps something in between. By some accounts, this will include the first lead-cooled BREST-300 fast neutron reactor, at Beloyarsk.

In addition, 5 GW of thermal power plants (mostly AST-500 integral PWR type) for district and industrial heat will be constructed at Arkhangelesk (4 units commissioned 2009-16), Voronezh (2 units 2012-18), Saratov, Dimitrovgrad and (small-scale, KLT-40 type PWR) at Chukoyka and Severodvinsk.

Rosatom's proposal for a rapid expansion of nuclear capacity is based initially on the cost effectiveness of completing the 9 GWe of partially built plant, at an average cost of US$ 680 per kilowatt, compared with US$ 950/kW for new gas-fired plant including necessary infrastructure. (New nuclear plant was projected at US$ 900/kW.) To get the funds, Minatom offered Gazprom the opportunity to invest in some of the partly completed nuclear plants. The argument is that the US$ 7.3 billion required for the whole 10 GWe (including the just-completed Rostov-1) would be quickly recouped from gas exports if the new nuclear plant reduced the need to burn that gas domestically.

The Floating Energy Unit with two KLT-40 nuclear reactors developed for icebreakers was approved in 2003, to serve remote areas. They would produce 100 MWe or 50-70 MWe plus up to 35 MW of heat. Construction of the first US$ 150 million unit at Severodvinsk, Archangelsk region, is now ready to proceed. Exports of combined power and desalination units is planned.

Rosatom's long-term strategy up to 2050 involves moving to inherently safe nuclear plants using fast reactors with a closed fuel cycle and MOX fuel. Fossil fuels for power generation to be largely phased out. Starting 2020-25 it is envisaged that fast neutron reactors will play a major role in Russia, and an optimistic scenario has expansion to 90 GWe nuclear capacity by 2050.

Technology improvements

The guidelines for developing large-scale nuclear power in Russia have been set out as follows:

Power costs not more than 3 cents/kWh,
Capital costs under US$ 1000/kW,
Service life at least 50 years,
Utilisation rate at least 90%.

The main reactor design now being deployed is the V-320 version of the VVER-1000, with 950 MWe net output. The V-428 version of VVER-1000 with western control systems (also known as AES-91 nuclear power plant) was earlier sold to China for Tianwan (Lianyungang) and was bid for Finland in 2002.

An advanced version of VVER-1000, the V-392, is under development and has been sold to India, as well as planned for Novovoronezh 6 & 7. It is expected to be bid for Sanmen and Yanjiang in China. (It is also known as AES-92 nuclear power plant.)

Another reactor type with advanced safety features which has been under development is the 640 MWe V-407 (VVER-640), a size of reactor not previously seen in Russia, and developed jointly with Siemens (now Framatome ANP). However, after beginning construction of the first at Sosnovy Bor, funds ran out and it has disappeared from recent plans.

A development of the RBMK is the MKER-800, with much improved safety systems and containment, but this too has been shelved.

The BN-800 fast reactor being built at Beloyarsk is designed to supersede the BN-600 unit there and utilise MOX fuel with both reactor-grade and weapons plutonium.

More recently Rosatom has undertaken the basic design for VVER-1500/V-448 pressurised water reactors as a priority. Design is expected to be complete in 2007 and the first units commissioned in 2012-13. Provisional sites for these larger units are Kursk and Leningrad power stations, which currently run 8 RBMK light water, graphite-moderated units between them, dating from 1974, and the first unit is planned for Leningrad NPP-2, starting construction in 2005.

However, the main current emphasis is the improvement in operation of present reactors with better fuels and greater efficiency in their use, closing much of the gap between Western and Russian performance. Fuel developments include the use of burnable poisons - gadolinium and erbium, as well as structural changes to the fuel assemblies.

With uranium-gadolinium fuel and structural changes, VVER-1000 fuel has been pushed out to 4-year endurance and VVER-440 fuel even longer. For VVER-1000, five years is envisaged by 2010, with enrichment levels increasing nearly by one third (from 3.77% to 4.87%) in that time, average burn-up going up by 40% (to 57.7 GWd/t) and operating costs dropping by 5%. With a 3 x 18 month operating cycle, burn-up would be lower (51.3 GWd/t) but load factor could increase to 87%. Comparable improvements were envisaged for later-model VVER-440 units.

For RBMK reactors the most important development has been the introduction of uranium-erbium fuel at all units, though structural changes have helped. As enrichment and erbium content are increased (eg to 2.8% and 0.6% respectively at Leningrad-2), increased burn-up is possible. For the BN-600 fast reactor, improved fuel means up to 560 days between refuelling.

Beyond these initiatives, the basic requirements for fuel have been set as: fuel operational lifetime extended to 6 years, improved burn-up of 70 GWd/tU, and improved fuel reliability. In addition, many nuclear plants will need to be used in load-following mode, and fuel which performs well under variable load conditions will be required.

