World Nuclear Association

Nuclear Power in Russia

(updated 19 March 2010)

- **Russia is moving steadily forward with plans for much expanded role of nuclear energy, doubling output by 2020.**
- **Efficiency of nuclear generation in Russia has increased dramatically since the mid 1990s.**
- **A major increase in uranium mine production is planned.**
- **Exports are a major Russian policy and economic objective.**

Contents

Russia's first nuclear power plant, and the first in the world to produce electricity, was the 5 MWe Obninsk reactor, in 1954. 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, but the nuclear industry was beset by problems. The Chernobyl accident led to a resolution of these, as outlined in the Appendix.

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. Economic reforms following the collapse of the Soviet Union meant an acute shortage of funds for nuclear developments, and a number of projects were stalled. 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.

Around 2000 nuclear construction revived and Rostov-1 (also 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. It was followed by Kalinin-3 in 2004.

By 2006 the government's resolve to develop nuclear power had firmed and there were projections of adding 2-3 GWe per year to 2030 in Russia as well as exporting plants to meet world demand for some 300 GWe of new nuclear capacity in that time frame.

In January 2010 the government approved the federal target program designed to bring a new technology platform for the nuclear power industry based on fast reactors. Rosatom's long-term strategy up to 2050 involves moving to inherently safe nuclear plants using fast reactors with a closed fuel cycle. Fossil fuels for power generation are to be largely phased out.

Electricity supply in Russia

Russia's electricity supply, formerly centrally controlled by RAO Unified Energy System (UES)*, faces a number of acute constraints. First, demand is rising strongly 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 has cut back on the very high level of natural gas supplies for electricity generation because it can make about five times as much money by exporting the gas to the west (27% of EU gas comes from Russia). UES' gas-fired plants burned about 60% of the gas marketed in Russia by Gazprom, and it is aimed to halve this by 2020. (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.

* In Russia, "energy" mostly implies electricity.

Electricity production reached 1016 billion kWh in 2007, with 160 billion kWh (16%) coming from nuclear power, 67% from gas and coal and 18% from hydro. In 2005 net export was 12 TWh and final consumption was 650 TWh (after distribution losses of 113 and energy sector use of 178 TWh). Nuclear capacity is about 10% of total 211 GWe. Electricity demand is projected to grow to 1426 billion kWh in 2015 (or maybe 1600 billion kWh in high scenario) and to 1700 to 2000 billion kWh by 2020, requiring 340 to 390 GWe total by then, requiring US$ 420 to $540 billion investment. Early in 2008 the projected annual electricity demand growth to 2020 was put at 4%. 2009 nuclear production was 163.3 billion kWh (83.7 TWh from VVER, 79.6 from RBMK and other).

Nuclear electricity output is rising strongly due simply to better performance of the nuclear plants, with capacity factors leaping from 56% to 76% 1998-2003 and then on to 79.5% in 2008. Energoatom aims for 90% capacity factor by 2015. In gross terms, output is projected to grow from about 150 billion kWh in 2005 to 166 in 2010, and 239 billion kWh in 2016 (18.6% of total). or more soberly to 230 billion kWh in 2020. Nuclear generating capacity is planned to grow more than 50% from 23 GWe gross (21.7 net) in 2006 to 35 GWe in 2016, and at least double to 51 GWe by 2020.

In 2006 Rosatom announced a target of nuclear providing 23% of electricity by 2020 and 25% by 2030, but 2007 plans approved by the government have scaled this back a little, and in 2009 it was pruned back more (see: Extending Nuclear Capacity below).

In parallel with this Russia is greatly increasing its hydro-electric capacity, aiming to increase by 60% to 2020 and double it by 2030. Hydro OGK is planning to commission 5 GWe by 2011. The 3 GWe Boguchanskaya plant in Siberia is being developed in collaboration with Rusal, for aluminium smelting. The aim is to have almost half of Russia's electricity from nuclear and hydro by 2030.

Following proposals worked out over several years, a government order consolidating the country's nuclear utilities was signed in 2001. Rosenergoatom, which in 2008 became Energoatom, took over all civil reactors including those under construction, and related infrastructure.

Energoatom operates within the context of 2003 state energy policy, and of state funding for new plants to meet policy goals. A policy priority is to reduce the use of natural gas for electricity and to double the nuclear output by 2020. The growth is to come from lifetime extension of first-generation units, upgrading, increased availability to 85% average (and hopefully more), together with new plants.

UES electricity tariffs were planned to increase from (US$) 1.1 c/kWh in 2001 to 1.9 c/kWh in 2005 and 2.4 c/kWh in 2015. 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.

In February 2007 UES said that it was aiming to raise up to US$ 15 billion by selling shares in as many as 15 power generation companies, having increased its investment target by 2010 from $79 to $118 billion. Late in 2006 UES raised $459 million by selling 14.4% of one of its generators, OGK-5, and since then the UES sell-off has continued with investors committing to continued expansion. In mid 2008 RAO UES was wound up, having sold off all its assets. Some of these were bought by EU utilities, for instance Finland's Fortum bought at auction 76.5% of the small utility TGC-10, which operates in well-developed industrial regions of the Urals and Western Siberia. From July 2008, 25% of all Russia's power is sold on the competitive market. The wholesale power market is expected to be fully liberalised by 2011.

InterRAO was initially a subsidiary of RAO UES, involved with international trade and investment in electricity, particularly with Finland, Belarus and Kazakhstan. It acquired some of RAO UES assets when that company was broken up. It is responsible for finding a foreign investor and structuring electricity marketing for the proposed Baltic nuclear power plant. It aims to increase its generation capacity from 8 to 30 GWe by 2015. In November 2008 Rosatom's share in InterRAO was increased to 57.28%.

Present nuclear capacity

Russia's nuclear plants, with 31 operating reactors totalling 21,743 MWe, comprise:

- 4 first generation VVER-440/230 or similar pressurised water reactors,
- 2 second generation VVER-440/213 pressurised water reactors,
- 9 third generation VVER-1000 pressurised water reactors with a full containment structure, mostly V-320 types,
- 11 RBMK light water graphite reactors now unique to Russia. The four oldest of these were commissioned in the 1970s at Kursk and Leningrad and are of some concern to the Western world. A further Kursk unit is under construction.
- 4 small graphite-moderated BWR reactors in eastern Siberia, constructed in the 1970s for cogeneration (EGP-6 models on linked map).

- One BN-600 fast-breeder reactor.

Apart from Bilibino, several reactors supply district heating - a total of over 11 PJ/yr.

Power Reactors in Operation

Reactor	Type V=PWR	MWe net, each	Commercial operation	Scheduled close
Balakovo 1	V-320	950	5/86	2015
Balakovo 2	V-320	988	1/88	2017
Balakovo 3-4	V-320	950	4/89, 12/93	2018, 2023
Beloyarsk 3	BN600 FBR	560	11/81	2010
Bilibino 1-4	LWGR EGP-6	11	4/74-1/77	2019-21
Kalinin 1-2	V-338	950	6/85, 3/87	2014, 2016
Kalinin 3	V-320	950	12/04	2034
Kola 1-2	V-230	411	12/73, 2/75	2018, 2019
Kola 3-4	V-213	411	12/82, 12/84	2011, 2014
Kursk 1-2	RBMK	925	10/77, 8/79	2021, 2024
Kursk 3-4	RBMK	925	3/84, 2/86	2013, 2015
Leningrad 1-2	RBMK	925	11/74, 2/76	2019, 2022
Leningrad 3-4	RBMK	925	6/80, 8/81	2025, 2011, +15 yr
Novovoronezh 3-4	V-179	385	6/72, 3/73	2016, 2017
Novovoronezh 5	V-187	950	2/81	2035 after upgrade
Smolensk 1-3	RBMK	925	9/83, 7/85,1/90	2013, 2020
Rostov 1	V-320	990	3/01	2030
Rostov 2	V-320	990	(Oct 2010)	
Total: 32		22,811 MWe		

V-320 is the base model of what is generically VVER-1000, V-230 and V-213 are generically VVER-440, V-179 & V-187 are prototypes. Rostov is also known as Volgodonsk.

Life extension and completing construction

Generally, Russian reactors are licensed for 30 years from first power. 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 to 25 years, necessitating major investment in refurbishing them. Generally the VVER-440 and RBMK units will get 15-year life extensions and the nine VVER-1000 units 25 years. So far 15-year extensions have been achieved for Novovoronezh-3 & 4, Kursk-1, Kola-1 & 2 and Leningrad-1, 2 & 3. Bilibino 1-4 have also been given 15-year licence extensions. (Kola 1 & 2 VVER-440 and the Kursk and Leningrad RBMK units are all models which the EU has paid to shut down early in countries outside Russia.)

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

Safety analyses for Kola 3 & 4, which are later-model VVER-440 reactors, are being undertaken with a view to 15-year life extension.

A plan for refurbishment, upgrade and life extension of Novovoronezh-5 was announced in mid 2009, this being the first second-generation VVER-1000 project. The initial estimate was RUR 1.66 billion (USD 52 million) but this had become USD 300 million a few months later. The work in 2010 is to include total replacement of the reactor control system and 80% of electrical equipment, and fitting upgraded safety systems, in particular, those of emergency and feed water.

In 2006, Rosatom said it was considering lifetime extensions and uprating all of its eleven operating **RBMK reactors**. Following significant design modifications made after the Chernobyl accident, as well as extensive refurbishment including replacement of fuel channels, a 45-year lifetime is seen as realistic for the 1000 MWe units. In 2009 they provided 45% of Russia's nuclear-generated electricity. A major contract for upgrading Leningrad unit 4 over 2008-11 is under way. Kursk 4 is next, and Kursk 2 & 3 with Smolensk 3 will soon follow. The R&D Institute of Power Engineering was preparing plans for 5% uprating of the later Leningrad, Kursk and Smolensk units. For Leningrad 2-4, fuel enriched to average 3% instead of 2.4% will give a 5% increase in power - some 140 MWe. Rostechnadzor has authorized trials in unit 2 of the new fuel, and early in 2010 it will consider authorizing a 5% uprate for long-term operation.

The Beloyarsk-3 BN-600 fast neutron reactor is being upgraded and prepared for 15-year life extension, but no details are available.

Several more reactors have been under construction - see following section.

There is considerable uncertainty about completing Kursk-5 - an upgraded RBMK design which is more than 70% built. However, Rosatom has been keen to see it completed and in January 2007 the Duma's energy committee recommended that the government fund its completion by 2010. In March 2007 the Industry Ministry recommended to the government that work proceed and Rosenergoatom then applied for RUR 27 billion (US$ 1 billion) from the ministry's 2008-10 federal budget to complete it. This did not materialise so its completion is contingent upon finding other funds, and discussions with Sberbank and industrial electricity consumers such as steel producers continued into 2009. All other RBMK reactors - long condemned by the EU - are due to close by 2024, which will leave it technologically isolated. According to Rosatom early in 2010 it requires RUR 45 billion and 3.5 years to finish, plus RUR 30 billion for grid improvement, compared with around RUR 60 billion for building the same capacity from scratch in the new projects under way. Rosatom says this means "there is no sense in completing the reactor construction". Accordingly it has been removed from WNA's "under construction" list.

Extending nuclear capacity

Rosatom's initial proposal for a rapid expansion of nuclear capacity was based on the cost effectiveness of completing the 9 GWe of then partially built plant. To get the funds, Minatom offered Gazprom the opportunity to invest in some of the partly completed nuclear plants. The argument was 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.

In September 2006 Rosatom announced a target of nuclear providing 23% of electricity by 2020, thus commissioning two 1200 MWe plants per year from 2011 to 2014 and then three per year until 2020 - some 31 GWe and giving some 44,000 MWe of nuclear capacity then.

In October 2006 Russia formally adopted a US$ 55 billion nuclear energy development program, with $26 billion of this to 2015 coming from the federal budget. The balance would be from industry (Rosatom) funds, and no private investment was involved. The Minister of Finance strongly supported the program to increase nuclear share from 15.6% to 18.6% of total, hence improving energy security as well as promoting exports of nuclear power technology. After 2015 all funding would be from Rosatom revenues.

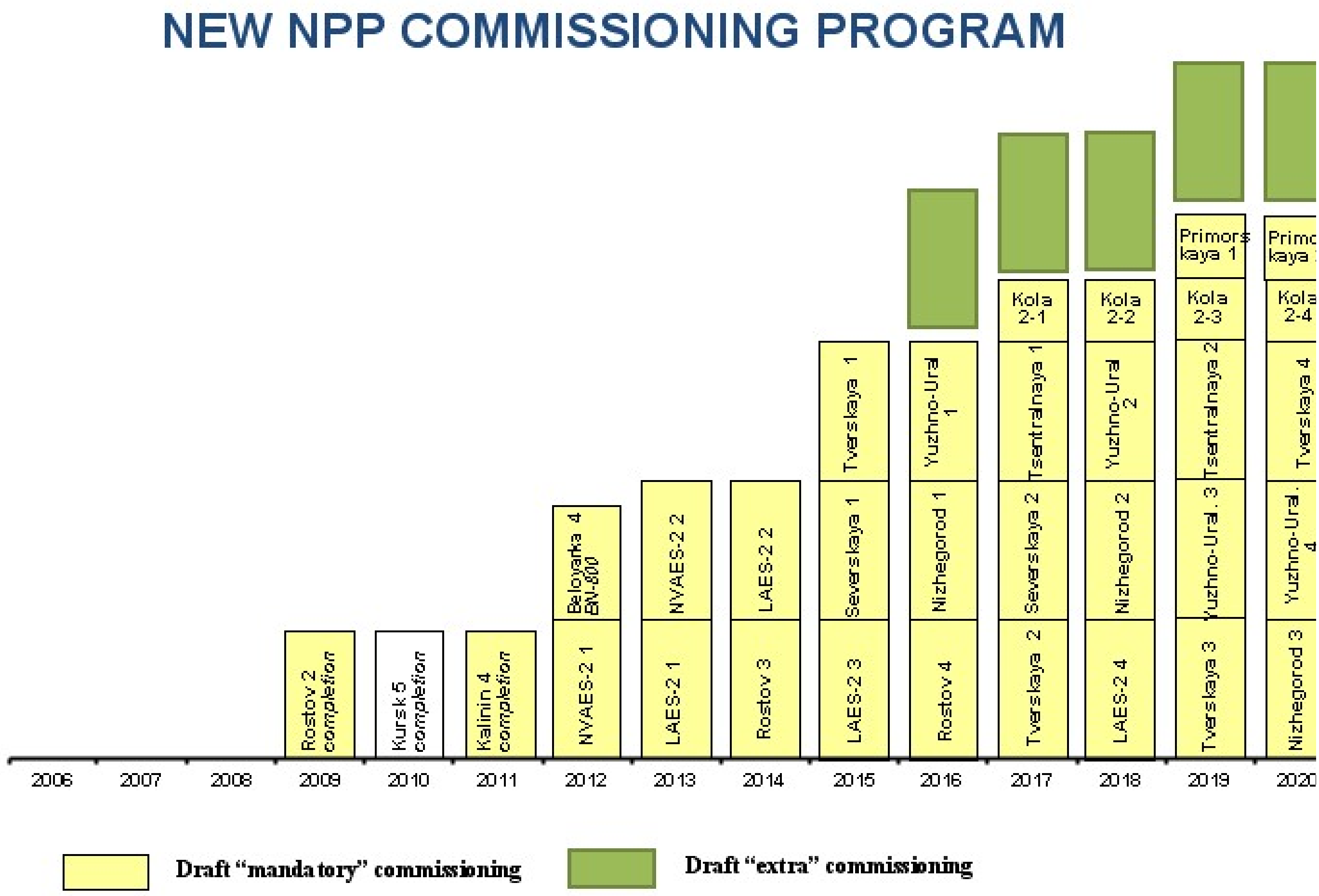
Several units have been uprated. In December 2009 Rostechnadzor approved a 4% increase in power from Balakovo-2, a V-320 unit completed in 1988. Volgodonsk-1, the newest operating V-320 unit, has been approved similarly.

