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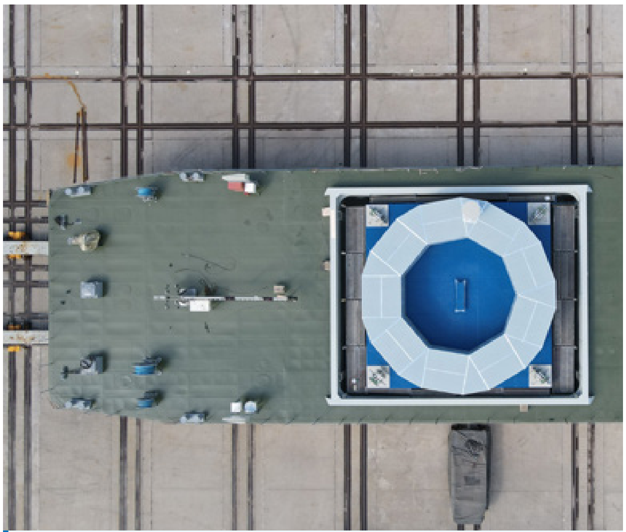
Coil Voyage to ITER

On November 1, a poloidal field coil PF1 was shipped from Saint Petersburg to France. It is an essential component of ITER, the world's largest tokamak built by the international community to demonstrate the possibility of nuclear fusion generation with obtaining more energy than spending.

The destination of its sea voyage is Marseille, from which it will travel 104 km by land to the ITER site in Cadarache. **"A huge road train will carry this out-of-gauge cargo at night, escorted by the police and gendarmerie. I have seen it traveling with another piece of equipment — that was spectacular! People living in nearby towns and villages poured out into the streets to take pictures of that captivating show,"** Head of Russia's ITER Center press office Alexander Petrov shares his impressions.

Why the coil is needed

The PF1 coil is a component of the ITER magnet system designed to obtain the first plasma in the fusion reactor. The magnets confine plasma whose temperature will reach 300 million degrees centigrade in certain modes of operation and keep it away from the tokamak chamber walls as no material can withstand such a high temperature. The idea of confining plasma with an electromagnetic field was first proposed by a team of Soviet scientists in the 1950s.



Russia's contribution to ITER

22 km of superconducting strands for toroidal field coil windings

11 km of superconducting strands for poloidal field coil windings

4 test stands for equatorial and upper port plug assemblies

58 central cassette assemblies of the divertor

Thermal testing of plasma-facing components

1 poloidal field coil PF1

18 upper ducts of the vacuum vessel

8 170 GHz/1 MW gyrotrons

9 plasma measurement and diagnostic systems

179 most energy-intensive panels of the tokamak's first wall

Engineering design of diagnostic port plugs

Power supply systems and switching equipment

Russian coil features

The PF1 poloidal field coil is a massive structure 9 meters in diameter weighing 200 tons, but it is the smallest out of six coils to be installed in ITER. Another coil, PF6, with an external diameter of 11.2 meters was manufactured and supplied by China. The four remaining coils (PF2 through PF5) are so large and heavy — their diameters range from 17 to 24 meters — that they are assembled on site. The PF1 will be installed last.

Development and production of the Russian-made poloidal field coil began in 2014.

It is composed as a stack of eight double pancakes, each wound with 'two-in-hand' niobium-titanium superconducting strands manufactured by Rosatom's subsidiaries. **"Here is an interesting fact: as known, the temperature inside the reactor will be ten times higher, that of the Sun while the temperature in the coils — that is, literally a couple of meters away from the reactor's heart — will be the lowest in the Solar System, around 4K,"** says Deputy Director of ITER Center Leonid Khimchenko. Tests on the superconductors were long and meticulous as engineers had to make sure that the strands meet specifications for electric current, durability, isolation, compound quality and others. Dimensional tolerances for the coil are less than 1 mm.

The first pancake was ready in 2016, and the last one in 2019. Vacuum pressure impregnation of the coil windings — one of the most critical and challenging tasks — was finished in March 2021. A year later, in March 2022, the coil passed acceptance tests. The coil, including its technology and components, was developed at

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Rosatom's Efremov Research Institute of Electrophysical Equipment (NIIEFA) and manufactured at Sredne-Nevsky Plant in Saint Petersburg. **"We have gone all the way from the development of detailed design documents and qualification of processes to complex engineering solutions and final tests that confirmed compliance with the requirements of the ITER Organization. I consider this event to be an indisputable achievement of the Russian academic community. It is the largest superconducting electric magnet ever made in the Russian Federation. The world does not have that many countries capable of making such products,"** says Igor Rodin, Deputy Director General for Nuclear Fusion and Magnet Technology and Director of Sintez Science and Technology Center at NIIEFA.

