Russian Nuclear Power Program  
(past, present, and future)

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CRL AECL
# Nuclear Power Units by Nation

<table>
<thead>
<tr>
<th>No.</th>
<th>Nation</th>
<th># Units</th>
<th>Net MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>104</td>
<td>100,460</td>
</tr>
<tr>
<td>2</td>
<td>France</td>
<td>59</td>
<td>63,363</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>53</td>
<td>45,218</td>
</tr>
<tr>
<td>4</td>
<td>Russia</td>
<td>31</td>
<td>20,843</td>
</tr>
<tr>
<td>5</td>
<td>Germany</td>
<td>18</td>
<td>20,643</td>
</tr>
<tr>
<td>6</td>
<td>Canada</td>
<td>22</td>
<td>15,222</td>
</tr>
<tr>
<td>7</td>
<td>S. Korea</td>
<td>19</td>
<td>15,850</td>
</tr>
<tr>
<td>8</td>
<td>Ukraine</td>
<td>15</td>
<td>13,200</td>
</tr>
<tr>
<td>9</td>
<td>UK</td>
<td>23</td>
<td>11,852</td>
</tr>
</tbody>
</table>
Russia’s Achievements

- NPPs – 16% of the total electricity production in Russia
- 2 VVER-1000 were recently put into operation in Ukraine
- 3 VVER-1000 to be commissioned before 2011 in Russia
- 1 BN-800 to be commissioned after 2011 in Russia
- 2 VVER-1000 under construction in China, 2 – in India, 1 – in Iran
- Fuel services to 76 power reactors in 13 countries (17% of global market)
- Over 40% of global enrichment services are of Russian origin, centrifuge enrichment plants with a total capacity of 15,000 tSWU/year
- Russia delivered to US 7,350 t of LEU = 250 t HEU = irreversible dismantling of about 10,000 warheads
- Facilities for HLRAW vitrification and storage
Milestones

• 1948 First Russian production reactor
• 1951 Production reactor
• 1954 Two options studied for production of weapons-grade plutonium and electrical energy:
  1) RBMK – water-cooled graphite moderated pressure-tube reactors;
  2) VVER – water-cooled water-moderated pressure-vessel reactors;
RBMK won the race as a dual-purpose reactor
1954 First NPP, IPPE, Obninsk (100 km from Moscow), 1 unit, 5 MW, water-cooled graphite moderated pressure-tube reactor (prototype of RBMK)
1954  First Russian nuclear transport reactor design for submarine (RDIPE, Moscow)
1958  Put into operation
1955  First fast reactor BR-1 (prototype of BN-350, BN-600), IPPE, Obninsk

1957  Explosion of a large reservoir with liquid HLRAW (Chelyabinsk, Ural Mountains) resulted in high-level radioactive contamination of very large areas. This accident is comparable with the Chernobyl’s disaster.

1958  Second NPP - Siberian NPP, Tomsk-7, 100 MW;
1961  Multipurpose ADE-3 reactor, Tomsk-7, production of plutonium, electrical energy and heat; Third NPP, Reactor ADE-1, Krasnoyarsk-26, Siberia
Pulse graphite reactor (RDIPE, Moscow)

1963  ARBUS Antarctic modular NPP

1964  Fourth NPP, Beloyarsk, 100 MW, nuclear steam superheating from 300°C to 510°C

1968  Modular NPP for the world’s fastest nuclear submarine “Papa”
High-Temperature Nuclear Reactors for Space Applications
Topaz-1 space thermionic nuclear power unit
1972 Desalination Installation Using BN-350 Reactor Aktau (Kazakhstan)
1975  Research reactor for testing nuclear rocket engine components (RDIPE, Moscow)

1977- 1983  Chernobyl NPP, 4 RBMK-1000

1983 - 1987  Ignalina NPP, 2 RBMK-1500

1986  Chernobyl disaster (April 26)

1988  International Project on Experimental Thermonuclear Reactor ITER
Nuclear Power Plants and Research Reactors Built to NIKIET Designs or with the Institute’s Participation
Russian NPPs
General Overview
## Russian Operating NPPs