Reactors under construction include Kalinin-4, a V-320 unit which is being built by Nizhny-Novgorod Atomenergopoekt and is due for completion in 2011. In September 2009 Rostechnadzor approved an operating licence for Rostov-2, and fuel loading was completed in December. It started up in January 2010, was grid connected in March, and is expected to enter full commercial operation in October. The Beloyarsk-4 BN-800 fast reactor has been delayed by lack of funds since construction start in 2006 and is now expected on line in 2014 (see also Transition to Fast Reactors subsection below).

From mid 2008 there are four standard third-generation VVER reactors being built: at Leningrad (two units to commence stage 2) and Novovoronezh (similarly) to be commissioned 2012-14. This leads to a program of starting to build at least 2000 MWe per year in Russia from 2009 (apart from export plants).

In April 2007 the government approved in principle a construction program to 2020 for electricity-generating plants. It was designed to maximise the share of electricity from nuclear, coal, and hydro, while reducing that from gas. This envisaged starting up one unit per year from 2009, two from 2012, three from 2015 and four from 2016. Present nuclear capacity would increase at least 2.3 times by 2020. This proved too ambitious.

Hence in September 2007 the first version of the following scheme was released, but noting that from 2012 to 2020 only two 1200 MWe units per year were within the "financial capacity of the federal task program". Accordingly, the third units for 2015 and 2016 were designated "proposed". In the February 2008 update of this, one 1200 MWe Tversk unit was brought forward to 2015 scheduled start-up, so was designated "planned".

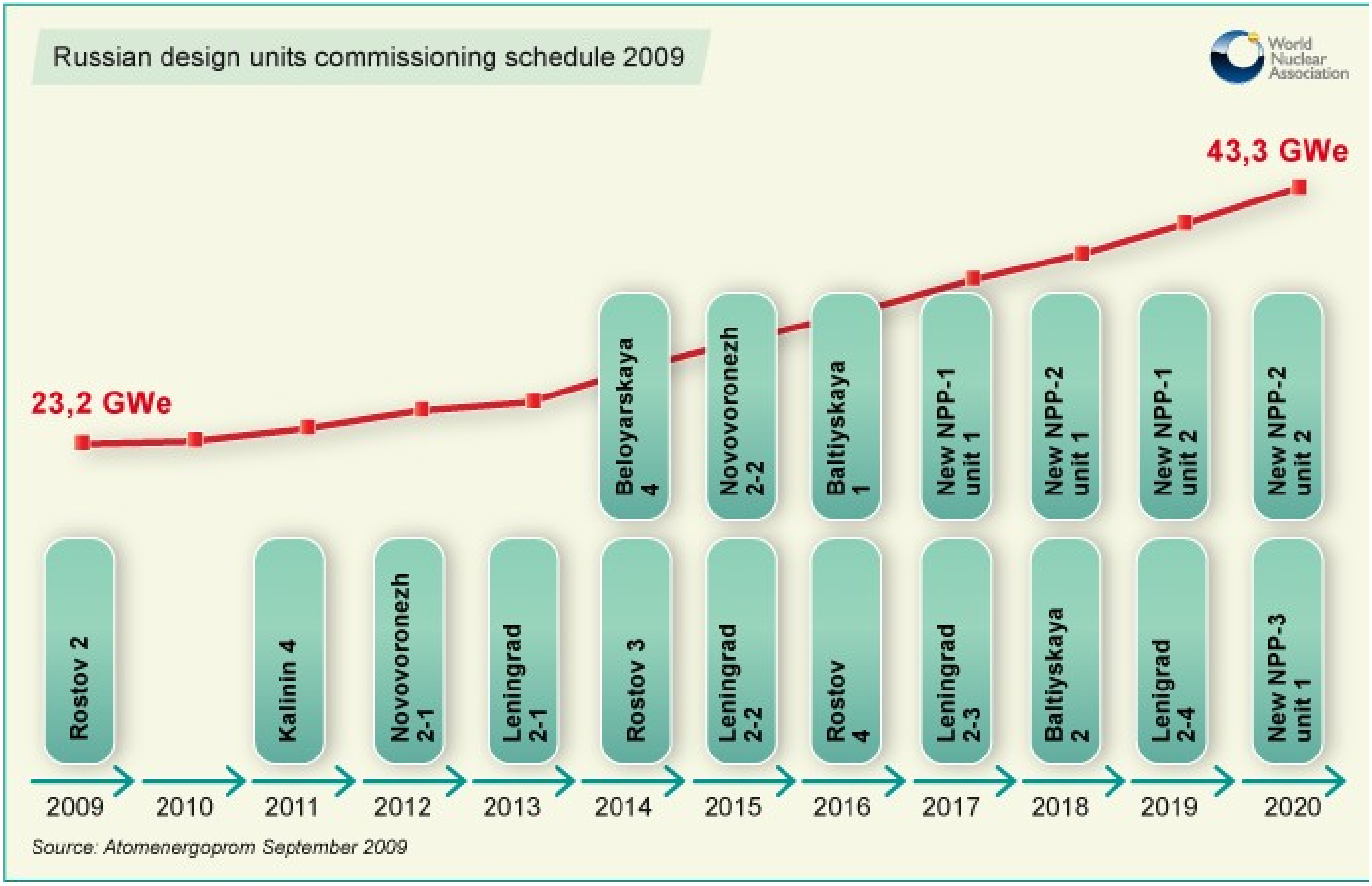


In February 2008 the earlier federal target plan (FTP) to 2020 was endorsed with little change except than an extra five VVER-1200 units were added as "maximum scenario" or "extra" in the last few years to 2020. As well as the 4800 MWe capacity now under construction, a further 12,000 MWe was planned for completion mostly by 2016, and then another 16,000 to 22,000 MWe proposed by 2020. Several new sites are involved. Some US$ 282 billion was to be invested by 2015, and a further $204 billion to 2020 on the projects listed. Also the new 300 MWe units were listed as being VBER-300 PWR types.

More significantly, the Ministry of Industry and Energy (MIE) and Rosatom were charged with promptly developing an action plan to attract investment into power generation. It is envisaged that by 2020 much generation will be privatized and competitive, while the state will control natural monopoly functions such as the grid.

From January 2009 the FTP was replaced by Rosatom's long-term activity program. This includes Kaliningrad and Kursk, both subject to private finance. However, capacity targets and expenditure are much as above. By 2030 nuclear share of electricity was expected to grow to 25%, from 16% then.

However, by April 2009 reduced electricity demand expectations due to the recession caused the whole construction program outlined above to be scaled back, and some projects put on hold. Ten units were deferred pending "economic upturn and electricity demand growth", expected in about two years. See Table below, where three units have been moved from planned to proposed accordingly. From mid 2009, half the capital for new nuclear plants will come from Rosatom budget and half from the state.



In July 2009 a revised federal target program (FTP) for 2010-2015 and until 2020 was approved and signed by the President. Projected federal budget funding was reduced to RUR 110 billion ($3.5 billion), apparently for 2010. This put Kursk II and Smolensk II into the picture for completion by 2020, ahead of many other units, and they have been shown thus in the Table below. On the other hand another presentation from Atomenergoprom in September 2009 (Figure above) has most of those "planned" in the Table below plus five other 1200 MWe units at unnamed sites coming on line by 2020, and 43.3 GWe nuclear being on line then - see graphic above.

In February 2010 the government announced that Rosenergoatom's investment program for 2010 amounted to RUR 163.3 billion, of which RUR 53 billion would come from the federal budget. Of the total, RUR 101.7 billion is for nuclear plant construction, almost half of this from Rosenergoatom funds. It includes the reactors listed below as under construction, as well as Volgodonsk 3, Leningrad II-2 and the Baltic plant. In March Rosatom said that it now intended to commission three new reactors per year from 2016.

The FTP program is based on VVER technology at least to about 2030. But it highlights the goal of moving to fast neutron reactors and closed fuel cycle, for which Rosatom proposed two options, outlined below in Transition to Fast Reactors subsection. In stage 1 of the second option, which was adopted, a 100 MWe lead-bismuth-cooled fast reactor is to be built, and in stage 2 over 2015-2020 a pilot demonstration 300 MWe lead-cooled BREST reactor and a multi-purpose fast neutron research reactor (MBIR) are to be built. In addition it is planned to build and commission a commercial complex to fabricate dense fuel, to complete construction of a pilot demonstration pyrochemical complex to fabricate BN fuel, and to test closed fuel cycle technologies. Fusion studies are included and the total R&D budget is RUR 55.7 billion, mostly from the federal budget. The FTP implementation is intended to result in a 70% growth in exports of high technology equipment, works and services rendered by the Russian nuclear industry by 2020.

See also subsections: Transition to Fast Reactors in this section, and Fast Reactors, in Reactor Technology section below

The FTP program envisages a 25-30% nuclear share in electricity supply by 2030, 45-50% in 2050 and 70-80% by end of century.

Major Power Reactors under Construction, Planned and officially Proposed

Plant	Reactor Type	MWe	Status, Start Construction	Commercial operation
Kalinin 4	V-320	1000	Const	10/2011
Vilyuchinsk	KLT-40S	40 x 2	Const 5/09	2012
Beloyarsk 4	BN-800 FBR	880	Const	2014
Novovoronezh II -1	VVER 1200/ V-392M	1200	Const 6/08	2012-13
Leningrad II-1	VVER 1200/ V-491	1200	Const 10/08	10/2013
Novovoronezh II -2	VVER 1200/ V-392M	1200	Const 7/09	2015
Subtotal of 7		**5560 gross, 5330 net**		
Rostov/ Volgodonsk 3	VVER 1000/ V-320	1100	Planned, 2010	2014
Leningrad II -2	VVER 1200	1200	Planned, 2011	2016
Rostov/ Volgodonsk 4	VVER 1000/ V-320	1100	Planned, 2011	2016
Baltic 1 (Kaliningrad)	VVER 1200	1200	Planned, Feb 2011	2016
Seversk 1	VVER 1200	1200	Planned, 2010	2016
Obninsk	SVBR-100	100	Planned, 2011	2015
Leningrad II -3	VVER 1200	1200	Planned, 2011	2016
Nizhegorod 1	VVER 1200	1200	Planned, 2012	2017
Seversk 2	VVER 1200	1200	Planned, 2012	2017
Tver 1	VVER 1200	1200	Planned, 2012	2017
Nizhegorod 2	VVER 1200	1200	Planned, 2013	2018
Tver 2	VVER 1200	1200	Planned, 2013	2017
Baltic 2 (Kaliningrad)	VVER 1200	1200	Planned, 2014	2018
Leningrad II -4	VVER 1200	1200	Planned, 2014	2019
Tsentral 1	VVER-1200	1200	Planned, 2013	2018
Tsentral 2	VVER-1200	1200	Planned, 2014	2019

Beloyarsk 5	BREST	300	Planned, 2016	2020
subtotal of 17	VVER 1200	**18,200 gross, approx 17,600 net**		
				dates very tentative:
Zheleznogorsk MCC	VBER-300	300	Proposed	2015
Zheleznogorsk MCC	VBER-300	300	Proposed	2016
Kursk II - 1	VVER 1200	1200	Proposed	2015
Kursk II - 2	VVER 1200	1200	Proposed	2017
Kursk II - 3	VVER 1200	1200	Proposed	2018
Kursk II - 4	VVER 1200	1200	Proposed	2019
Smolensk II - 1	VVER 1200	1200	Proposed	2017
Smolensk II - 2	VVER 1200	1200	Proposed	2018
Smolensk II - 3	VVER 1200	1200	Proposed	2019
Smolensk II - 4	VVER 1200	1200	Proposed	2020
Kola II -1	VK-300, VBER 300 or VVER	300	Proposed	2020
South Ural 1	VVER 1200	1200	Deferred	was 2016
Novovoronezh II -3	VVER 1200	1200	Proposed	2017 ?
Tsentral 1	VVER 1200	1200	Deferred, 2013	2018
South Ural 2	VVER 1200	1200	Proposed	was 2018
Kola II - 2	VK-300 or VBER 300	300	Proposed	2018
Novovoronezh II -4	VVER 1200	1200	Proposed	2019 ?
Tver 3	VVER 1200	1200	Proposed	2019
South Ural 3	VVER 1200	1200	Proposed	2019
Tsentral 2	VVER 1200	1200	Proposed	was 2019
Kola II - 3	VK-300 or VBER 300	300	Proposed	2019
Primorsk 1	VK-300 or VBER 300	300	Proposed	2019
Nizhegorod 3	VVER 1200	1200	Proposed	2019
Nizhegorod 4	VVER 1200	1200	Proposed	2020
Tsentral 3	VVER 1200	1200	Proposed	2019 ?
Tsentral 4	VVER 1200	1200	Proposed	2020 ?
South Ural 4	VVER 1200	1200	Proposed	2020
Tver 4	VVER 1200	1200	Proposed	2020
Kola II - 4	VK-300 or VBER 300	300	Proposed	2020
Primorsk 2	VK-300 or VBER 300	300	Proposed	2020
Pevek	KLT-40S	40x2	Proposed	2020
Beloyarsk 6	BN-1200	1200	Proposed (approved)	2024?
subtotal of 30 units		**28,000 approx**		

VVER-1200 is the reactor portion of the AES-2006 nuclear power plant. Rostov is also known as Volgodonsk. South Urals was to be BN-800, and may revert.

Seversk is near Tomsk, Tver is near Kalinin, Nizhegorod is a new site near Nizhniy Novgorod, 400 km east of Moscow, and Tsentral (central) at Bui in Kostrama region. South Ural is 140 km west of Chelyabinsk. Primorsk is in the far east, as is Vilyuchinsk in the Kamchatka region, and Pevek in the Chukotka Autonomous Region near Bilibino, which it will replace. Vilyuchinsk and Pevek are floating nuclear power or cogeneration plants.

Rostov/ Volgodonsk 3 & 4 environmental statement and construction application were approved by Rostechnadzor in May 2009, and the construction licence was granted to Energoatom in June. Rosatom brought forward the completion dates of the two units to 2013 and 2014 after deciding that they would have V-320 type of VVER with improved steam generators and capacity of 1100 MWe. This is expected to save some RUR 10 billion relative to the AES-2006 technology. First criticality of unit 3 is planned for Decemeber 2013. Nizhniy Novgorod Atomenergoproekt (NN AEP) is principal contractor for units 3 & 4, expected to cost RUR 146 billion (US$ 5 billion). It expects unit 2 which it is building to start up in January 2010, with grid connection in March and full commercial operation in October.