New interpretation

Standing initially for 'International Thermonuclear Experimental Reactor', the acronym ITER is now associated with the Latin word 'iter' meaning a way, journey or road.

"This is an event of immense significance both for the Russian companies that contributed to the production of this critical component of the future fusion reactor and for the project in general. It is a breakthrough result of many years of effective teamwork between leading Russian research institutes and industrial companies, as well as a convincing demonstration of our research and technology potential," Director of Rosatom's ITER Center Anatoly Krasilnikov said upon the shipment of the coil. According to him, Russia extends research and deployment of high technology, including for industrial applications, despite the unprecedented sanctions imposed by the West.

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Invitation to Smart City

Rusatom Infrastructure Solutions (part of Rosatom) goes international with its Smart City digital product. Negotiations with representatives of Uzbekistan, Kyrgyzstan, Tajikistan and Turkey are currently underway.

What Rosatom's Smart City is

Rusatom Infrastructure Solutions (RIS) is Rosatom's division integrating non-nuclear energy and utilities assets of the Russian nuclear corporation and its competence center for urban and regional development, including Smart City projects.

Launched in 2019, the first Smart City platform was developed and deployed in Sarov to assist its then mayor Alexei Golubev in managing the town. The initial goal was to establish an easy-to-use communication channel for local residents to report on issues and have them straightened out.

The idea to organize a problem-solving hub proved successful: local residents got an opportunity to inform authorities of the existing problems, such as litter on the streets, potholes, non-working street lights and others, through a dedicated website and a mobile app. The new platform kick-started changes in administrative processes, with top-down task routings and procedures improved. As a result, response time decreased dramatically. The platform was totally transparent for both the authorities and local residents, featuring obligatory progress reports, photo proofs and other information.

New functions were gradually added to the system. Sensors installed on waste containers signaled when they needed to be emptied, thus helping optimize waste collection schedules and routes. Water and electricity flow meters helped detect unnoticed leaks and turned-on lights. The Smart Crossroads system reduced traffic jams and decreased the number of car accidents.

The platform sparked interest from other municipalities. After Sarov, the Smart City platform was deployed in the resort town of Zheleznovodsk, with more tourism-related functionality added, such as info kiosks and a mobile app helping tourists find information about local attractions, cultural events, hotels, restaurants and others. Mineral water flow meters showed that some tourists come to the town for a weekend, not only for longer stays, and municipal authorities launched a number of initiatives to improve the urban environment for them.

During the pandemic, information about the people affected was plotted on the Smart City map for the medical staff to have a full picture of the disease spread. Those and other digital functions of the Smart City platform spurred its expansion into Rosatom's nuclear host communities.

Following the platform's success, the RIS team began modifying it for regional authorities. The Murmansk Region was the first to deploy the platform.

At present, RIS runs eight projects on the regional scale; the Smart City platform has been deployed in 78 cities and towns, including 18 restricted-access towns hosting nuclear facilities. RIS takes part in sectoral competitions and wins different nominations, which proves that Rosatom's Smart City is one of the best products in the segment.

RIS projects employ the Lean Smart City methodology based on a continuous improvement model. CEO of RIS Ksenia Sukhotina has stressed repeatedly that they deploy digital solutions only after the team have studied carefully, streamlined and digitalized each process. Besides, RIS utilizes to the maximum extent possible and integrates all the IT solutions deployed before to minimize municipal expenses.

Entering export markets

In late October, Alexei Golubev, who was appointed Chief Executive Officer of RIS subsidiary Smart City Digital Platforms and Solutions, took part in ICTWEEK Uzbekistan 2022 Forum in Samarkand. That was his third visit to sectoral events held in Uzbekistan.

In October, the Smart City platform and its features were presented to the Mayor's Office of Samarkand. The city administration showed interest in the smart transportation center, problem-solving hub, and tourist information kiosks. **"After the initial talks are over, we will demonstrate those solutions that might fit their needs and discuss what we have to offer, what needs they have and on what terms the platform can be deployed,"** Alexei Golubev said.