<table>
<thead>
<tr>
<th>#</th>
<th>NPP</th>
<th>Reactor</th>
<th>Unit #</th>
<th>Year</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Novovoronezh</td>
<td>VVER-440 VVER-1000</td>
<td>3, 4</td>
<td>1971, 1972</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1980</td>
</tr>
<tr>
<td>2</td>
<td>Kola</td>
<td>VVER-440</td>
<td>1, 2, 3, 4</td>
<td>1973, 1974, 1981, 1984</td>
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<tr>
<td>3</td>
<td>Leningrad</td>
<td>RBMK-1000</td>
<td>1, 2, 3, 4</td>
<td>1973, 1975, 1979, 1981</td>
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<tr>
<td>4</td>
<td>Bilibino</td>
<td>EGP-6 (12 MW)</td>
<td>1, 2, 3, 4</td>
<td>1974, 1974, 1975, 1976</td>
</tr>
<tr>
<td>5</td>
<td>Kursk</td>
<td>RBMK-1000</td>
<td>1, 2, 3, 4</td>
<td>1976, 1979, 1983, 1985</td>
</tr>
<tr>
<td>6</td>
<td>Beloyarsk</td>
<td>BN-600</td>
<td>3</td>
<td>1980</td>
</tr>
<tr>
<td>7</td>
<td>Smolensk</td>
<td>RBMK-1000</td>
<td>1, 2, 3</td>
<td>1982, 1985, 1990</td>
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<tr>
<td>8</td>
<td>Kalinin</td>
<td>VVER-1000</td>
<td>1, 2, 3</td>
<td>1984, 1986, 2004</td>
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<tr>
<td>9</td>
<td>Balakovo</td>
<td>VVER-1000</td>
<td>1, 2, 3, 4</td>
<td>1985, 1987, 1988, 1993</td>
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<tr>
<td>10</td>
<td>Volgodonsk</td>
<td>VVER-1000</td>
<td>1</td>
<td>2001</td>
</tr>
<tr>
<td>Действующие АЭС NPPs in Operation</td>
<td>BBЭР-440 VVER-440</td>
<td>BBЭР-1000 VVER-1000</td>
<td>РБМК-1000 RBMK-1000</td>
<td>БН-600 BN-600</td>
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<tr>
<td>----------------------------------</td>
<td>-------------------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------------</td>
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<tr>
<td>Количество блоков Number of Units</td>
<td>6</td>
<td>8</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>MBt (ел.) MW (el.)</td>
<td>2 594</td>
<td>8 000</td>
<td>11 000</td>
<td>600</td>
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<tr>
<td>АЭС с реакторами NPP with reactors</td>
<td>2002, %</td>
<td>2003, %</td>
<td>Максимальный Maximal</td>
<td>Минимальный Minimal</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>----------------------</td>
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<tr>
<td><strong>ВВЭР VVER</strong></td>
<td>77,82</td>
<td>79,55</td>
<td>86,60 Наличнинская АЭС Halinin NPP</td>
<td>64,33 Кольская АЭС Hola NPP</td>
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<tr>
<td><strong>РБМК и несерийные блоки RBMK and non-commercial reactors</strong></td>
<td>66,20</td>
<td>73,30</td>
<td>83,47 Смоленская АЭС Smolensk NPP</td>
<td>37,66 Билибинская АЭС Bilbino NPP</td>
</tr>
<tr>
<td><strong>Всего Total</strong></td>
<td>71,73</td>
<td>76,28</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>
Kalinin NPP. VVER-1000 Reactor Hall
Smolensk NPP. RBMK-1000 Reactor Hall
Kursk NPP. Turbines/Generators Hall
Kola NPP. 4 VVER-440 Reactors (beyond the Polar circle)
Kursk NPP. 4 RBMK-1000
Chernobyl NPP. RBMK-1000 Unit 4
The Greatest Disaster in Nuclear Industry
April 26, 1986, Ukraine (130 km from Kiev)
(Explosion, evacuation, empty villages, cleaning debris with robot and manually, building sarcophagus)
ЧЕРНОБЫЛЬ. 29.IV.86 К 7 ЧАС.