Novovoronezh phase II is being built by Moscow AtomEnergoProekt, with work starting in 2007. This is the lead plant for deploying the AES-2006 units. First concrete was poured for unit 1 of this (unit 6 at the site) in June 2008 and it is expected to be commissioned in 2012, with unit 2 following in 2013, at a total cost of US$ 5 billion for 2136 MWe net. Rostechnadzor licensed construction of unit 2 in October 2008 and construction started in July 2009. The plant is on one of the main hubs of the Russian grid.

A general contract for **Leningrad phase II** was signed with St Petersburg AtomEnergoProekt (SPb AEP) in August 2007 and Rostechnadzor granted site licences in September 2007. A specific engineering, procurement and construction contract for the first two 1170 MWe (net) units was signed in March 2008. First concrete was poured on schedule for unit 1 in October 2008 and it is due to be commissioned in October 2013, with the second in 2016, originally at a cost of US$ 5.8 billion ($2480/kW) possibly including some infrastructure. Total project cost was estimated at $6.6 billion. Rostechnadzor granted a construction licence for the second reactor in July 2009, but construction was deferred. Each reactor will also provide 1.05 TJ/hr (9.17 PJ/yr) of district heating. They are designed to replace the oldest two Leningrad units. A design contract for the next two units (3 & 4) was signed with SPb AEP in September 2008, and public consultation on these was held in Sosnovy Bor in mid 2009. An environmental review by Rostechnadzor was announced for them in January 2010 and a site development licence is expected soon after.

The first 1200 MWe unit of the **Seversk** AES-2006 plant 32 km northwest of Tomsk was due to start up in 2015 after construction start in 2010, with the second unit in 2017, but has been postponed by two years. The plant will also supply 7.5 PJ/yr of district heating. Atomenrgopoekt Moscow is to build the plant at estimated cost of RUR 134 billion (US$ 4.4 billion). Rostechnadzor granted a site development licence in November 2009 and site work has commenced. Seversk is the site of a major enrichment plant and former weapons facilities. A design contract for the low-speed turbine generators has been signed between Moscow AEP which is responsible for design and engineering, and Alstom Atomenergomash. This will be the first Russian plant using the low-speed turbines.

The **Nizhegorod** plant near Nizhniy Novgorod is to comprise four AES-1200 units of 1150 MWe net and costing RUR 269 billion (US$ 9.4 billion), the first coming on line in 2016 to address a regional energy deficit. In February 2008 Rosatom appointed Nizhny-Novgorod Atomenergoproekt (NN-AEP) as the principal designer of the plant. Bids will be invited for construction over 2012-17. Rostechnadzor issued a positive site review (licence?) for units 1 & 2 early in 2010.

The **Tver** plant at Udomlya and not far from Kalinin is being designed by Nizhny-Novgorod Atomenergoproekt (NN-AEP), and in January 2010 it was announced that Rostechnadzor would conduct an environmental review of it for the first two VVER-1200 units, these being on the general scheme of electricity generators deployment to 2020. No firm dates are given for the project, though a site development licence is expected in March 2010.

The 2340 MWe **Tsentral** (Central) nuclear power plant is to be 10 km northwest of Bui Town in the Kostroma region, on the Kostroma River. It was another of those deferred but following Rosatom October 2008 decision to proceed, it now appears that it will start construction in 2013 with the first unit completed in 2018. Moscow Atomenergoproekt is the architect-engineer. A site development licence is expected by mid 2010, and a construction licence in 2012. The cost of the project and infrastructure is expected to be RUR 130 billion ($ 5 billion).

Apart from the February 2008 plan, Rosatom subsidiary InterRAO EES proposed a **Baltic or Baltiyskaya** nuclear plant in **Kaliningrad** on the Baltic coast to generate electricity for export, and with up to 49% European equity. Private equity would be an innovation for Russia. The plant would comprise two 1200 MWe VVER units designed by St Petersburg Atomenergoproekt, sited at Neman, close to the Lithuanian border and costing some RUR 194 billion (EUR 4.45 billion, $6.6 billion), for 2300 MWe net.

The Baltic plant directly competes with the plan for a new unit at Visaginas near Ignalina in Lithuania. Rosenergoatom has said that the plant is deliberately placed "essentially within the EU" and is designed to be integrated with the EU grid. Two thirds of the power would be exported to Germany, Poland and Baltic states. Transmission to northern Germany would be via Poland or an undersea cable, and require some EUR 1 billion in transmission infrastructure. There is already substantial transmission capacity east through Lithuania to the St Petersburg region if that were added to the options. The European equity would be in order to secure markets for the power. Lithuania was invited to consider the prospect, instead of building Visaginas as a Baltic states plus Poland project.

Project approval was confirmed by government decree in September 2009, following initial approval in mid 2008 as an amendment to the federal target program (FTP) of 2007. St Petersburg Atomenergoproekt will be the principal contractor, but Atomstroyexport is also involved. Site work was planned to begin in February with construction start either in July 2010 or in 2011 and the first unit is planned to come on line in 2016, after 54 months construction, supplying Energoatom. Second unit construction is planned over 2012-18. Licensing by Rostechnadzor is expected by June 2010. Czech power utility CEZ has expressed interest in the project, as has Iberdrola from Spain, whose engineering subsidiary already works at Kola, Balakovo and Novovoronezh nuclear power plants. It appears that the Baltic plant may be the initial project involving Siemens in close collaboration with Rosatom, enhancing the project's credibility for foreign investment. Rosatom has said that the project will not be delayed if 49% private equity or long-term sales contracts are not forthcoming.

The Baltic plant and two other ventures with Rusal (see below) will apparently require private equity.

Energoatom signed a purchase contract for the first floating nuclear power plant for **Vilyuchinsk**, on the Kamchatka Peninsula in the far east, in July 2009. The 2x35 MWe plant, named *Academician Lomonosov*, is due to be completed in 2011 and commissioned in 2012. See FNPP subsection below.

In December 2009 AKME-Engineering was set up by Rosatom and the En+ Group (a subsidiary of Russian Machines Co/ Basic Element Group) as a 50-50 JV to develop and build a pilot 100 MWe

SVBR unit at **Obninsk**, by 2020, subsequently shortened to 2015. En+ is an associate of EuroSibEnergo and a 53.8% owner of Rusal, which has been in discussion with Rosatom regarding nuclear power plants to serve its aluminium smelter plans (see Aluminium & Nuclear Power sub section below). The project cost was estimated at RUR 16 billion, and En+ was prepared to put in most of this, with Rosatom contributing the technology. Since this is thus a public-private partnership, it was not basically funded from the federal budget.

UES was reported to support construction of new nuclear plants in the regions of Yaroslavl, Chelyabinsk (South Urals) and Vladimir, with two to four units at each**.**

Further Power Reactors Proposed, uncertain status

Unit	Type	MWe each gross	Start-up
Leningrad II 5-6	VVER-1200	1200	
North-west 1 & 2	BWR VK-300	300	
Tatar 1 - 3	VVER-1200	1200	
Yaroslavl	?		
Chelyabinsk (S.Urals)	?		
Vladimir	?		
Plants with low priority for UES:			
Bashkira 1-4	PWR		
Balokovo 5 & 6	PWR for Rusal smelter	1000	2013?
Far East 1-4	PWR, 1/3 for Rusal smelter	1000	

Transition to Fast Reactors

The BN-800 **Beloyarsk-4** fast reactor designed by OKBM Afrikantov is intended to replace the BN-600 unit 3 at Beloyarsk, though the RUR 64 billion (US$ 2.05 billion) project has been delayed by lack of funds since construction start in 2006. It now seems to have adequate funding, though start-up has been moved from 2012 to 2014 due to delays in equipment supplies, but now mid 2013 is said to be possible. The construction funds included $280 million in 2008, RUR 6.7 billion ($227 million) in 2009, and similar in 2010. At the end of 2009 the project was reported as on schedule. The reactor pressure vessel is due to be fully installed by November 2010.

In May 2009 St Petersburg Atomenergopoekt said it was starting design work on a BN-800 reactor for China, where two are proposed at coastal sites. A high-level agreement was signed in October 2009 regarding these.

OKBM Afrikantov is developing a BN-1200 reactor as a next step towards a BN-1800. Rosatom's Science and Technology Council has approved the BN-1200 reactor for Beloyarsk, with pilot plant construction planned to start in 2020.

Moving in the other direction, and downsizing from BN-800 etc, a pilot 100 MWe SVBR-100 unit is to be built at Obninsk by AKME-Engineering by 2020. This is a modular lead-bismuth cooled fast neutron reactor concept from OKB Gidropress, and is designed to meet regional needs in Russia and abroad. If built in clusters of 10 to 16 units it is claimed to be competitive with VVER types.

Rosatom put forward two fast reactor implementation options for government decision in relation to the Advanced Nuclear Technologies Federal Program 2010-2020. The first focused on a lead-cooled fast reactor such as BREST with its fuel cycle, and assumed mobilisation of all available resources on this project with a total funding of about RUR 140 billion (about $3.1 billion). The second multi-track option was favoured, since it involved lower risks than the first. It would result in technical designs of the Generation IV reactor and associated closed fuel cycles technologies by 2014, and a technological basis of the future innovative nuclear energy system featuring the Generation IV reactors working in closed fuel cycles by 2020. A detailed design would be developed for a multi-purpose fast neutron research reactor (MBIR) by 2014 also. This second option was designed to attract more funds apart from the federal budget allocation, was favoured by Rosatom, and was accepted.

In January 2010 the government approved the federal target program (FTP) "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. It anticipated RUR 110 billion to 2020 out of the federal budget, including RUR 60 billion for fast reactors, and subsequent announcements started to allocate funds among three types: BREST, SVBR and continuing R&D on sodium cooled types. The FTP implementation will enable commercializing new fast neutron reactors for Russia to build over 2020-2030. 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.

Federal target Program Funding for Fast Neutron Reactors to 2020

cooling	Demonstration reactor	timing	Construction RUR billion	R&D RUR billion	Total RUR billion
Pb-Bi cooled	SVBR 100 MWe	by 2015	10.153	3.075	13.228
Na cooled	(BN-600, BN-800)	to 2016	0	5.366	5.366
Pb cooled	BREST 300 MWe	2016-20	15.555	10.143	25.698
	MBIR 150 MWt	2012-20	11.390	5.042	16.432
	Total:		37.1		60.7

Source: Government decree #50, 2010. Mosr (RUR 9.5 billion) of the funding for SVBR construction is from "other sources".

Starting 2020-25 it is envisaged that fast neutron reactors will play an increasing role in Russia, though these will probably be new designs such as BREST with a single core and no blanket assembly for plutonium production. An optimistic scenario has expansion to 90 GWe nuclear capacity by 2050.

See also Fast Reactors, in Reactor Technology section below.

Aluminium and nuclear power

In 2006 the major aluminium producer SUAL (which in March 2007 became part of RUSAL) signed an agreement with Rosatom to support investment in new nuclear capacity at **Kola,** to power expanded aluminium smelting there from 2013. Four units totalling 1000 MWe were envisaged for Kola stage 2 underpinned by a 25-year contract with SUAL, but economic feasibility is in doubt and the project appears to have been dropped and replaced by two others.

Since 2007 Rosatom and RUSAL, now the world's largest aluminium and alumina producer, have been undertaking a feasibility study on a nuclear power generation and aluminium smelter at **Primorye in Russia's far east.** This proposal is taking shape as a US$ 10 billion project involving four 1000 MWe reactors and a 600,000 t/yr smelter with Atomstroyexport having a controlling share in the nuclear side. The smelter would require about one third of the output from 4 GWe, and electricity exports to China and North and South Korea are envisaged.

In October 2007 a $8 billion project was announced for the world's biggest aluminium smelter at **Balakovo** in the Saratov region, complete with two new nuclear reactors to power it. The 1.05 million tonne per year aluminium smelter is to be built by RUSAL and would require about 15 billion kWh/yr. The initial plan was for the existing Balakovo nuclear power plant of four 950 MWe reactors to be expanded with two more - the smelter would require a little over one third of the output of the expanded power plant. However, in February 2010 it was reported that RUSAL proposed to build its own 2000 MWe nuclear power station, with construction to start in 2011. Aluminium smelting is energy-intensive and requires reliable low-cost electricity to be competitive. Increasingly it is also carbon-constrained - this smelter will emit about 1.7 million tonnes of CO2 per year just from anode consumption.

RUSAL has announced an agreement with the regional government which will become effective when the nuclear plant expansion is approved by Rosatom or an alternative is agreed. Balakovo units 5 & 6 have been listed as prospective for some time but were dropped off the 2007-08 Rosatom plan for completing 26 new power reactors by 2020 as they were low priority for UES grid supply. Balakovo is on the Volga R. 800 km SE of Moscow.

Nuclear icebreakers and merchant ship

Nuclear propulsion has proven technically and economically essential in the Russian Arctic where operating conditions are beyond the capability of conventional icebreakers. The power levels required for breaking ice up to 3 metres thick, coupled with refuelling difficulties for other types of vessels, are significant factors. The nuclear fleet has increased Arctic navigation from 2 to 10 months per year, and in the Western Arctic, to year-round. Greater use of the icebreaker fleet is expected with developments on the Yamal Peninsula and further east.

The icebreaker Lenin was the world's first nuclear-powered surface vessel (20,000 dwt) and remained in service for 30 years (1959-89), though new reactors were fitted in 1970.

It led to a series of larger icebreakers, the six 23,500 dwt Arktika-class, launched from 1975. These powerful vessels have two 171 MWt OK-900 reactors delivering 54 MW at the propellers and are used in deep Arctic waters. The Arktika was the first surface vessel to reach the North Pole, in 1977. The seventh and largest Arktika class icebreaker - 50 Years of Victory (50 Let Pobedy) entered service in 2007. It is 25,800 dwt, 160 m long and 20m wide, and is designed to break through ice up to 2.8 metres thick. Its performance in service has been impressive.

For use in shallow waters such as estuaries and rivers, two shallow-draught Taymyr-class icebreakers of 18,260 dwt with one reactor delivering 35 MW were built in Finland and then fitted with their nuclear steam supply system in Russia. They are built to conform with international safety standards for nuclear vessels and were launched from 1989.

A more powerful icebreaker of 110 MW net and 55,600 dwt is planned, with further dual-draught ones of 32,400 dwt and 60 MW power at propellers. The first of these third-generation icebreakers is expected to be finished in 2015 at a cost of RUB 17 billion.

In 1988 the NS Sevmorput was commissioned in Russia, mainly to serve northern Siberian ports. It is a 61,900 tonne 260 m long lash-carrier (taking lighters to ports with shallow water) and container ship with ice-breaking bow. It is powered by the same KLT-40 reactor as used in larger icebreakers, delivering 32.5 propeller MW from the 135 MWt reactor and it needed refuelling only once to 2003.

Russian experience with nuclear powered Arctic ships totals about 300 reactor-years in 2009. In 2008 the Arctic fleet was transferred from the Murmansk Shipping Company under the Ministry of Transport to Atomflot, under Rosatom.

Floating nuclear power plants (FNPP)

Rosatom is planning to construct seven or eight floating nuclear power plants by 2015. The first of them, named *Academician Lomonosov,* began construction in April 2007 at Severodvinsk with intended completion in 2010 originally to supply that region, but now designated for Vilyuchinsk, Kamchatka. Each FNPP has two 35 MWe KLT-40S nuclear reactors. (If primarily for desalination this set-up is known as APVS-80.) The 21,500 tonne barge for each twin unit will be 144 metres long, 30 m wide. Three 12-year operating cycles are envisaged, with maintenance between them.