Representatives of Tajikistan, Kyrgyzstan and Turkey also took interest in Smart City. Tajikistan will soon sign a memorandum providing for the Smart City deployment, RIS hopes. In Turkey, presentation of the platform features and functionality gathered a very large audience. **"This speaks to the fact that smart cities are high on the agenda in terms of their economic and social effects,"** Alexei Golubev pointed out. At present, RIS is developing a financial and economic model of the Smart City deployment. Communities surrounding the Akkuyu NPP construction site in Turkey are considered as pilot deployment locations.

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The Research Ten

Rosatom's research division plays a special role within the Russian nuclear corporation. Research lays foundation for the improvement of existing goods and development of new hi-tech products and services offered by Rosatom in the nuclear technology and power segments. You can find more about its key areas of research in this article.

Rosatom's research division brings together ten research and development institutes and centers. The division is managed by the Science and Innovation JSC and also comprises the ITER Center responsible for the obligations undertaken by Russia as part of the ITER project. Its R&D activities are mostly structured around ten main areas — this makes it easier to consolidate efforts and funds and excludes duplication and conflicts of intellectual property rights.

The first area of research comprises Proryv (Breakthrough) Project, fast-neutron reactors, and closed nuclear fuel cycle initiatives. Earlier this year, researchers conducted bench experiments to verify and validate the estimated design specifications, safety cases, computer codes, performance and life of the equipment. At the next stage, R&D activities will be carried out in the pilot demonstration energy complex (PDEC), which is now constructed in Russia. They will be focused on obtaining reactor performance

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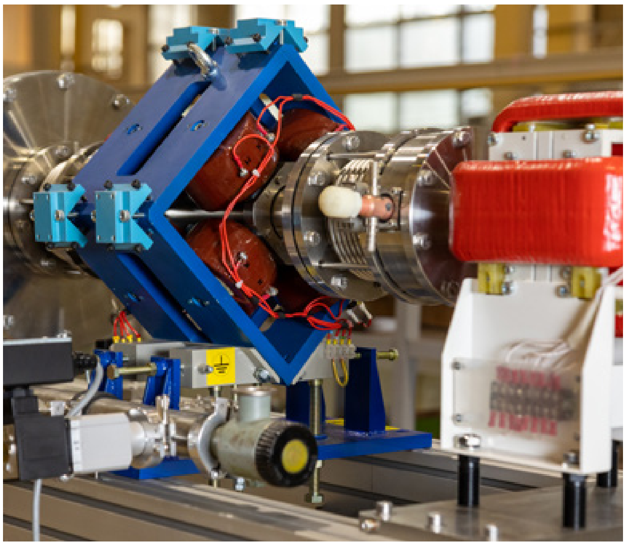


parameters, demonstrating the possibility of closing the nuclear fuel cycle, fuel recycling, lead coolant experiments, etc.

The second area is advanced nuclear power generation technology on the basis of VVER reactors, including development of spectral shift control reactors (VVER-S) and supercritical water-cooled reactors (VVER-SKD). Researchers are working to develop a computer code for precise neutronic modeling of steady and unsteady-state transport. Rosatom's scientists study a new effect of elastic interaction between electron antineutrinos and massive xenon nuclei in partnership with Kurchatov Institute. Compact and inexpensive neutrino monitoring devices can prove useful to increase safety of nuclear facilities and ensure nuclear non-proliferation.

The third area is spent nuclear fuel reprocessing and multiple recycling of nuclear materials. Research in this area aims to maximize the use of energy potential of fissile materials and minimize the amount and activity of radioactive waste. Researchers have demonstrated that it is possible in principle to use uranium-plutonium REMIX fuel in thermal neutron reactors repeatedly (up to 7 times). A molten salt reactor is being designed to dispose of minor actinides. R&D activities will last until at least 2024. The results obtained will be used to build a pilot molten salt nuclear facility. For now, minor actinides are burnt up in BN-800, a commercial fast neutron reactor. Researchers also develop methods for spent nuclear fuel partitioning, high-level radioactive waste solidification with mineral-like matrices, and the so-called Iron PUREX, a method of using fuel claddings as matrices.