[Image of rabbits in an empty street with text in Russian]
Russian Power Reactors Operating Abroad

- Armenia - 1 VVER-440 (1980)
- Lithuania – 1 RBMK-1500 (1987)

In total: 26 VVERs
Russian Power Reactors
Principle Schemes and Major Parameters
Reactor EGP-6 – Electricity to the consumer

Steam drum

Turbine

Generator

Transformer

Turbine

Generator

Transformer

Suez

Control rods

Fuel

Mixing unit

Condenser

Circulation pump

User of heat

Graphite moderator

Feedwater pump

Air condensing plant

Woolcondenzation unit

Steam drum

Turbine

Generator

Transformer

Suez

Control rods

Fuel
Реактор РВМК – отпуск электроэнергии потребителю

Reactor RBMK – Electricity to the consumer

Steam drum

Control rods

Fuel

Main coolant pump

Graphite moderator

Turbine

Generator

Transformer

Cooling water pond

Circulation pump

Feedwater pump
Reactor VVER – Electricity to the consumer

- СУЗ: Control rods
- Парогенератор: Steam generator
- ТУРБИНА: Turbine
- ГЕНЕРАТОР: Generator
- ТРАНСФОРМАТОР: Transformer
- Пруд-охладитель: Cooling water pond
- ГЦН: Main coolant pump
- Конденсатор: Condenser
- Циркуляционный насос: Circulation pump
- Питательный насос: Feedwater pump
- Топливо: Fuel
- Корпус реактора: Reactor vessel
Reactor BN-600 – Electricity to the consumer

- Control rods
- Steam generator
- Turbine
- Generator
- Condenser
- Main coolant pump of the secondary circuit
- Feedwater pump
- Cooling water pond
- Transformer
## Major Parameters of Russian Power Reactors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VVER-440</th>
<th>VVER-1000</th>
<th>EGP-6</th>
<th>RBMK-1000</th>
<th>RBMK-1500</th>
<th>BN-600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power, MW</td>
<td>1375</td>
<td>3000</td>
<td>62</td>
<td>3200</td>
<td>4800</td>
<td>1470</td>
</tr>
<tr>
<td>Electrical power, MW</td>
<td>440</td>
<td>1000</td>
<td>12</td>
<td>1000</td>
<td>1500</td>
<td>600</td>
</tr>
<tr>
<td>Thermal efficiency, %</td>
<td>32.0</td>
<td>33.0</td>
<td>-</td>
<td>31.3</td>
<td>31.3</td>
<td>-</td>
</tr>
<tr>
<td>Coolant pressure, MPa</td>
<td>12.3</td>
<td>15.7</td>
<td>6.2</td>
<td>6.9</td>
<td>6.9</td>
<td>-</td>
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<tr>
<td>Coolant flow, t/h</td>
<td>40,800</td>
<td>84,800</td>
<td>600</td>
<td>48,000</td>
<td>32,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Coolant temperature, °C</td>
<td>270/298</td>
<td>290/322</td>
<td>265</td>
<td>284</td>
<td>284</td>
<td>550/520</td>
</tr>
<tr>
<td>Steam flow rate, t/h</td>
<td>2700</td>
<td>5880</td>
<td>96</td>
<td>5600</td>
<td>-</td>
<td>660</td>
</tr>
<tr>
<td>Steam pressure, MPa</td>
<td>4.3</td>
<td>5.9</td>
<td>6.0</td>
<td>6.6</td>
<td>6.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Steam temperature, °C</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>280</td>
<td>280</td>
<td>505</td>
</tr>
<tr>
<td>Core: D/H m/m</td>
<td>3.8/11.8</td>
<td>4.5/10.9</td>
<td>-</td>
<td>-</td>
<td>11.8/7</td>
<td>2.1/0.75</td>
</tr>
<tr>
<td>Fuel enrichment, %</td>
<td>3.6</td>
<td>4.3</td>
<td>3.0-3.6</td>
<td>2.0-2.4</td>
<td>2.0</td>
<td>17-33</td>
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<tr>
<td>No. of fuel assemblies</td>
<td>349</td>
<td>163</td>
<td>273</td>
<td>1580</td>
<td>1661</td>
<td>369</td>
</tr>
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</table>
Future Developments

- Replacement for RBMK-1000 – MKER-800, 1000 and 1500
- Replacement for VVER-1000 – VVER-1500
- Replacement for BN-600 – BN-800, 1800
- Lead-cooled fast reactors BREST-300, 1200
- Lead-bismuth cooled modular fast reactor
- Gas-cooled modular helium reactor
- Modular NPPs – UNITERM
- Floating NPPs with integral reactors “NIKA-70”
- Supercritical water-cooled reactors: thermal - 800 and 1200 MWe and fast – 1200 MWe
- Developing thermonuclear (fusion) reactor ITER
MKER-1000