The keel of the first floating nuclear power plant using KLT-40 reactors was laid in April 2007 at Sevmash in Severodvinsk, but in August 2008 Rosatom cancelled the contract and transferred it to the Baltiysky Zavod shipyard at St Petersburg, which has experience in building nuclear icebreakers. A new keel-laying took place in May 2009 and the first reactor was delivered from OKBM Afrikantov soon after. The new site for its deployment is Vilyuchinsk, Kamchatka peninsula, to ensure sustainable electricty and heat supplies to the naval base there. Completion and towing to the site is expected in 2012 and grid connection in 2013. The Baltiyskiy Zavod contract is reported to be RUR 9.98 billion. In June 2009 Rostechnadzor approved the environmental review for the siting license for the facility, as well as the justification of investment in it.

In August 2009 OKBM Afrikantov shipped the second reactor for this to Baltiyskiy Zavod. The assembling and acceptance tests were carried out at Nizhniy Novgorod Machine Engineering Plant (NMZ). Three companies had contributed: OKBM (development of design and technical follow-up of the manufacture and testing), Izhorskiye Zavody (manufacture of the reactor pressure vessel), and NMZ (manufacture of component parts and reactor assembling).

The second plant of this size is planned for Pevek on the Chukotka peninsula in the far northeast, near Bilibino. The third is for Chersky in Yakutia, the two site comprising the Chaun-Bilibino energy hub. In June 2010 a "roadmap" for deployment of up to eight further FNPPs is expected, on the occasion of launching the barge for the first. As of early 2009, four floating plants were designated for northern Yakutia in connection with the Elkon uranium mining project in southern Yakutia, and in 2007 an agreement was signed with the Sakha Republic (Yakutia region) to build one of them, using smaller ABV reactors. Five were intended for use by Gazprom for offshore oil and gas field development and for operations on the Kola peninsula near Finland and the Yamal peninsula in central Siberia. Electricity cost is expected to be much lower than from present alternatives.

The larger end of the floating nuclear power plant (FNPP) range uses a pair of 325 MWe VBER-300 reactors on a 49,000 tonne barge, and a smaller one could use a single RITM-200 reactor providing 55 MWe, this being a possible successor to the KLT-40. ATETs-80 and ATETs-200 are twin-reactor cogeneration units using KLT-40 and may be floating or land-based. The former produces 85 MWe plus 120,000 m3/day of potable water. The small ABV-6 reactor is 38 MW thermal and a pair mounted on a 97-metre barge is known as Volnolom floating NPP, producing 12 MWe plus 40,000 m3/day of potable water by reverse osmosis.

Heating

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 VK-300 units commissioned to 2016), Voronezh (2 units 2012-18), Saratov, Dimitrovgrad and (small-scale, KLT-40 type PWR) at Chukoyka and Severodvinsk. Russian nuclear plants provided 11.4 PJ of district heating in 2005, and this is expected to increase to 30.8 PJ by about 2010. (A 1000 MWe reactor produces about 95 PJ per year internally to generate the electricity.)

Heavy engineering and turbine generators

The main reactor component supplier is OMZ's Komplekt-Atom-Izhora facility which is doubling the production of large forgings so as to be able to manufacture three or four pressure vessels per year from 2011. OMZ is expected to produce the forgings for all new domestic AES-2006 model VVER-1200 nuclear reactors (four per year from 2016) plus exports. At present Izhora can produce the heavy high-quality forgings required for Russia's VVER-1000 pressurized water reactors at the rate of two per year. These forgings include reactor pressure vessels, steam generators, and heavy piping. In 2008 the company is reconstructing its 12,000 tonne hydraulic press, claimed to be the largest in Europe, and a second stage of work will increase that capacity to 15,000 tonnes.

Turbine generators for the new plants are mainly from Power Machines subsidiary LMZ, which has six orders for high-speed (3000 rpm) turbines: four of 1200 MWe for Novovoronezh and Leningrad, plus smaller ones for Kalinin and Beloyarsk. The company plans also to offer 1200 MWe low-speed (1500 rpm) turbines from 2014. This will be to compete with Alstom Atomenergomash, the joint venture between French turbine manufacturer Alstom and Atomenergomash, an AEP subsidiary, which will produce low-speed turbine generators based on Alstom's Arabelle design, sized from 1200 to 1700 MWe. Silovy Mashiny plans to invest RUB 6 billion in a factory near St Petersburg to produce half-speed steam turbine generators of 1200 MWe from 2013, also in competition with Alstom Atomenergoomash. It is 25% owned by Siemens.

Reactor technology

In September 2006 the technology future for Russia was focused on four elements:

- Serial construction of AES-2006 units, with increased service life to 60 years,
- Fast breeder BN-800,
- Small and medium reactors - KLT-40 and VBER-300,
- High temperature reactors (HTR).

VVER-1000, AES-92

The main reactor design being deployed until now has been the V-320 version of the VVER-1000 pressurised water reactor with 950-1000 MWe net output. It is from OKB Gidropress (Experimental Design Bureau Hydropress), has 30-year basic design life and dates from the 1980s. A later version of this for export is the V-392, with enhanced safety and seismic features, as the basis of the AES-92 power plant. All models have four coolant loops, with horizontal steam generators. VVER stands for water-cooled, water-moderated energy reactor.

Advanced versions of this VVER-1000 with western instrument and control systems have been built at Tianwan in China and are being built at Kudankulam in India - as AES-91 and AES-92 nuclear power plants respectively. The former was bid for Finland in 2002. The latter was bid for Sanmen and Yangjiang in China in 2005 and was accepted for Belene in Bulgaria in 2006. These have 40-year design life. (Major components of the two designs are the same except for slightly taller pressure vessel in AES-91, but cooling and safety systems differ. The AES-92 has greater passive safety features, the AES-91 has extra seismic protection. The V-428 in the AES-91 is the first Russian reactor to have a core-catcher.)

VVER-1200, AES-2006

Development of a third-generation standardised VVER-1200 reactor of about 1170 MWe net folloowed, as the basis of the AES-2006 power plant. This is an evolutionary development of the well-proven VVER-1000/ V-320 and then the third-generation V-392 in the AES-92 plant, with longer life (50 years and aiming for 60, not 30), greater power, and greater efficiency (36.56% instead of 31.6%). Compared with the V-392, they have the same number of fuel assemblies (163) but a wider pressure vessel, slightly higher operating pressure and temperature, and higher burn-up (up to 70 GWd/t instead of 43-55). The lead units are being built at Novovoronezh II, to start operation in 2012-13, and at Leningrad II for 2013-14. Both plants will use Areva's Teleperm safety instrument and control systems. Leningrad II's V-491 design is quoted as the reference plant for further units at Tianwan in China, but the V-392M is very similar apart from safety systems configuration.

A typical AES-2006 plant will be a twin set-up with two of these OKB Gidropress reactor units expected to run for 50 years with capacity factor of 90%. Capital cost was said to be US$ 1200/kW (though the first contract of them is more like $2100/kW) and construction time 54 months. They have enhanced safety including that related to earthquakes and aircraft impact with some passive safety features, double containment and core damage frequency of $1x10^{-7}$.

In Europe the basic technology is being called the Europe-tailored reactor design, MIR-1200 (Modernized International Reactor), and bid for Temelin 3 & 4, Turkey and Finland.

Russian PWR nuclear power reactors*

Generic reactor type	Reactor plant model	Whole power plant
VVER-300	V-478	(under development, based on VVER-640), Gen III+
VVER-440	V-230 V-213	
VVER-640	V-407	(under development), Gen III+
VVER-600	V-498	(under development, based on V-491), Gen III+
VVER-1000	V-320	most Russian & Ukraine plants
	V-338	Kalinin 1-3, Temelin 1&2, S. Ukraine 2
	V-446	based on V-392, adapted to previous Siemens work, Bushehr
	V-413	AES-91
	V-428	AES-91 Tianwan, based on V-392, Gen III
	V-412	AES-92 Kudankulam, based on V-392, Gen III
	V-392	AES-92 Belene contract?, meets EUR standards, Gen III
	V-466	AES-91/99 Olkiluoto bid, Belene proposal, Gen III+
VVER-1200	V-392M	AES-2006 Novovoronezh, Gen III+
	V-491	AES-2006 Leningrad, Gen III+
VVER-1200A	V-501	AES-2006, Gen III+
VVER-1300	V-488	AES-2006M, Gen III+
VVER-1500	V-448	(under development), Gen III+

Early V numbers referred to models which were widely built in several countries, eg V-230, V-320. Then the V-392 seemed to be a general export version of the V-320. Later V numbers are fairly project-specific, with the differences in safety systems and I&C, outside the basic reactor plant.

Generation III or III+ ratings are as advised by Gidropress.

The AES-2006M is an uprated VVER-1200 with less conservative design and new steam generators, giving it 1300 MWe. Following this is a so-called super VVER, designated AES-2010, which will be much more efficient and is claimed to require only 130-135 tonnes of natural uranium per year (compared with typical 190 tU now) per gigawatt.

Gidropress shows the VVER-1200 /V-392M and V-491 reactors evolving into VVER-1300 /V-488 (in AES-2006M power plant) and into the VVER-1200A /V-501 (similar, but 2-loop design) reactors in the next few years. The last is expected to have lower construction cost.

VVER-1500

About 2005 Rosatom (the Federal Atomic Energy Agency) promoted the basic design for VVER-1500 pressurised water reactors by Gidropress as a priority. Design was expected to be complete in 2007, but the project was shelved in 2006. It remains a 4-loop design, with increased pressure vessel diameter to 5 metres, 241 fuel assemblies in core, burn-up up to 60 GWd/t and life of 60 years. It is a Generation III+ model meeting EUR criteria.

Other large VVER

Another reactor type with advanced safety features (passive safety systems) which was under development is the 640 MWe V-407 (VVER-640), developed by Gidropress jointly with Siemens (now Areva NP). After apparently beginning construction of the first at Sosnovy Bor, funds ran out and it disappeared from plans. However, it is still on the drawing boards, now as a Generation III+ type, with four cooling loops, low power density, low-enriched fuel (3.6%), and only 45 GWd/t burn-up.

Gidropress is also developing a VVER-600 from V-491 (1200 MWe), and a VVER-300 unit from the shelved VVER-640.

A Generation IV Gidropress project is the supercritical VVER (VVER-SKD or VVER-SCWR) with higher thermodynamic efficiency (45%) and higher breeding ratio (0.95) and oriented towards the closed fuel cycle.

Fast Reactors

The **BN-800** fast neutron (bystry neutron) reactor being built by OKBM Afrikantov at Beloyarsk is designed to supersede the BN-600 unit there and utilise MOX fuel with both reactor-grade and weapons plutonium. It will be 880 MWe gross and have fuel burn-up of 70-100 GWd/t. Further BN-800 units were planned and a **BN-1200** was being designed by OKBM for operation from 2020, s a next step towards a BN-1800. The BN-1200 has a 60-year design life and burn-up of up to 120 GWd/t. This represents a technological advantage for Russia and the BN-800 has been picked up by China. There is also significant export or collaborative potential with Japan. In February 2010 a government decree allocated RUR 5.37 billion funding for sodium-cooled fast reactor development.

However, Beloyarsk-4 is likely to be the last such reactor built, with a fertile blanket of depleted uranium around the core. Further fast reactors are expected to have an integrated core to minimise the potential for weapons proliferation from bred Pu-239. Beloyarsk-5 is planned as a BREST design though a report in June 2009 said that Rosatom's Science and Technology Council approved the construction of Beloyarsk-5 with BN-1200 reactor.

The **BREST** lead-cooled fast reactor (Bystry Reaktor so Svintsovym Teplonositelem) is another innovation, from NIKIET, with the first unit being proposed for Beloyarsk-5. This will be a new-generation fast reactor which dispenses with the fertile blanket around the core and supersedes the BN-600/800 design, to give enhanced proliferation resistance. In February 2010 a government decree approved RUR 40 billion (US$ 1.3 billion) funding for an initial 300 MWe BREST unit at Beloyarsk over 2016-20, though it appears that only RUR 15.555 billion would come from the federal budget. See Advanced Reactors paper.

The pilot demonstration 100 MWe **SVBR-100** unit is to be built in IPPE at Obninsk by AKME-Engineering by 2015. RUR 13.23 billion was allocated for this in February 2010, including RUR 3.75 billion from the federal budget. SVBR-75/100 is a modular lead-bismuth cooled fast neutron reactor concept from OKB Gidropress in Podolsk. It is based on naval technology, and is designed to meet regional needs in Russia and abroad. It is proposed as a replacement for Novovoronezh 3&4 (in the present reactor halls), and for Kozloduy in Bulgaria. If built in clusters of 10 to 16 units it is claimed to be competitive with VVER types. It is described by Gidropress as a multi-function reactor. See Small Nuclear Reactors paper.

Another new reactor, also described as a multi-function fast reactor - MBIR - is to be built at the Research Institute of Atomic Reactors (RIAR) at Dimitrovgrad. See R&D section below.

Small Floating VVERs

After many years of promoting the idea, in 2006 Rosatom approved construction of a nuclear power plant on a barge (floating power module - FPM) to supply power and heat to isolated coastal towns. See Floating Nuclear Power Plant subsection above.

Two OKBM Afrikantov **KLT-40S** or **KLT-40C** reactors derived from those in icebreakers, but with low-enriched fuel (less than 20% U-235), will supply 70 MWe of power plus 586 GJ/hr (5.1 PJ/yr) of heat. They will be mounted on a 21,500 tonne, 144 m long barge. Refuelling interval is 3-4 years on site, and at the end of a 12-year operating cycle the whole plant is returned to a shipyard (Zvezdochka, near Sevmash has been mentioned) for a 2-year overhaul and storage of used fuel, before being returned to service. Each reactor is about 150 MWt and can deliver 38.5 MWe if no cogeneration is required.

The smaller **ABV** reactor units are under development by OKBM Afrikantov, with a range of sizes from 45 MW thermal (ABV-6M) down to 18 MWt (ABV-3), giving 4-18 MWe outputs. The PWR/VVER units are compact, with integral steam generator. The whole unit of some 600 tonnes (ABV-6) will be factory-produced for ground or barge mounting. The ABV-6M would require a 3500 tonne barge, the ABV-3: 1600 tonne. The core is similar to that of the KLT-40 except that enrichment is 16.5% and average burnup 95 GWd/t. Refuelling interval is about 8-10 years, and service life about 50 years. In mainly desalination mode the ABV-6M is expected to produce 55,000 m3/day of potable water by reverse osmosis. The company said at the end of 2009 that an ABV-R7D would cost RUR 1.5 billion, but that Rosatom preferred the larger and proven KLT-40 design.

OKBM Afrikantov is developing a new icebreaker reactor – **RITM-200** – to replace the current KLT 40 reactors. This is an integral 210 MWt, 55 MWe PWR with inherent safety features. For floating nuclear power plants a single RITM-200 would replace twin KLT-40S yielding 40 MWe net (instead of 77 MWe) and requiring a barge one third the displacement. The refueling period would be 10 years (instead of about 3years) and the service life 60 years instead of 40.