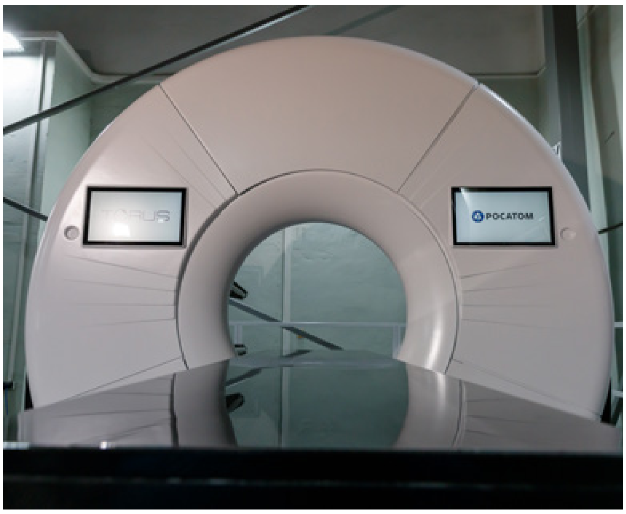
The fourth area is hydrogen economy. It centers on the development of a high-temperature gas-cooled reactor that can be used to produce hydrogen on a commercial scale. Other research programs in this area provide for the creation of hydrogen storage, transportation and application solutions.

The fifth area encompasses research into laser technology. A multi-functional mobile laser unit capable of generating a 100-meter beam is about to be put into commercial operation. It can cut steel and concrete structures up to 20 cm thick, including under water. The work is also underway to create detectors capable of locating explosives of different compositions, including behind barriers and at a distance of up to 6 meters. Researchers are working to create a pilot version of a fully-fledged inspection system.

The sixth area covers nuclear fusion and plasma technologies. A lab prototype of a plasma propulsion engine is being developed and tested. It was found out that the well-studied mechanisms of ion acceleration and breakaway from magnetic field ensure high energy and propulsion performance of the engine. Pilot systems for pulsed neutron and corpuscular flux monitoring were developed, assembled and tested to improve diagnostics of high-temperature plasma and high-power fluxes and radiation. Researchers are also working to improve tokamak performance parameters and develop a continuous magnetron discharge sputtering technique for the deposition of chromium coatings on fuel claddings.

The seventh area comprises new materials and technologies. A new material for the VVER-S RPV shells and welds has been developed and qualified. Researchers also develop methods and techniques for the production of uranium silicide accident tolerant fuel — they study pellet properties and conduct in-pile tests on fuel rod prototypes. Another project aims to develop a special alloy, which will be more resistant to hydrogen pickup, for the use in guide tubes of VVER and PWR fuel assemblies.

The eighth area includes research and development of small modular reactors (SMRs). Researchers are working on the validation of design solutions for RITM-200 SMRs and RITM-200-based small nuclear power plants to improve their design performance. In particular, they have validated life extension for core systems and equipment and built prototypes to test a passive containment heat removal system, an emergency core cooling system, and others. Calculations are made for severe beyond-design-basis accidents. New types of fuel are developed and validated for the Shelf-M reactor to ensure deeper burnup and extend the fuel campaign to eight or more years.



The ninth area is superconductivity. Researchers developed and assembled a hybrid high-temperature superconductor (HTS) fault current limiter. Calculations were made and experiments conducted to demonstrate technical and economic feasibility of creating a superconducting grid power regulator. Bench tests were completed on a HTS conductor for power output systems. HTS conductors reduce the cost of construction or replacement of power output systems by 15%.

The tenth area is nuclear medicine. Researchers are developing a toroidal external beam radiotherapy unit Torus. Its advantages include relatively small dimensions, low radiation protection requirements for the premises, an equalizing filter, a higher dose rate, and others. Another field of research comprises laser lithotripsy in urology. The work is ongoing to develop a new modification of a dual-line laser lithitriptor featuring a microsecond pulse duration.

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Atoms for Energy Security

The same month last year, we wrote that the energy market was very close to the situation the world faced 50 years before during the 1973 oil crisis when nuclear energy began to be perceived as protection against energy market shocks. Our forecast has proved right.

Comparing historical settings

Half a century ago, the global economy was going through a high-inflation economic boom driven by extensive consumption of energy resources, primarily oil. Oil rigs in the US were working at full capacity while the country imported oil.

In the second half of 2021, the global economy was also growing at pace, having posted a 5.9% growth, 0.3 percentage points above the June forecast, according to the IMF. Demand for natural gas was growing, and so were gas prices. Balancing around USD 200 per 1,000 cubic meters in January 2021, the price of gas at the Dutch TTF hub surged to USD 1,389 in October 2021 and closed the year at USD 781 per 1,000 cubic meters.