All RBMK reactors now use recycled uranium from VVER reactors and some has also been used experimentally at Kalinin-2 and Kola-2 VVERs. It is intended to extend this. A related task is to utilise surplus weapons-grade plutonium in MOX fuel for up to seven VVER-1000 reactors from 2008 and the one fast reactor (Beloyarsk-3) from 2007.

Main Russian PWR nuclear power reactors (in order of development)

Generic reactor type	Reactor model	Power plant
VVER-440	V-230	
	V-213	
VVER-1000	V-320	
	V-428	AES-91

	V-392	AES-92
VVER-1500	V-448	

Resources

Russia has substantial recoverable resources of uranium, with about 4% of world resources up to US$ 80/kg. In 2002 it produced some 2900 tonnes of uranium from mines.

Some uranium also comes from reprocessing spent fuel from VVER-440, fast neutron and submarine reactors - some 2500 tonnes of uranium has so far been recycled into RBMK reactors. Also 32 tonnes of plutonium has been accumulated for use in MOX, and added to this will be 34 tonnes of weapons-grade plutonium from military stockpiles to be used in VVER-1000 and fast neutron reactors.

All this is expected to suffice for at least 80 years, or more if recycling is increased. However, from 2020 it is intended to make more use of fast neutron reactors.

Fuel Cycle Facilities

Many of Russia's fuel cycle facilities were originally developed for military use and hence are located in former closed cities (names bracketed) in the country.

The only operating conversion plant is at Angarsk near Irkutsk in Siberia, with 18,700 tonnes U/yr capacity. Four enrichment plants totalling 20 million kg SWU/yr of centrifuge capacity operate at Novouralsk near Yekaterinburg in the Urals, and Zelenogorsk (Krasnoyarsk-45), Seversk near Tomsk and Angarsk near Irkutsk - all in Siberia. The first two service foreign demand and the last specialises in enriching reprocessed uranium.

Diffusion technology was phased out by 1992 and all plants now operate 5th or 7th generation gas centrifuges, with further fitting of 7th & eventually 8th generation equipment planned.

The Novouralsk plant is the largest (10 M SWU/yr) and can enrich to 30% U-235 (for research and BN fast reactors), the others only to 5% U-235. Zelenogorsk is 5.8 M SWU/yr and is introducing ISO9001 quality assurance system. It is also the site for downblending of ex-weapons uranium for sale to the USA. A significant proportion of the capacity of both plants is taken up by enrichment of former tails (depleted uranium).

Most fuel pellets for RBMK and VVER-1000 reactors were being made at Ust Kamenogorsk in Kazakhstan, but Russia's plants at Electrostal 50 km east of Moscow - the huge Elemash plant and Novosibirsk in Siberia have increased production. They also make the actual fuel assemblies. Elemash is the principal exporter of fuel assemblies. Chepetsk near Glazov in Udmurtia makes zirconium cladding.

Spent Fuel and Reprocessing

Russian policy is to close the fuel cycle as far as possible and utilise recycled uranium, and eventually also to use plutonium in MOX fuel.

At present the spent fuel from RBMK reactors and from VVER-1000 reactors is stored (mostly at reactor sites) and not reprocessed.

Spent fuel from VVER-440 reactors, the BN-600 and from naval reactors is reprocessed at the Mayak 400 t/yr RT-1 plant at Ozersk (Chelyabinsk-65) in the Urals. It started up in 1971 and employs the Purex process. Recently it has run at about one third capacity, following the loss of foreign contracts. Recycled uranium is used in fresh RBMK fuel and separated plutonium is stored. High-level wastes are vitrified. and stored. Plans to upgrade the RT-1 plant and enable it to take VVER-1000 fuel, have been approved. Spent fuel storage capacity is being increased from 6000 to 9000 tonnes.

The partly-built larger RT-2 plant at Zheleznogorsk (Krasnoyarsk-26) in Siberia has been cancelled and is to be dismantled. Some VVER-1000 spent fuel is stored there pending reprocessing. (A dual-purpose graphite-moderated reactor principally producing military plutonium, with associated underground reprocessing plant, is also there.)

A 60 t/yr commercial MOX fabrication plant was planned at Zheleznogorsk. Another MOX plant for disposing of military plutonium is planned at Seversk (Tomsk-7) in Siberia, to the same design as its US equivalent. (Seversk has the other two dual-purpose but basically military plutonium production reactors, totalling 2500 MWt.) A pilot MOX plant is at Mayak.

No waste repository is yet available, though site selection is proceeding in granite on the Kola Peninsula.

Decommissioning

Three civil reactors are being decommissioned: an experimental LWGR type at Obinsk which started up in 1954, and two larger prototype VVER-440 units at Novovoronezh, a V-210 and V-365 type, which await dismantling.