Exports of combined power and desalination units is planned, with China, Indonesia, Malaysia, Algeria, Cape Verde and Argentina being mentioned as potential buyers, though Russia would probably retain ownership of the plant with operational responsibility, and simply sell the output.

VBER-300

OKBM Afrikantov's VBER-300 PWR is a 295 MWe unit developed from naval power plants and was originally envisaged in pairs as a floating nuclear power plant. As a cogeneration plant it is rated at 200 MWe and 1900 GJ/hr for heat or desalination. The reactor is designed for 60 year life and 90% capacity factor. It was planned to develop it as a land-based unit with Kazatomprom, with a view to exports, and the first unit was to be built at Aktau in Kazakhstan. However, this agreement has stalled, and OKBM has been looking for a new partner to develop it. There is support for two demonstration units at Zheleznogorsk for the Mining & Chemical Combine (MMC).

VK-300 BWR

The VK-300 boiling water reactor is being developed by the Research & Development Institute of Power Engineering (NIKIET) for both power (250 MWe) and desalination (150 MWe plus 1675 GJ/hr). It has evolved from the VK-50 BWR at Dimitrovgrad, but uses standard components wherever possible, eg the reactor vessel of the VVER-1000. A feasibility study on building 4 cogeneration VK-300 units at Archangelsk was favourable, delivering 250 MWe power and 31.5 TJ/yr heat.

RBMK

A development of the RBMK was the MKER-800, with much improved safety systems and containment, but this too has been shelved. Like the RBMK itself, it was designed by VNIPIET (All-Russia Science Research and Design Institute of Power Engineering Technology) at St Petersburg.

HTRs

In the 1970-80s OKBM undertook substantial research on high temperature gas-cooled reactors (**HTR**s). In the 1990s it took a lead role in the international **GT-MHR** (Gas Turbine-Modular Helium Reactor) project based on a General Atomics (US) design. Preliminary design was completed in 2001 and the prototype was to be constructed at Seversk (Tomsk-7, Siberian Chemical Combine) by 2010, with construction of the first 4-module power plant (4x285 MWe) by 2015. Initially it will be used to burn pure ex-weapons plutonium, and replace production reactors which still supply electricity there. But in the longer-term perspective HTRs are seen as important for burning actinides, and later for hydrogen production.

International

From 2001 Russia has been a lead country in the IAEA Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). In 2006 Russia joined the Generation-IV International Forum, for which NEA provides the secretariat. Russia Russia is also a member of the NEA's Multinational Design Evaluation Program which is increasingly important in rationalising reactor design criteria.

Improving reactor performance

A major recent emphasis has been 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 from 2.4 or 2.6% to 2.8% enrichment and 0.6% erbium) increased burn-up is possible and the fuel can stay in the reactor six years. Also from 2009 the enrichment is profiled along the fuel elements, with 3.2% in the central section and 2.5% in the upper and lower parts. This better utilises uranium resources and further extends fuel life in the core.

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 project has been 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.

Uranium resources and mining

Russia has substantial economic resources of uranium, with about 10% of world reasonably assured resources plus inferred resources up to US$ 130/kg - 546,000 tonnes U (2007 Red Book). Exploration expenditure has nearly doubled in two years to about US$ 52 million in 2008. Historic uranium exploration expenditure is reported to have been about $4 billion.

Uranium production is starting to increase. In 2007 it produced some 3413 tonnes of uranium from mines, in 2008 it rose to 3521 tU and in 2009 it was 31% higher at 3564 tU (domestic production), plus 1060 tU from ARMZ Kazakh operations (share of Zarechnoye, Karatua & Akbastau). In 2006 there were three mining projects in Russia, in 2008 there were three more under construction and a further three projected. Cost of production in remote areas is said to be US$ 60-90/kg.

AtomRedMetZoloto (ARMZ) is the state-owned company which took over Tenex and TVEL uranium exploration and mining assets in 2007, as a subsidiary of Atomenergoprom. It inherited 19 projects with a total uranium resource of about 400,000 tonnes, of which 340,000 tonnes are in Elkonskiy uranium region and 60,000 tonnes in Streltsovskiy and Vitimskiy regions. The rights to all these resources had been transferred from the Federal Subsoil Resources Management Agency (Rosnedra).

JSC ARMZ Uranium Holding Company (as it is now known) is responsible for all Russian uranium mine assets and also Russian shares in foreign joint ventures. In 2008, 78.6% of JSC Priargunsky, all of JSC Khiagda and 97.85% of JSC Dalur was transferred to ARMZ.

In March 2009 the Federal Financial Markets Service of Russia registered RUR 16.4 billion of additional shares in ARMZ placed through a closed subscription to pay for uranium mining assets, on top of a RUR 4 billion issued in mid 2008 to pay for the acquisition of Priargunsky, Khiagda and Dalur. In November 2009 SC Rosatom paid a further RUR 33 billion for ARMZ shares, increasing its equity to 76.1%.

In 2009 the government accepted Rosatom's proposal for ARMZ and Elkonsky Mining and Metallurgical Combine to set up the "open-type joint stock company" EGNK-Project. The state's contribution through Rosatom to the EGMK-Project authorized capital will be RUR 2.657 billion, including RUR 2.391 billion in 2009 and RUR 0.266 billion in 2010. EGMK-Project is being set up to draw up the project and design documentation for Elkonsky Mining and Metallurgical Combine (see below).

Present production by ARMZ is principally from the Streltsovskiy district of the Transbaikal or Chita region of SE Siberia near the Chinese and Mongolian borders, where major uranium deposits were discovered in 1967, leading to large-scale mining, originally with few environmental controls. Krasnokamensk is the main town serving the mines.

Several large underground mines operated by JSC **Priargunsky** Industrial Mining & Chemical Union (PIMCU) supply low-grade ore to a central mill. Historical production from Priargunsky is reported to be 130,000 tU (some from open cut mines) and current known resources (RAR + IR) are quoted as 133,000 tU at 0.159%U. 2007 production was 3037 tU and current capacity is 3500 tU/yr, about one tenth from heap leaching. Some production has been exported to France, Sweden and Spain.

A lesser amount of production is from new operations at **Khiagda** in Buryatiya about 500 km northwest of Priargunsky's operations, and from **Dalur** in the Kurgan region between Chelyabinsk and Omsk, just east of the Urals, also known as the Zauralsk uranium region. Both are low-cost (US$ 40/kg) in situ leach (ISL) operations. Uksyanskoye is the town supporting Dalur mine, Rudnik Kadala that for Khiagda. JSC Khiagda reports estimated resources of 100,000 tU.

In 2008 ARMZ said that it intends to triple production to 10,300 tU per year by 2015, with some help from Cameco, Mitsui and local investors. ARMZ plans to invest RUB 203 billion (US$ 6.1billion) in the development of uranium mining in Russia in 2008-2015. It aims for 20,000 tU per year by 2024. (With increasing use of fast reactors, this level of production could support a major expansion in nuclear power generation to the end of the century.)

Production would be expanded at Priargunsky from 3000 to 5000 tU/yr by 2020, with Mine #6 construction to begin in 2009 for stage 1 production in 2019 and stage 2 in 2024. Mine #8 is due to begin producing in 2011. Production at Dalur is to be increased from 350 to 800 tU/yr by 2019 (expanding from the Dalmatovskoye deposit to Khoklovskoye then Dobrovolskoye) and at Khiagda (Khiagdinskoye deposit) from 150 to 650 tU/yr by 2013 and 1800 tU/yr by 2017. Total cost is projected at 67 billion rubles ($2 billion), mostly at Priargunsky, with RUB 4.8 billion ($144 million) there by end of 2009 including a new $30 million, 500 tonne per day sulfuric acid plant due to be commissioned in June 2009, replacing a 1976 acid plant.

Development of **Olovskoye** and **Gornoye** deposits* in the Transbaikal region near Priargunsky and Khiagda would add 600 tU/yr production from each by 2017 for 135 billion rubles ($5.7 billion). In 2007 newly-formed ARMZ set up two companies to undertake this:

- Uranium Mining Company **Gornoye** to develop the Gornoye and Berezovoye mines in the Krasnochikoysky and Uletovsky districts in Chita, with underground mining and some heap leach (ore grade 0.226%U); and

- **Olovskaya** Mining & Chemical Company to develop the Olovskoye deposits in the Chernyshevsk district of Chita region with underground, open cut and heap leach (ore grade 0.88%U).

First production from both is planned for 2014, ramping up to 600 tU/yr each by 2016.

* 2006 plans were for 2000t/yr at new prospects in Chita Region and Buryatia (Gornoye, Berezovoye, Olovskoye, Talakanskoye properties etc.), plus some 3000t at new deposits.

However, ARMZ's principal focus announced in 2008 is development of the massive **Elkon** project with several mines in the Sakha Republic (Yakutia) some 1200 km north-northeast of the Chita region. Production would ramp up from 2013, to 3000 tU in 2015 and 5000 tU/yr by 2024, for RUB 90.5 billion ($2.7 billion) - confirming 2006 plans. ARMZ set up two companies:.

- **Elkon** Mining & Chemical Combine (EMMC) to develop the substantial Elkonsky deposits;

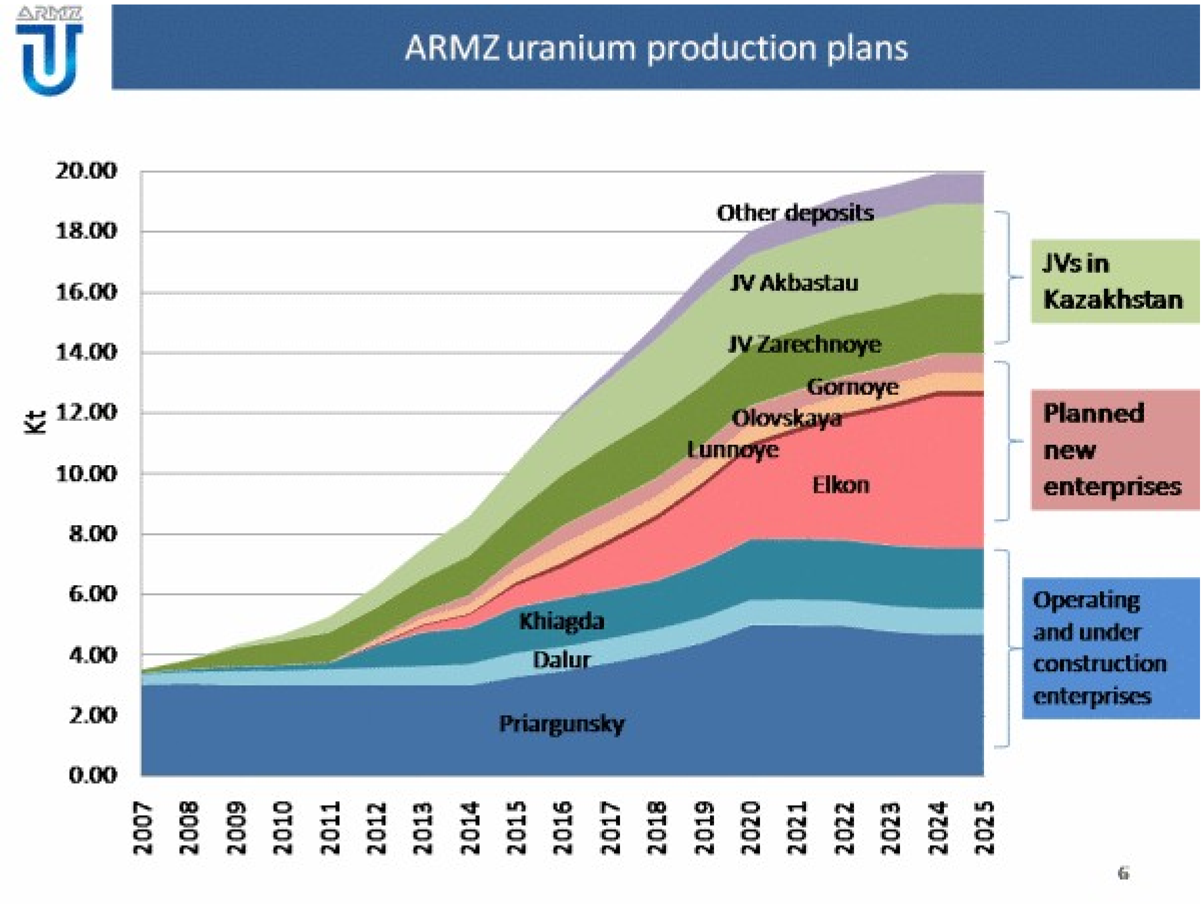
- JSC **Lunnoye** is set up to develop a small deposit jointly by ARMZ and a gold mining company Zoloto Seligdara as a pilot project to gain practical experience in the region in a polymetallic orebody. Lunnoye is expected in full production in 2016, reaching 100 tU/yr. It has reserves of 800 tU and 13 t gold.

The Elkon MMC project involves the JSC Development Corporation of South Yakutia and aims to attract outside funding to develop infrastructure and mining in a public-private partnership, with ARMZ holding 51%. Foreign equity including from Japan, South Korea and India is envisaged, and in March a joint venture arrangement with India was announced. The Elkon MMC developments are to become "the locomotive of the economic development of the entire region", building the infrastructure, electricity transmission lines, roads and railways, as well as industrial facilities, from 2010. Of 15 proposed construction sites, three have been tentatively selected: at the mouth of Anbar River, Diksi Village and Ust-Uga Village. The building of four small floating co-generation plants to supply heat and electricity to northern regions of Yakutia is linked with the Elkon project in southern Yakutia.

There are eight deposits in the Elkon project with resources of 320,000 tU (RAR + IR) at average 0.146%U, with gold by-product: Elkon, Elkon Plateau, Kurung, Neprokhodimoye, Druzhnoye (southern deposits), as well as Severnoye, Zona Interesnoye and Lunnoye (see above). First production from EMMC is expected in 2015 ramping up to 1000 tU/yr in 2018, 2000 tU/yr in 2020 and 5000 tU/yr by 2024, making it Russia's largest uranium mining complex. However, it is remote, and mining will be underground, incurring significant development costs.

Plans announced in 2006 for 28,600 t/yr U_3O_8 output by 2020, 18,000t of this from Russia* and the balance from Kazakhstan, Ukraine, Uzbekistan and Mongolia have since taken shape as outlined above. In April 2007 an agreement was signed with Mongolia for uranium exploration, mining and processing.

* See details for April 2008 ARMZ plans. In 2007 TVEL applied for the Istochnoye, Kolichkanskoye, Dybrynskoye, Namarusskoye and Koretkondinskoye deposits with 30,000 tU in proved and probable reserves close to the Khiagda mine in Buryatia.
From foreign projects: Zarechnoye 1000 t, Southern Zarechnoye 1000 t, Akbastau 3000 t (all in Kazakhstan); Aktau (Uzbekistan) 500 t, Novo-Konstantinovskoye (Ukraine) 2500 t. In addition Russia would like to participate in development of Erdes deposit in Mongolia (500t) as well as in Northern Kazakhstan deposits Semizbai (Akmolonsk Region) and Kosachinoye.



(this chart is now slightly out of date but still gives a general picture)

In 2006 Priargunsky won a tender to develop Argunskoye and Zherlovoye deposits in the Chita with about 40,000 tU reserves. Khiagdinsk, Dolmatovsk and Khokhlovsk have also been identified as three new mines to be developed.