In 1973, a military crisis drove oil prices high up. After it was made public that the US supported Israel in the Yom Kippur War, the OPEC countries, Egypt and Syria imposed an embargo on oil imports to the US and its allies. The price of oil grew 600% that year.

In 2022, after Russia was put under sanctions that complicated gas transportation and payments, the price of gas sped up growth to exceed USD 3,300 per 1,000 cubic meters. Like oil 50 years ago, natural gas is now high on the energy, economic and political agenda.

When comparing the present-day situation with the state of affairs half a century ago, we took note of the fact that nuclear energy was then considered one of the means of crisis resolution. Active construction of nuclear stations began in the USA, Japan and France. Their considerations proved right: nuclear power plants made a distinct contribution to energy security of those countries during the current energy crisis caused by supply chain disruptions. With a shortage of energy resources, such countries as Finland, Hungary, Bulgaria, the Czech Republic and Slovakia have a more reliably functioning energy systems than if they had no nuclear capacity built by Soviet and, later, Russian engineers. Even Germany, the most stalwart opponent of nuclear energy, decided to postpone the shutdown of its last three operating reactors until April 2023 (they were planned to be stopped by the end of this year) to support its power industry and somewhat cool down electricity prices by not purchasing more natural gas.

We wondered a year ago whether the energy crisis could revive interest in nuclear. Our guess was right. Speaking at the Russian Energy Week, IAEA Deputy Director General Mikhail Chudakov confirmed that the geopolitical situation and the crisis caused

by sanctions and hydrocarbon supply disruptions in Europe and many other countries were key drivers behind explosive growth of interest in nuclear energy. The crisis is felt in everyday life. In Austria, where the IAEA is headquartered, gas bills has grown threefold, and electricity bills 2.6-fold.

New interest in nuclear

The International Energy Agency (IEA) places its hopes on renewables. **"Faster deployment of renewables and efficiency improvements in the European Union bring down EU natural gas and oil demand by 20% this decade, and coal demand by 50%, a push given additional urgency by the need to find new sources of economic and industrial advantage beyond Russian gas,"** the latest World Energy Outlook reads. The share of nuclear energy remains flat in all of the scenarios considered.

However, there is an opinion in the expert community that no increase in renewable generation will improve the situation. **"Oil prices will remain high on a 10-year horizon. Gas prices will be quite high until 2025. Technology potential for improving**

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green energy efficiency flattens out because it is impossible to rely endlessly on the S curve and it is also difficult at this point to further increase efficiency of electric vehicles. This is why the existing economies are slated to experience nuclear renaissance, with nuclear energy serving as a foundation for a reliable power supply," says Alexander Malanichev, a visiting professor of the Russian Economic School.

A record high number of 50 countries made statements on the need to embark on national nuclear programs at the IAEA General Conference in September. Almost every European country supported nuclear. 32 countries are busy setting up necessary infrastructure for yet-to-be-built nuclear facilities. The IAEA stays in close contact with emerging nuclear countries, carrying out infrastructure peer reviews.

"We have seen interest in nuclear growing over the last two — previous and current — years. There will be 873 GW of installed capacity by 2050, according to our optimistic scenario," Mikhail Chudakov said on the REW Forum. At present, the total installed capacity of nuclear power plants worldwide is 382.8 GW, according to the IAEA.

Here are a few examples of interest.

Belarus is considering the possibility of increasing the number of reactors in view of a growing electricity consumption in the national economy. **"I believe our cooperation with Rosatom has good prospects"**, Belarus Minister of Energy Mikhail Karankevich said when speaking at the Russian Energy Week.

In Egypt, major work is ongoing to build the first VVER-1200 reactor for El Dabaa Nuclear Power Plant. First concrete for the reactor was poured this July. Late last October, the national nuclear watchdog issued a construction license for the second reactor unit.

In August 2022, right when the gas prices peaked, Slovakia's regulator ÚJD SR issued an operation and fuel loading permit for Mochovce 3. Before then, operational readiness of the reactor had been under administrative scrutiny since December 2016. With nuclear fuel loaded this September, the reactor went critical in late October.

Also in late October, Poland chose the US company Westinghouse as a technology vendor for the construction of the country's first nuclear power plant. The same very day, news came out that two Polish companies, ZE PAK and PGE (Polska Grupa Energetyczna), signed a letter of intent with Korea Hydro & Nuclear Power for the cooperation in construction of another nuclear station. Here are more details on Polish agreements.