Organisation

The Ministry of Atomic Power (Minatom) succeeded a Soviet ministry in 1992. In 2004 its civil side came under the Ministry for Energy and Industry, as the Federal Atomic Energy Agency (FAEA, known as Rosatom). Its entities include:

- Rosenergoatom - nuclear power generation (restructured in 2002),
- Nuclear Fuel Cycle department,
- TVEL - producing nuclear fuel,
- Technabexport (Tenex) - foreign trade in nuclear fuel.
- Atomstroyexport - foreign trade in equipment,

Because of the links with military programs, a culture of secrecy pervaded the old Soviet nuclear power industry. After the 1986 Chernobyl accident, changes were made and a nuclear safety committee established. The State Committee for Nuclear and Radiation Safety - Gosatomnadzor (GAN) succeeded this in 1992 - reporting direct to the President. It is responsible for licensing, regulation and operational safety of all facilities, for safety in transport of nuclear materials, and for nuclear materials accounting. Its inspections can result in legal charges against operators. . However, on some occasions when it suspended operating licences, Minatom successfully overrode this. In 2004 GAN was renamed the Federal Atomic Supervisory Service.

In addition, there are a number of EU-related groups which support Eastern Europe and Russian regulatory and safety authorities.

Safety has evidently been improving at Russian nuclear power plants. In 1993 there were 29 incidents rating level 1 and higher on the INES scale, in 1994 there were nine, and since then to 2003, no more than four.

The main nuclear construction company, Atommash, went bankrupt in 1995 but has now been restructured and as EMK-Atommash, is prospering. Other firms supplying the sector are also growing.

Radon is the organisation responsible for medical and industrial radioactive wastes. It has 16 storage sites for wastes up to intermediate level and operates some facilities at nuclear power and submarine decommissioning sites. It is independent of Rosatom.

Exports

Soviet exports of enrichment services began in 1973, and Russia has strongly continued this, along with exports of radioisotopes. After 1990, uranium exports began, through Tenex.

Exports of nuclear fuel cycle goods and services topped US$ 2 billion in 1999, including $500 million in fuel assemblies and $1.6 billion in other goods and services. Exports were US$ 2.51 billion in 2001 and $2.62 billion in 2002. Russia provides nearly one third of European uranium needs and is also selling diluted ex-military uranium for civil use through USA. The latter supplies about 15% of world reactor requirements and is part of a US$ 12 billion deal between US and Russian governments, with a non-proliferation as well as commercial rationale.

Rosatom claimed to be able to undercut world prices for nuclear fuel and services by some 30%.

It is also pushing ahead with plans to store and probably reprocess foreign spent fuel, and the Russian parliament has overwhelmingly supported a change in legislation to allow this. The proposal involves some 10% of the world's spent fuel over ten years, or perhaps up to 20,000 tonnes of spent fuel, to raise US$ 20 billion, two thirds of which would be invested in expanding civil nuclear power. In July 2001 President Putin signed into effect three laws including one to allow this import of spent nuclear fuel.

The President has also set up a special commission to approve and oversee any spent fuel accepted. There will be 20 members, five each from the Duma, the Council, the government and presidential nominees. It will be chaired by Dr Zhores Alferov, who is a parliamentarian, Vice-President of the Russian Academy of Sciences and a Nobel Prize physicist.

It is not expected that spent fuel shipments will occur in the near future as substantial investment is first needed within Russia to improve safety, and any spent fuel of US origin must be approved by the US government. Hence no applications are expected to occupy the commission for some time. (Until the mid 1990s Russia imported spent fuel from Finland, and some also comes from Eastern Europe under Soviet-era contracts.)

Atomstroyexport (ASE) has three reactor construction projects abroad, all involving VVER-1000 units. First, it took over building a reactor (V-446 type) for Iran at the Bushehr power plant, a project commenced by Siemens KWU but then aborted. Then it sold two large new AES-91 power plants (with V-491 reactors) to China for Jiangsu Tianwan at Lianyungang (under construction, due to start up in 2004-05) and two AES-92 units (V-392 reactors) to India for Kudankulam (under construction, start-up due in 2008). It is likely that ASE will build a second unit at Bushehr.

China has called for competitive bids for four large third-generation reactors to be built as soon as possible at Sanmen and Yangjiang. ASE is expected to bid the AES-92 power plant with V-392 reactors for these.

Outlook

Overall there is increasing acceptance of the need to press ahead with nuclear energy in Russia while expanding the country's role internationally at both the front and the back end of the fuel cycle.

Russia's future international role will be built on its reputation over the last decade as a reliable commercial provider of fuel-related services. It is now engaged with international markets in nuclear energy, well beyond its traditional eastern European client states. With the consolidation of western nuclear fuel cycle vendors, the competition may be welcomed.

Non-proliferation

Russia is a nuclear weapons state, party to the Nuclear Non-Proliferation Treaty (NPT) under which a safeguards agreement has been in force since 1985. It undertook nuclear weapons tests from 1949 to 1990.

The Soviet Union also used 116 nuclear explosions (81 in Russia) for geological research, creating underground gas storage, boosting oil and gas production and excavating reservoirs and canals. Most were in the 3-10 kiloton range and all occurred 1965-88.

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