In May 2007 Tenex (now ARMZ) won its bid to develop eight deposits in the Elkon area of southern Yakutia with reported resources of 320,000 tU: Elkon, Elkon Plateau, Kurung, Neprokhodimoye, Druzhnoye, Severnoye, Interesnoye & Lunnoye. First production is expected in 2013 ramping up to 5000 tU/yr by 2020, making it Russia's largest uranium mining complex. Some US$ 3.6 billion is to be invested in the Elkon project.

In October 2006 Japan's Mitsui & Co with Tenex agreed to undertake a feasibility study for a uranium mine in eastern Russia to supply Japan. First production from the Yuzhnaya mine in Sakha (Yakutia) Republic is envisaged for 2009. Mitsui has an option to take 25% of the project, and is funding $6 million of the feasibility study. Construction of the Yuzhnaya mine is likely to cost US$ 245 million, with production reaching 1000 tU/yr by 2015. This would represent the first foreign ownership of a Russian uranium mine.

Two uranium mining joint ventures have been established in Kazakhstan with the intention of providing 6000 tU/yr for Tenex (now ARMX) from 2007: JV Zarechnoye and JV Akbastau for mining at Budenovskoye. (see Kazakhstan paper) ARMZ had 50% of JV Karatau there also, but exchanged thjis for an equity share in Canada's Uranium One.

Following from previous deals with Tenex, In November 2007 Cameco signed an agreement with ARMZ. The two companies are to create joint ventures to explore for and mine uranium in both Russia and Canada, starting with identified deposits in northwestern Russia and the Canadian provinces of Saskatchewan and Nunavut.

The Federal Subsoil Resources Management Agency (Rosnedra) said in late 2008 that it is planning to transfer about 100,000 tonnes of uranium resources to miners, notably ARMZ, in 2009-10, and 14 projects, mainly small to medium deposits, have been prepared for licensing then. They are located mainly in Streltsovskiy, Zauralskiy and Vitimskiy uranium regions.

The projects prepared for licensing include:

in Chita Region - Zherlovskoye, Pyatiletnee, Dalnee and Durulguevskoye;
in Republic of Buratiya - Talakanskoye, Vitlausskoye, Imskoye, Tetrakhskoye, and Dzhilindinskoye;
in Kurgan Region - Dobrovolnoye;
in Khabarovsk Territory - Lastochka;
in Republic of Tyva - Ust-Uyuk and Onkazhinskoye;
in Republic of Khakassia - Primorskoye.

All together these projects have 76,600 tonnes of reasonably assured and inferred resources, plus 106,000 tonnes of undiscovered resources.

In February 2009 Rosnedra published a list of deposits to be offered for tender in 2009 . They are located in the Republic of Karelia, Irkutsk Region and Leningrad Region. In particular, Tyumenskiy in Mamsko-Chuiskiy District of Irkutsk Region is to be offered for development. Also, in the second quarter of 2009 Shotkusskaya ploshchad in Lodeinopolsky District of Leningrad Region will be put out to tender. In the Republic of Karelia the offer comprises Salminskaya ploshchad in Pitkyaranskiy District and the Karku deposit. None of these 2009 offerings has reasonably assured or inferred resources quoted, only "undiscovered" resources in Russia's P1 to P3 categories.

In addition to ARMZ, private companies may also participate in tenders for mining the smaller and remote uranium deposits being prepared for licensing. ARMZ is open to relevant investment projects with strategic partners, and Lunnoye deposit is an example where a private company Zoloto Seligdara is partnering with ARMZ.

Secondary supplies:

Some uranium also comes from reprocessing used fuel from VVER-440, fast neutron and submarine reactors - some 2500 tonnes of uranium has so far been recycled into RBMK reactors.

Also arising from reprocessing used fuels, some 32 tonnes of reactor-grade plutonium has been accumulated for use in MOX. Added to this there is now 34 tonnes of weapons-grade plutonium from military stockpiles to be used in MOX fuel for BN-600 and BN-800 fast neutron reactors at Beloyarsk, supported by a $400 million payment from the USA. Some of this weapons plutonium may also be used in the MHR high-temperature gas-cooled reactor under development at Seversk.

About 28% of the natural uranium feed sent to USEC in USA for enrichment, and contra to the LEU supplied from blended-down Russian military uranium, is being sent to Russia for domestic use. The value of this to mid 2009 was US$ 2.7 billion, according to Rosatom. See also Military Warheads as Source of Fuel paper.

Russia's uranium supply 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: front end

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. In 2009 the conversion and enrichment plants are being taken over by the newly-established JSC Enrichment & Conversion Complex, a subsidiary of Atomenergoprom.

Conversion

The main operating conversion plant is at Angarsk near Irkutsk in Siberia, with 18,700 tonnes U/yr capacity. It is part of the JSC Angarsk Electrolysis & Chemical Combine, whose prime function is conversion and enrichment of uranium.

The Elektrostal conversion plant, 50 km east of Moscow, has 700 tU/yr capacity for reprocessed uranium, initially that from VVER-440 fuel. It is owned by Maschinostroitelny Zavod (MSZ) whose Elemash fuel fabrication plant is there. Some conversion of Kazakh uranium has been undertaken for west European company Nukem, and all 960 tonnes of recycled uranium from Sellafield in UK, owned by German and Netherlands utilities, has been converted here.

Enrichment

Four enrichment plants totalling 24 million kg SWU/yr of centrifuge capacity operate at Novo-Uralsk near Yekaterinburg in the Urals, Zelenogorsk (Krasnoyarsk-45), Seversk near Tomsk and Angarsk near Irkutsk - the last three all in Siberia. The first two service foreign primary demand and Seversk specialises in enriching reprocessed uranium, including that from western Europe.

The Novouralsk (Novo-Uralsk) plant is part of the JSC Urals Electrochemical Combine in the Sverdlovsk region. It has operated 8th generation centrifuges since 2003, and is trialling 9th generation units.

The Zelenogorsk plant is also known as the PA ElectroChemical Plant (ECP) in the Krasnoyarsk region (120 km east of that city), and has ISO 14001 environmental accreditation. It is the site of a new deconversion plant (see below).

The Seversk plant is part of the JSC Siberian Chemical Combine (SKhK), Tomsk region, which opened in 1953. It is about 15 km from Tomsk. As well as the enrichment plant the site has several plutonium production reactors (now closed), a MOX plant and other facilities.

Angarsk, near Irkutsk in Siberia, is part of the JSC Angarsk Electrolysis & Chemical Combine. It is also the site of the new International Uranium Enrichment Centre (IUEC) and fuel bank.

Diffusion technology was phased out by 1992 and all plants now operate modern gas centrifuges, with further fitting of 8th generation equipment in progress. The last 6th & 7th generation centrifuges were set up in 2005, 8th generation equipment has been supplied since 2004, now at about 240,000 units per year and are replacing 5th generation models. (6th generation units are still produced for export to China.) The technology is attributed by Nuclear.Ru to VNIPIET in St Petersburg, though Tenex has taken over responsibility for manufacturing the equipment through JSC Russian Gas Centrifuge and JSC Khimprom Engineering.

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. The JSC Electrochemical Plant (ECP) at Zelenogorsk is 5.8 M SWU/yr and is introducing ISO9001 quality assurance system.

A significant proportion of the capacity of both plants - some 7 M SWU/yr - is taken up by enrichment of former tails (depleted uranium), including for west European companies Areva and Urenco. According to WNA sources, about 10,000 to 15,000 tonnes of tails per year, with U-235 assays between 0.25% and 0.40%, has been shipped to Russia for re-enrichment to about 0.7% U-235 since 1997. The tails are stripped down to about 0.10% U-235, and remain in Russia, being considered a resource for future fast reactors. The contracts for this work for Urenco and Areva end in 2010.

A portion of the Zelenogorsk capacity, about 4.75 M SWU/yr, is taken up with re-enrichment of tails to provide 1.5% enriched material for downblending Russian HEU destined for USA. It is also the site for downblending of ex-weapons uranium for sale to the USA.

Seversk capacity is about 3 M SWU/yr, and some recycled uranium (from reprocessing) has been enriched here for Areva, under a 1991 ten-year contract covering about 500 tonnes UF_6. (French media reports in 2009 alleging that wastes from French nuclear power plants was stored at Seversk probably refer to tails from enrichment of the recycled uranium.) It is understood to be enriching the 960 tU of reprocessed uranium from Sellafield in UK, belonging to its customers in Germany and Netherlands, sent to Elektrostal in eight shipments over 2001-09.

Angarsk is the smallest of three Siberian plants, with capacity of about 2.6 million SWU/yr. In 2008 Kazatomprom set up a 50-50 joint venture with Tenex for financing a 5 million SWU/yr increment to the Angarsk plant, with each party to contribute about US$ 1.6 billion and hold 50% equity. It now appears that initial JV capacity will be about 3 M SWU/yr, with first production in 2011. This is distinct from the IUEC.

The International Uranium Enrichment Centre (IUEC) is being set up at Angarsk, near Irkutsk (see following section). Two projects are under way to increase the capacity of this from 2.6 to 4.2 and then to almost 10 million SWU/yr by 2015. The latter stage will be with Kazakhstan and other IUEC partners, who will share the $2.5 billion cost. See section below.

Deconversion

Russia's W-ECP deconversion plant is at Zelenogorsk Electrochemical Plant (ECP). The 10,000 t/yr deconversion (defluorination) plant was built by Tenex under a technology transfer agreement with Areva NC, so that depleted uranium can be stored long-term as uranium oxide, and HF is produced as a by-product. The W-ECP plant is similar to Areva's W2 plant at Pierrelatte in France and has mainly west European equipment. It was commissioned in December 2009.

Fuel fabrication

This is undertaken by JSC TVEL, which supplies 74 nuclear power plants in Russia and abroad as well as 30 research reactors and fuel for naval and icebreaker reactors. Its operations are certified against ISO 9001.

TVEL has two fuel fabrication plants:

- the huge Maschinostroitelny Zavod (MSZ) at Elektrostal 50 km east of Moscow - known as Elemash,
- Novosibirsk Chemical Concentrates Plant (NCCP) in Siberia, and
- Chepetsk Mechanical Plant (CMP) near Glazov in Udmurtiya makes zirconium cladding and also some uranium products.

Most fuel pellets for RBMK and VVER-1000 reactors were being made at the Ulba plant at Ust Kamenogorsk in Kazakhstan, but Elemash and Novosibirsk have increased production. MSZ produces fuel assemblies for both Russian and west European rectors using fresh and recycled uranium. It also fabricates research reactor and icebreaker fuel. Novosibirsk produces mainly VVER 440 & 1000 fuel, including that for initial use in China. MSZ/Elemash is the principal exporter of fuel assemblies.

A 60 t/yr commercial mixed oxide (MOX) Fuel Fabrication Facility (MFFF) is scheduled to start up at Zheleznogorsk (formerly Krasnoyarsk-26, 70 km NE of Krasnoyarsk) by 2014, operated by the Mining & Chemical Combine (MCC) to make 400 fuel assemblies per year for the BN-800 and future fast reactors. This is funded to RUR 5.1 billion (US$ 169 million) over 2010-12.

A small MOX fuel fabrication plant has operated at the Mayak plant at Ozersk since 1993. A new 14 tonne per year plant to fabricate dense mixed nitride fuel for fast neutron reactors is planned at PA Mayak, to operate from 2018. In the federal target program to 2020, RUR 9.35 billion (US$ 310 million) is budgeted for it. Later it may be expanded to 40 tonnes per year.

The Research Institute of Atomic Reactors (RIAR) at Dimitrovgrad, Ulyanovsk, has a small MOX fuel fabrication plant, and under the federal target program this has been allocated RUR 2.95 billion (US$ 83 million) for expansion to produce 400 fuel assemblies per year. Its main research has been on the use of military plutonium in MOX, in collaboration with France, USA and Japan.

Another MOX plant for disposing of military plutonium is planned at Seversk (Tomsk-7) in Siberia, to the same design as its US equivalent.

TVEL's Moscow Composite Metal Plant designs and makes control and protection systems for nuclear power reactors.

International Uranium Enrichment Centre (IUEC) and fuel bank

The IUEC concept was inaugurated at the end of 2006 in collaboration with Kazakhstan, and in March 2007 the IAEA agreed to set up a working group and continue developing the proposal. In September 2007 the joint stock company Angarsk International Uranium Enrichment Centre (JSC Angarsk IUEC) was registered and a year later Rostechnadzor licensed the Centre. Late in 2008 Ukraine's Nuclear Fuel Holding Company took a 10% stake in it, matching Kazatomprom's 10%. Armenia has also decided to participate in IUEC, while accession negotiations proceed with South

Korea, Finland, and Belgium. Mongolia is reported to be interested, and Russia has invited India to participate in order to secure fuel for its Kudankulam plant. The aim is for Techsnabexport eventually to hold only 51%. Each 1% share is priced at US$ 7500.

The centre is to provide assured supplies of low-enriched uranium for power reactors to new nuclear power states and those with small nuclear programs, giving them equity in the project, but without allowing them access to the enrichment technology. Russia will maintain majority ownership. IUEC will sell both enrichment services (SWU) and enriched uranium product. Arrangements for IAEA involvement are being sorted out in 2009, and in 2010 a feasibility study will be commenced on IUEC investment, initially for equity in JSC Angarsk Electrolysis & Chemical Combine (AECC) so that part of its capacity supplies product to IUEC shareholders.

The existing enrichment plant at **Angarsk** will feed the IUEC and accordingly has been removed from the category of "national strategic installations", though it has never been part of the military program. In February 2007 the IUEC was entered into the list of Russian nuclear facilities eligible for implementation of IAEA safeguards. The USA has expressed support for the IUEC at Angarsk.

Development of the IUEC will be in three phases:

1. Use part of the existing capacity at Angarsk in cooperation with Kazatomprom and under IAEA supervision,
2. Expand capacity (perhaps double) with funding from new partners,
3. Full internationalisation with involvement of many customer nations under IAEA auspices.

In November 2009 the IAEA Board approved a Russian proposal to create an international fuel bank of low-enriched uranium under IAEA control at Angarsk. The bank will comprise 120 tonnes of low-enriched uranium (as UF_6, assay 2.0 - 4.95% U-235), available to any IAEA member state in good standing which is unable to procure fuel for political reasons. It will be fully funded by Russia, and the fuel will be made available to IAEA at market rates, using a formula based on preceding spot prices. This initiative will complement a proposed IAEA fuel bank by making more material available to the IAEA for assurance of fuel supply to countries without their own fuel cycle facilities. The 120 tonnes is sufficient for two full fuel loads for a typical 1000 MWe reactor, or six re-loads, and is (in 2009) worth some $250 million.

Used Fuel and Reprocessing, Wastes

Rosatom's national enterprise for radioactive waste management, RosRAO, commenced operation in 2009 under a temporary arrangement pending finalisation of regulations under new radwaste management legislation. It incorporates Radon, and now has branches in each of seven federal districts. Money from the radwaste generators is accumulated in the SC Rosatom's bank account as a special fund. Rosatom plans to draft two more laws: on decommissioning and used fuel management.

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. However, its achievements in doing this are limited. At present the used fuel from RBMK reactors and from VVER-1000 reactors is stored (mostly at reactor sites) and not reprocessed.