1 reactor core
2 water pipes
3 downcomer
4 steam-water pipes
5 steam separator
6 steam pipe
7 passive-cooling system
8 refuelling machine
9 bridge crane
10 containment
Naturally safe lead-cooled fast reactor BREST-300

1 core
2 concrete shaft
3 steam generator
4 pump
5 vessel
6 control and protection systems
7 thermal insulation
Our Collaboration with Russia on Supercritical Water-Cooled Nuclear Reactors
Multiple products are key to sustainable future and competitive designs

- Sustainable Fuel input
- Electric power
- Hydrogen and process heat
- Drinking water
- Industrial isotopes

- Pump
- Generator
- Turbine
- Core
- Heat for Co-Generation or IP/LP Turbines
- Brine
# Modern Concepts of Pressure-Channel SCW Reactors

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>CANDU</th>
<th>ChUWR</th>
<th>KP-SKD</th>
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<tbody>
<tr>
<td><strong>Country</strong></td>
<td>-</td>
<td>Canada</td>
<td>Russia (RDIPR)</td>
<td></td>
</tr>
<tr>
<td><strong>Spectrum</strong></td>
<td>-</td>
<td>Thermal</td>
<td>Thermal</td>
<td>Fast</td>
</tr>
<tr>
<td><strong>Power electr.</strong></td>
<td>MW</td>
<td>1140</td>
<td>1200</td>
<td>1200</td>
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<tr>
<td><strong>Thermal eff.</strong></td>
<td>%</td>
<td>45</td>
<td>44</td>
<td>43</td>
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<tr>
<td><strong>Pressure</strong></td>
<td>MPa</td>
<td>25</td>
<td>24.5</td>
<td>25</td>
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<tr>
<td><strong>$T_{\text{coolant}}$</strong></td>
<td>C</td>
<td>350-625</td>
<td>270-545</td>
<td>400-550</td>
</tr>
<tr>
<td><strong>Flow rate</strong></td>
<td>kg/s</td>
<td>1320</td>
<td>1020</td>
<td>-</td>
</tr>
<tr>
<td><strong>Core H/D</strong></td>
<td>m/m</td>
<td>4/-</td>
<td>6/12</td>
<td>3.5/11</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>-</td>
<td>UO$_2$/Th</td>
<td>UCG</td>
<td>MOX</td>
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<tr>
<td><strong>Enrichment</strong></td>
<td>% .wt.</td>
<td>4</td>
<td>4.4</td>
<td>-</td>
</tr>
<tr>
<td><strong>$T_{\text{max cladding}}$</strong></td>
<td>C</td>
<td>850</td>
<td>630</td>
<td>650</td>
</tr>
<tr>
<td><strong>Moderator</strong></td>
<td>-</td>
<td>D$_2$O</td>
<td>Graphite</td>
<td>-</td>
</tr>
<tr>
<td>Fluid</td>
<td>( p_{cr}, ) MPa</td>
<td>( t_{cr}, ) °C</td>
<td>( \rho_{cr}, ) kg/m³</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------</td>
<td>------------------</td>
<td>------------------------</td>
<td></td>
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<tr>
<td>Carbon dioxide (CO₂)</td>
<td>7.38</td>
<td>31.1</td>
<td>468</td>
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<tr>
<td>Freon-134a</td>
<td>4.06</td>
<td>101</td>
<td>512.0</td>
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<tr>
<td>Water (H₂O)</td>
<td>22.10</td>
<td>374</td>
<td>315</td>
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### SCW Experimental Facilities (Obninsk, Russia)

<table>
<thead>
<tr>
<th>Facilities</th>
<th>SKD and SVD-2</th>
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<tbody>
<tr>
<td>Power</td>
<td>0.8 and 10 MW</td>
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<td>Coolant</td>
<td>Water</td>
</tr>
</tbody>
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**Thermalhydraulic parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Pressure</td>
<td>28 and 26 MPa</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>450°C</td>
</tr>
<tr>
<td>Outlet temperature</td>
<td>500 and 505°C</td>
</tr>
<tr>
<td>Mass flow rate</td>
<td>0.8 and 19.4 kg/s</td>
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SCW Facility (10 MW) (Obninsk, Russia)
References

• Russian Nuclear Power Plants, ROSENERGOATOM, Information book
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Thank you for your attention