Fictitious partner

The nuclear plant construction project will earn money and create new jobs for the

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American economy before anything else. US Energy Secretary Jennifer Granholm wrote about it in her Twitter: **"Poland will select the US government and Westinghouse for the first part of their $40B nuclear project, creating or sustaining 100,000+ jobs for American workers."**

It is questionable whether the American company is capable of delivering the project on its own. There are two reasons for doubt. First, Westinghouse does not have enough of nuclear construction competencies; second, it does not have capacity to manufacture and supply a reactor.

The company failed to build four reactors at two US nuclear stations, V. C. Summer and Vogtle, having admitted in 2017 that it had run out of budget and schedule. The problems undermined financial stability of the company, and Westinghouse went bankrupt. Construction of the two reactors at V. C. Summer was suspended. At the Vogtle Electric Generating Plant, the only nuclear station under construction in the US, Westinghouse acted as an EPC contractor, but reactors for the plant were manufactured by the Korean company Doosan.

It is not quite clear, therefore, what is really meant when Westinghouse is called a 'technology vendor'. We might assume that the American company will transfer a set of documents, consult the customer and supply certain components, for example, I&C for the Polish plant. It is not known yet who will manufacture the reactor.

The outlook of Poland's partnership with Korean companies is not certain either, but for another reason. In October, Westinghouse filed a suit with a US federal court against KHNP and KEPCO. The American company

alleges that APR-1400, a reactor exported by South Korea, employs System 80 solutions. It is a pressurized water reactor developed by Combustion Engineering that has been part of Westinghouse since 2000. The legal suit aims to oblige the two Korean companies to obtain a permit from Westinghouse for the construction of APR-1400 reactors, which might result in a direct ban on the construction of these reactor in the Czech Republic, Poland and Saudi Arabia. The Korean companies do not agree with Westinghouse's demands.

Russia's contribution to sustainable energy

Russia has overtaken the lead in nuclear technology exports from the USA. This was mentioned by IAEA Director General in his speech at a conference in the Carnegie Foundation in the USA. **"I think this is a challenge for America. It has traditionally been the leader, it lost this leadership but I heard the [US] Secretary of Energy say that we want to regain this leadership."**

Statistics show Rosatom is a leading player of the nuclear technology market and

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possesses extensive competences in nuclear fuel, reactor and construction technologies. According to AtomEnergoProm's Annual Report 2021, Russia accounts for 15% of uranium production, 38% of nuclear fuel enrichment, and 17% of nuclear fuel supplies. Rosatom also has the largest number of nuclear reactors under construction worldwide.

Of course, the market leadership is not important per se. Russia offers nations all over the globe an opportunity to make a contribution to a clean, sustainable and energy-secured future.

Speaking on the REW Forum, Mikhail Chudakov said we should build more nuclear stations than planned to achieve the net-zero goal because other energy sources will not ensure the required pace of decarbonization and energy reliability. Hydro power plants cease to be a reliable source of electricity due to climate changes: water reservoirs shrink and dry up, and power generation decreases. Wind and solar farms feed little power into the greed, occupy immense areas and have a low utilization factor,

so they cannot reliably supply industrial facilities with power. In addition, no large-capacity batteries have been developed yet to compensate for the shortcomings of wind and solar.

Finally, nuclear contributes not only to climate but also to economic goals thanks to the stability of pricing. The share of fuel in the cost of power generated at nuclear power plants is as small as 5% — unlike at fossil fuel power stations where fuel can account for up to 80% of the total cost. For this reason, changes in the nuclear fuel price have little effect on the price of electricity supplied by nuclear stations. Moreover, long fuel cycles and the possibility of purchasing nuclear fuel for a few years in advance protect the buyers from short-term price fluctuations caused by political or economic instability. That means that energy self-sufficiency and, as a result, political independence will be secured for at least 60 years (if we are talking about Russian-designed reactors). In this sense, Rosatom exports energy security and political independence rather than nuclear generation technology.

It is a great challenge, though, to build the planned nuclear capacity. Nations need to invest USD 3 trillion in the next 30 years, or six times more than invested in the previous 30 years (USD 0.5 trillion). The number of reactors going online every year should also grow 3 to 4 times. "This goal is achievable if there is a political will and public support," Mikhail Chudakov is confident. The question is what political will there will be.

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