Used fuel from VVER-440 reactors, the BN-600 and from naval reactors is reprocessed at the Mayak Chemical Combine's 400 t/yr RT-1 plant (Chelyabinsk-65) at Ozersk, near Kyshtym 70 km northwest of Chelyabinsk in the Urals. The original reprocessing plant at the site was hastily built in the mid 1940s, for military plutonium production in association with five producer reactors (the last shut down in 1990). The RT-1 plant started up in 1971 and employs the Purex process. It is reported to be running at about 100 t/yr capacity, following the loss of foreign contracts. About 93% of its feed is from Russian and Ukrainian VVER-440 reactors, about 3% from naval sources or icebreakers and 3% from BN-600. Recycled uranium is enriched to 2.6% U-235 by mixing RepU product from different sources and used in fresh RBMK fuel, while 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 and were to be completed in 2008. The 2009 federal program has it reaching 500 t/yr from 2012. Used 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 was to be dismantled. However, this may be under review and it could form part of the new Global Nuclear Infrastructure Initiative (see international section below). A 6000 tonne pool storage was built in 1985 and some VVER-1000 used fuel is stored there pending reprocessing. This RT-2 pool storage is planned to be refurbished. (A dual-purpose graphite-moderated reactor principally producing military plutonium, with associated underground reprocessing plant, is also there.)

Since 2004 an 8600 tonne dry storage facility for used fuel (INF DSF-2) has been under construction at Zheleznogorsk and this is due to be completed in 2010 at a cost of about US$ 500 million for the Mining & Chemical Combine (MCC). Initially it will take RBMK fuel from Leningrad and Kursk power plants. Further stages will take VVER-1000 fuel and increase capacity to 36,000 tonnes by 2016.

A small MOX fuel fabrication plant has operated at the Mayak plant at Ozersk since 1993. It can produce 40 fuel assemblies per year for fast reactors. A 60 t/yr commercial MOX fabrication plant is under construction at Zheleznogorsk (the site of the ADE2 military plutonium production reactor). 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 had the other two dual-purpose but basically military plutonium production reactors, totalling 2500 MWt. One of these - ADE4 - was shut down in April 2008, the other - ADE5 - in June 2008.)

No waste repository is yet available, though site selection is proceeding in granite on the Kola Peninsula. In 2003 Krasnokamensk in the Chita region 7000 km east of Moscow was suggested as the site for a major spent fuel repository. Then in 2008 the Nizhnekansky Rock Mass in Krasnoyarsk Territory was put forward as a site for a national deep geological repository. Rosatom said the terms of reference for the facility construction would be tabled by 2015 to start design activities and set up an underground rock laboratory. A decision on construction is due by 2025, and the facility itself is to be completed by 2035. Phase one of the facility is to be designed to hold 20,000 tonnes of intermediate- and high-level wastes, which will be retrievable.

Low- and Intermediate-level wastes are mostly handled similarly to those in other countries. Radon has been the organisation responsible for medical and industrial radioactive wastes. It has had 16 storage sites for wastes up to intermediate level. Not far outside Moscow, the major Radon facility has both laboratories and disposal sites. Other near-surface storage facilities were in 2008 planned for Sosnovy Bor, Glazov, Gatchina, Novovoronezh, Kirovochepetsk, Murmansk, Sarov, Saratov, Bilibino, Kransokamensk, Zelenogorsk, Seversk, Dimitrovgrad, Angarsk, and Udomlya. In 2010 RosRAO plans to draft a general scheme with locations of radwaste repositories (from both nuclear power plant operations and nuclear weapons disposal) to be set up by 2020-2035.

However, Russia has also for many years used deep-well injection for low- and intermediate-level wastes from some facilities, notably Seversk, Zelenogorsk and Dimitrovgrad. These are mainly wastes from reprocessing. A Central Europe review report in 1999 said that the wells ranged from 300 up to 1500 metres deep, and that Seversk was the main site utilising the method, with 30 million cubic metres injected. This practice has delayed Russian acceptance of an IAEA standard for radioactive waste disposal, since it has no packaging or engineered barriers and relies on the geology alone for safe isolation.

In 2008 there were tentative plans to build 4 to 6 regional waste repositories for low- and intermediate-level waste containing short-lived radionuclides in North-West, East-European, South Urals regions and in European South of Russia. For wastes containing long-lived radionuclides, establishing one or two repositories in Siberia and South Urals was envisaged.

Decommissioning

Five civil reactors are being decommissioned: an experimental 50 MWt LWGR type at Obninsk which started up in 1954 (% MWe), two early and small LWGR (AMB-100) units - Beloyarsk 1 & 2, and two larger prototype VVER-440 units at Novovoronezh, a V-210 and V-365 type. The last four were shut down 1981-90 and await dismantling. The fuel has been removed from these and that from Novovoronezh has been shipped to centralised storage in Zheleznogorsk and will be stored there for about ten years before reprocessing. The Beloyarsk fuel is still on site since reprocessing technology for it is not available.

At Novovoronezh 1 & 2 a decommissioning project with partial dismantling of equipment is being prepared and a licence is expected in 2010. Work will take several years, and buildings are likely to be re-used. In particular that portion of the site houses the district heating pumps and equipment, which provides 75% of the heat for the city, and a spare parts store for Energoatom.

In 2010 SC Rosatom plans to adopt a decommissioning concept for uranium-graphite plutonium production reactors. So far 12 out of 13 production reactors have been shut down at Mayak Chemical Combine at Ozersk (5), near Kyshtym, at Siberian Chemical Combine, Seversk (5, including ADE3, 4 & 5), and at Mining & Chemical Combine, Zheleznogorsk (3, including ADE1 & prospectively: ADE2). ADE2 was due to remain shut down after mid 2009, but was restarted for the 2009-10 heating season. The fuel has been removed from the shut-down reactors and nearly all of it has been reprocessed at Mayak and Seversk. The concept provides for building multiple safety barriers and sealing of shut-down reactors rather than their dismantling, at a cost estimated to be RUR 2 billion (US$ 67 million) each. All 13 are expected o be decommissioned by 2025.

Three nuclear powered icebreakers have been decommissioned: *Lenin*, *Sibir* and *Arktika,* also the support vessel: *Lepse* which holds some used nuclear fuel from the Arctic fleet. *Lenin* is being turned into a museum.

Several plutonium production reactors also remain to be decommissioned.

The government said it plans to spend some $5 billion to 2015 on decommissioning and waste management.

Organisation

The State Corporation (SC) Rosatom took over Russia's nuclear industry in 2007, from the Federal Atomic Energy Agency (FAEA, also known as Rosatom). This was formed from the Ministry for

Atomic Energy (Minatom) in 2004, which had succeeded a Soviet ministry in 1992. The civil parts of the industry, with a history of over 60 years, are consolidated under AtomEnergoProm (AEP).

During 2008 there has been a major reorganisation or "privatisation" of nuclear industry entities involving change from Federal State Unitary Enterprises (FSUE) to Joint Stock Companies (JSC), with most or all of the shares held by AtomEnergoProm. By mid August 2008, 38 of 55 civil nuclear FSUEs had been reformed. Some renaming occurred due to new restrictions on the use of "Russia" or derivatives (eg "Ros") in JSC names.

The State Nuclear Energy Corporation Rosatom (as distinct from the earlier Rosatom agency) is a non-profit company set up in 2007 to hold all nuclear assets on behalf of the state. In particular, it will hold all the shares in the civil holding company AtomEnergoProm (AEP). It took over the functions of the Rosatom agency and works with the Ministries of Industry and Energy (MIE) and of Economic Development and Trade (MEDT) but does not report to any particular ministry.

SC Rosatom divisions are:
- Nuclear defence
- Nuclear & Radiation Safety (now including Radon - see below)State Nuclear Energy Corporation Rosatom
- Nuclear Power - Atomenergoprom
- Research & Training
- Atomflot - Arctic fleet of 7 nuclear icebreakers and one nuclear merchant ship.

AtomEnergoProm is the single vertically-integrated state holding company for Russia's nuclear power sector, separate from the military complex. It was set up at the end of 2007 to include uranium production, engineering, design, reactor construction, power generation and research institutes in its several branches, but not used fuel reprocessing or disposal facilities for the time being. The April 2007 Presidential decree establishing it specifies nuclear materials, which may be owned exclusively by the state, lists Russian legal entities allowed to possess nuclear materials and facilities, existing joint stock companies to be incorporated into the Atomenergoprom, and lists federal state unitary enterprises to be corporatized first and incorporated into the Atomenergoprom at a later stage. Exclusive state ownership of nuclear materials had been seen as a barrier to competitiveness and other Russian corporate entities will now be allowed to hold civil-grade nuclear materials, under state control.

Entities from Atomenergoprom itself down to various third-level subsidiaries will be joint stock companies eventually. Public investment in the bottom level operations is envisaged - the joint venture between Alstom and Atomenergomash to provide large turbines and generators is cited as an example.

JSC AtomEnergoProm's entities include the following (most are JSCs):

- ARMZ Uranium Holding Co (formerly AtomRedMetZoloto) – uranium production – owns Russian mine assets and foreign JV shares

- Technabexport (Tenex) - foreign trade in uranium products and services,

- JSC Enrichment & Conversion Complex,

- TVEL - nuclear fuel fabrication,
- St Petersburg Atomenergoproekt - power plant design,

- Moscow Atomenergoproekt (AEP) - power plant design,
- Nizhny-Novgorod Atomenergoproekt (AEP) - power plant design,
- VNIPIET – design of nuclear power projects,
- Atomstroyexport (ASE) - construction of nuclear plants abroad.
- Energospetsmontazh – construction and assembly, also repair of nuclear plants,
- Atomenergomash (AEM) - a group of companies building reactors,
- OKBM Afrikantov (formerly just OKBM - Experimental Design Bureau of Machine-building - Mashinostroyeniya) at Nizhny Novgorod- reactor design and construction,
- OKB Gidropress (Experimental Design Bureau pressurised water - Hydropress) at Podolsk near Moscow - PWR reactor design,
- Energoatom (formerly Rosenergoatom) - responsible for construction and operation of nuclear power generation,
- Atomenergoremont – maintenance and upgrading of nuclear power plants
- Research & Development Institute for Power Engineering (NIKIET) at Moscow - power plant design (originally: submarine power plants)

Atomstroyexport (ASE), established by merger in 1998, emerged from the reorganisation as a closed joint stock company owned by Atomenergoprom (50.2%) and Gazprombank (49.8%, it is 69% owned by Gazprom). Early in 2009 the Atomenergoprom and related equity was increased to 89.3% by additional share issue, leaving Gazprombank with 10.7%. It is responsible for export of nuclear plants to China, Iran, India and Bulgaria. In 2009 NUKEM Technologies GmbH, which specialises in decommissioning, waste management and engineering services, became a 100% subsidiary of Atomstroyexport.

InterRAO was formerly a joint venture of Rosenergoatom and RAO UES, the utility which was broken up in mid 2008. It is now 57.3% owned by Rosatom and focused on electricity generation in areas such as Armenia and the Kaliningrad part of Russia, as an exporter and importer of electricity. It has 8 GWe of generating plant of its own and plans to increase this to 30 GWe by 2015, with the Baltic nuclear plant at Kaliningrad as an early priority.

In July 2008 the divisions of Atomernergoproekt were converted to joint stock companies, with all shares held by Atomenergoprom. St Petersburg Atomenergoproekt works closely with Atomstroyexport (ASE) on exported plants and is responsible for Leningrad II plant under construction.

Nizhny-Novgorod AEP is building plants at Volgodonsk and Kalinin, where it has linked with ASE to utilize some 1980s VVER equipment not required for Bulgaria's new Belene plant. Moscow AEP is building Novovoronezh (though some reports NN AEP is involved there).

Rostechnadzor is the regulator, set up (as GAN) in 1992, reporting direct to the President. 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, being 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 in the 1990s, Minatom successfully overrode this. In 2004 GAN was renamed the Federal Technological & Atomic Supervisory Service: Rostechnadzor.

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. Also, up until 2001 many employees received annual radiation doses of over 20 mSv, but since 2002 very few have done so.

Rosatom's national enterprise for radioactive waste management, RosRAO, commenced operation in 2009 under a temporary arrangement. It incorporates Radon, and now has branches in each of seven federal districts. 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.

UES was the electricity monopoly and also operated fossil fuel power stations, but it has now been broken up.

The former main nuclear fabrication company, Atommash, was established in 1973 at Volgodonsk and went bankrupt in 1995. It was then profoundly restructured and resurrected as EMK-Atommash before becoming part of JSC Energomash, a major diversified engineering company apparently independent of Rosatom/AEP. Atommash has now largely moved away from nuclear equipment, though Atomenergomash (part of AEP) is reported to be keen to resuscitate it as an alternative heavy equipment supplier to OMZ. In 2009 Atomenergomash was doing due diligence on the Energomash group, apparently with a view to taking a half share in it, "to create competition in the segment of monopoly suppliers of long-lead nuclear equipment."

Objedinennye Mashinostroitelnye Zavody (OMZ - Uralmash-Izhora Group) itself is the largest heavy industry company in Russia, and has a wide shareholding. Izhorskiye Zavody, the country's main reactor component supplier, became part of the company in 1999, and Skoda Steel and Skoda JS in Czech Republic joined in 2003. OMZ is expected to produce the forgings for all new domestic AES-2006 model VVER-1200 nuclear reactors (four per year from 2016), plus exports. At present Izhora can produce the heavy forgings required for Russia's VVER-1000 reactors at the rate of two per year, and it is manufacturing components for the first two Leningrad II VVER-1200 units.

The Power Machines Company (JSC Silovye Mashiny Concern, or Silmash) was established in 2000 and brought together a number of older enterprises including Leningradsky Metallichesky Zavod - LMZ, Elektrosila, Turbine Blades Factory, etc. Siemens holds 26% of the stock. Silmash makes steam turbines up to 1200 MWe, including the 1000 MWe turbines for Atomstroyexport projects in China, India and Iran, and has supplied equipment to 57 countries worldwide. It is making 1200 MWe turbine generators for the Leningrad and Novovoronezh II nuclear plants. A significant amount of Power Machines' business is in Asia.

The Russian EnergyMachineBuilding Company (REMCO) was established as a closed joint stock company in Russia in 2008, amalgamating some smaller firms, with half the shares owned by Atomenergomash. It is one of the largest manufacturers of complex heat-exchange equipment for nuclear and thermal power plants, oil and gas industry. Its subsidiaries include JSC Machine-Building Plant ZiO-Podolsk and JSC Engineering Company ZIOMAR.

JSC Machine Building Plant ZiO-Podolsk is one of the largest manufacturers designing and producing equipment for nuclear power and other plants. It has made equipment, including steam generators and heat exchangers, for all nuclear plants in the former USSR. It is increasing capacity to four nuclear equipment sets per year. It appears to be 51% owned by REMCO. It is making the reactor pressure vessel and other main equipment for the BN-800 fast reactor at Beloyarsk as well as steam generators for Novovoronezh, Kalinin-4, Leningrad and Belene.

Centrifuges for China under a US$ 1 billion contract are manufactured at both Tocmash and Kovrov Mechanical plant, both of which will become part of the Fuel Company being established by TVEL.

For more up to date information on heavy engineering, see paper on Heavy Manufacturing of Power Plants .

Early in 2006 Rosenergoatom set up a subsidiary to supply floating nuclear power plants (BNPPs) ranging in size from 70 to 600 MWe. The plants are designed by OKBM in collaboration with others. The pilot plant, now under construction, is 70 MWe plus heat output and incorporates two KLT-40S reactors based on those in icebreakers.

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 $1.6 billion in other goods and services. Exports were US$ 2.5 billion in 2001 and and rose to $3.5 billion in 2004. In 2006 they were again US$ 3.5 billion. Russia provides nearly one third of European uranium needs and is also selling diluted ex-military uranium for civil use through USA.

The latter "Megatonnes to Megawatts" program supplies about 15% of world reactor requirements for enriched uranum and is part of a US$ 12 billion deal between US and Russian governments, with a non-proliferation as well as commercial rationale. However, Rosatom confirmed in mid 2006 that no follow-on program of selling Russian high-enriched uranium from military stockpiles was anticipated once this program concludes in 2013. The 20-year program is equivalent to about 153,000 tonnes of natural uranium.

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

In May 2009 Tenex signed long-term enrichment services contacts with three US utilities - AmerenUE, Luminant and Pacific Gas & Electric - and one in Japan - Chubu. The contracts cover supply from 2014 to 2020. Then in June it signed a contract for supply of enriched uranium product over the same period with Exelon, the largest US nuclear utility.

It was also pushing ahead with plans to store and probably reprocess foreign spent fuel, and earlier the Russian parliament overwhelmingly supported a change in legislation to allow this. The proposal involved 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 (essentially an export of services, since Russia would be paid for it).

The President also set up a special commission to approve and oversee any spent fuel accepted, with five members each from the Duma, the Council, the government and presidential nominees, chaired by Dr Zhores Alferov, a parliamentarian, Vice-President of the Russian Academy of Sciences and Nobel Prize physicist. This scheme was progressed in 2005 when the Duma ratified the Vienna Convention on civil liability for nuclear damage. However in July 2006 Rosatom announced it would not proceed with taking any foreign-origin used fuel, and the whole scheme lapsed.

Atomstroyexport (ASE) has three reactor construction projects abroad, all involving VVER-1000 units. First, it took over building a reactor 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 to China for Jiangsu Tianwan at Lianyungang (both now operating) and two AES-92 units to India for Kudankulam (under construction, start-up due in 2010). It is likely that ASE will build a second unit at Bushehr and agreements have been signed for two more at Tianwan in China, units 5 & 6 being VVER-1200 type. In 2007 a memorandum of understanding was signed to build four VVER-1200 units at Kudankulam (reaffirmed early in 2008). In 2009 four more were confirmed for Haripur in West Bengal.

An intergovernmental agreement to construct a nuclear power plant and give a loan to Belarus is planned for signature in the first half of 2010. All preparatory work near Ostrovets in Grodno Region been completed on schedule to allow commissioning of the two reactors in 2016 and 2018. It will be a 2400 MWe AES-2006 plant developed by SPb AEP based on AES-91 design. Atomstroyexport will the principal construction contractor.

Russia's policy for building nuclear power plants in non-nuclear weapons states is to deliver on a turnkey basis including supply of all fuel and repatriation of used fuel for the life of the plant. Evidently India is being treated as a weapons state, since Russia will supply all the enriched fuel for Kudankulam, but India will reprocess it and keep the plutonium.

When China called for competitive bids for four large third-generation reactors to be built at Sanmen and Yangjiang, ASE unsuccessfully bid the AES-92 power plant for these.

In October 2006 its bid for two AES-92 units for Belene was accepted by Bulgaria. ASE leads a consortium including Areva NP and Bulgarian enterprises in the EUR 4.0 billion project.

ASE is reported to be under consideration by Fortum to supply Finland's sixth nuclear power reactor if it is built at Loviisa. It is also considered a leading contender to build two large reactors in Belarus, and despite disagreements over 2009-10 is likely to build the first of a series of small reactors (probably VBER-300) in Kazakhstan.

A potentially wide-ranging memorandum of understanding with Enel of Italy is for cooperation on nuclear power projects in Eastern and Central Europe (where Enel has a major presence), using Russian technology. Most of these export prospects bring ASE into direct competition with western reactor vendors.

Since 2006 Rosatom has actively pursued cooperation deals in South Africa, Namibia, Chile and Morocco as well as with Egypt, Algeria, Vietnam and Bangladesh. Tenex has also entered agreements to mine and explore for uranium in South Africa (with local companies) and Canada (with Cameco).

In September 2008 ARMZ signed a MOU with a South Korean consortium headed by Kepco on strategic cooperation in developing uranium projects. This includes joint exploration, mining and sales of natural uranium in the Russian Federation and possibly beyond.

In February 2008 ASE formed an alliance with TechnoPromExport (TPE), an exporter of all other large-scale power generation types. This will rationalize their international marketing. TPE boasts of having completed 400 power projects in 50 countries around the world totalling some 87 GWe.

International 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.

President Putin's Global Nuclear Infrastructure Initiative was announced early in 2006. This is in line with the International Atomic Energy Agency (IAEA) 2005 proposal for Multilateral Approaches to the Nuclear Fuel Cycle (MNA) and with the US Global Nuclear Energy Partnership (GNEP). The head of Rosatom said that he envisages Russia hosting four types of international nuclear fuel cycle service centres (INFCCs) as joint ventures financed by other countries. These would be secure and maybe under IAEA control. The first is an International Uranium Enrichment Centre (IUEC) - one of four or five proposed worldwide (see separate section). The second would be for reprocessing and storage of used nuclear fuel. The third would deal with training and certification of personnel, especially for emerging nuclear states. In this context there is a need for harmonized international standards, uniform safeguards and joint international centers. The fourth would be for R&D and to integrate new scientific achievements.

In March 2008 AtomEnergoProm signed a general framework agreement with Japan's Toshiba Corporation under which they will explore collaboration in the civil nuclear power business. The Toshiba partnership is expected to include cooperation in areas including design and engineering for new nuclear power plants, manufacturing and maintenance of large equipment, and "front-end civilian nuclear fuel cycle business". In particular the construction of an advanced Russian centrifuge enrichment plant in Japan is envisaged, also possibly one in the USA. The companies say that the "complementary relations" could lead to the establishment of a strategic partnership. Toshiba owns 77% of US reactor builder Westinghouse and is also involved with other reactor technology.

Regarding reactor design, Rosatom is keen to be involved in international projects for Generation IV reactor development and is keen to have international participation in fast neutron reactor development, as well as joint proposals for MOX fuel fabrication. In April 2007 Red Star, a government-owned design bureau, and US company Thorium Power agreed to collaborate on testing Thorium Power's seed and blanket fuel assemblies at the Kurchatov Institute with a view to using thorium-based fuel in VVER-1000 reactors. (see Thorium paper for details)

In 2006 the former working relationship with Kazakhstan in nuclear fuel supplies was rebuilt. Kazatomprom has agreed to a major long-term program of strategic cooperation with Russia in uranium and nuclear fuel supply, as well as development of small reactors, effectively reuniting the two countries' interests in future exports of nuclear fuel to China, Japan, Korea, the USA and Western Europe.

In April 2007 a joint venture company to manufacture the turbine and generator portions of new nuclear power plants was announced by French engineering group Alstom and JSC Atomenergomash. The 49:51 **Alstom Atomenergomash** LLC joint venture, in which both parties will invest EUR 200 million, is established at Podolsk, near Moscow. It includes the technology transfer of Alstom's state of the art Arabelle steam turbine and generator (available up to 1750

MWe). First production is expected in 2011 with output reaching three 1200 Me turbine and generator sets per year in 2013.

In September 2007 Mitsubishi Heavy Industries (MHI) signed an agreement with Russia's Ural Turbine Works (UTZ) to manufacture, supply and service gas and steam turbines in the Russian market. Under the agreement, MHI, Japan's biggest machinery maker, will license its manufacturing technologies for large gas turbines and steam turbines to UTZ - part of the Renova Group. The agreement also calls for a joint venture to be established in Russia to provide after-sales service.

Research & Development

Russia has had substantial R&D on nuclear power for six decades. The premier establishment for this is the Kurchatov Institute in Moscow, which has run twelve research reactors there, six of which are now shut down. The F-1 research reactor there was started up in December 1946 and recently marked its 60th anniversary in operation.

Many research reactors were constructed in the 1950s and 60s. In 1998 more than 60 non-military research and test reactors were operational in Russia, plus three in former Soviet republics and eight Russian ones elsewhere. Most of these use ceramic fuel enriched to 36% or 90% U-235.

In 1954 the world's first nuclear powered electricity generator began operation in the then closed city of Obninsk at the Institute of Physics and Power Engineering (FEI). The AM-1 (Atom Mirny -- peaceful atom) reactor is water-cooled and graphite-moderated, with a design capacity of 30 MWt or 5 MWe. It was similar in principle to the plutonium production reactors in the closed military cities and served as a prototype for other graphite channel reactor designs including the Chernobyl-type RBMK (reaktor bolshoi moshchnosty kanalny -- high power channel reactor) reactors. AM-1 produced electricity until 1959 and was used until 2000 as a research facility and for the production of isotopes.

Also in the 1950s the FEI at Obninsk was developing fast breeder reactors (FBRs). In 1955 the BR-1 (bystry reaktor -- fast reactor) fast neutron reactor began operating. It produced no power but led directly to the BR-5 which started up in 1959 with a capacity of 5 MWt which was used to do the basic research necessary for designing sodium-cooled FBRs. It was upgraded and modernised in 1973 and then underwent major reconstruction in 1983 to become the BR-10 with a capacity of 8 MWt which is now used to investigate fuel endurance, to study materials and to produce radioisotopes.

Russia's State Scientific Centre - Research Institute of Atomic Reactors (RIAR), said to be the biggest nuclear research centre in Russia, is in Dimitrovgrad, in Ulyanovsk county 1300 km SE of Moscow. It was founded in 1956 and researches fuel cycle, radiochemicals and radioactive waste management, as well as producing radionuclides for medicine and industry. The BOR-60 fast reactor is operated here by RIAR, along with five other research reactors. It started up in 1969 and is to be replaced about 2015 with a 100 MW sodium-cooled fast reactor - MBIR. This will be a research reactor capable of testing lead, lead-bismuth and gas coolants as well as sodium, and running on MOX fuel. RIAR intends to set up an on-site closed fuel cycle, using pyrochemical reprocessing it has developed at pilot scale.

In 2009 the Moscow Engineering and Physics Institute (MEPhI) was renamed the National Research Nuclear University and reformed to incorporate a number of other educational establishments. While partly funded by Rosatom, it is the responsibility of the Federal Education Agency (Rosobrazovaniye).

In mid 2009 the Russian government said that it would provide more than RUR 120 billion (about US$3.89 billion) over 2010 to 2012 for a new program devoted to R&D on the next generation of nuclear power plants. It identified three priorities for the nuclear industry: improving the performance of light water reactors over the next two or three years, developing a closed fuel cycle based on deployment of fast reactors in the medium term, and developing nuclear fusion over the long term.

In 2010 the government is to allocate RUR 500 million (about US$ 170 million) of federal funds to design a space nuclear propulsion and generation installation in the megawatt power range. In particular, SC Rosatom is to get RUR 430 million and Roskosmos (Russian Federal Space Agency) RUR 70 million to develop it. The work will be undertaken by NIKIET (Research & Development Institute for Power Engineering) in Moscow, based on previous developments including those of nuclear rocket engines. A conceptual design is expected in 2011, with the basic design documentation and engineering design to follow in 2012. Tests are planned for 2018.

Public Opinion

An April 2008 survey carried out by the Levada Centre found that 72% of Russians were in favour of at least preserving the country's nuclear power capacity and 41% thought that nuclear was the only alternative to oil and gas as they deplete. Over half said that they were indignant about Soviet attempts to cover up news of the Chernobyl accident in 1986.

Non-proliferation

Russia is a nuclear weapons state, and a depository state of the Nuclear Non-Proliferation Treaty (NPT) under which a safeguards agreement has been in force since 1985. The Additional Protocol was ratified in 2007. However, Russia takes the view that voluntary application of IAEA safeguards are not meaningful for a nuclear weapons state and so they are not generally applied. One exception is the BN-600 Beloyarsk-3 reactor which is safeguarded so as to give experience of such units to IAEA inspectors.

However, this policy is modified in respect to some uranium imports. All facilities where imported uranium under certain bilateral treaties goes must be on the list of those eligible and open to international inspection, and this overrides the voluntary aspect of voluntary offer agreements. It includes conversion plants, enrichment, fuel fabrication and nuclear power plants. Also the IUEC at Angarsk will be open to inspection.

Russia undertook nuclear weapons tests from 1949 to 1990.

Russia's last plutonium production reactor which started up in 1964 is due to be closed down in May 2009 - delayed because it also provides district heating, and replacement plant for this will not be ready until then. The reactor will be held in reserve for heating, not decommissioned. The other two such production reactors were closed in 2008. All three closures are in accordance with a 2003 US-Russia agreement.

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.

Appendix:

Background: Soviet nuclear culture

In the 1950s and 1960s 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 light water cooled graphite moderated reactor - RBMK), and one from naval propulsion units, very much as in USA (the VVER series - pressurised, water cooled and moderated). 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 had been set up to produce eight sets of nuclear plant equipment each year (reactor pressure vessels, steam generators, refueling machines, pressurizers, service machinery – a total of 250 items). In 1981 it manufactured the first VVER-1000 pressure vessel, which was shipped to South Ukrainian NPP. Later, its products were supplied to Balakovo, Zaporozhie, Smolensk, Kalinin, Rovno and Khmelnitsky plants. By 1986 Atommash had produced 14 pressure vessels (of which five have remained at the factory), instead of the eight per year intended. Then Chernobyl put the whole nuclear industry into a long standby. 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.

An early indication of the technological carelessness was substantial pollution followed by a major accident at Mayak Chemical Combine (then known as Chelyabinsk-40) near Kyshtym in 1957. The failure of the cooling system for a tank storing many tonnes of dissolved nuclear waste resulted in a non-nuclear explosion having a force estimated at about 75 tonnes of TNT (310 GJ). This killed 200 people and released some 740 PBq of radioactivity, affecting thousands more. Up to 1951 the Mayak plant had dumped its wastes into the Techa river, whose waters ultimately flow into the Ob River and Arctic Ocean. Then they were disposed of into Lake Karachay until at least 1953, when a storage facility for high-level wastes was built - the source of the 1957 accident. Finally, a 1967 duststorm picked up a lot of radioactive material from the dry bed of Lake Karachay and deposited it on to the surrounding province. The outcome of these three events made some 26,000 square kilometres the most radioactively-polluted area on Earth by some estimates, comparable with Chernobyl.

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 contributed strongly to huge gains in safety and reliability of Soviet-era nuclear plants - WANO having come into existence as a result of Chrnobyl. 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.

In March 2007 Russia signed a cooperation declaration with the OECD's Nuclear Energy Agency (NEA), bringing it much more into the mainstream of world nuclear industry development. Russia has been participating for some years in the NEA's work on reactor safety and nuclear regulation and is hosting an NEA project on reactor vessel melt-through. This agreement is expected to assist Russia's integration into the OECD.

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