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Removing Heat from Tokamak

February witnessed two events related to component supplies for the International Thermonuclear Experimental Reactor (ITER) project from Russia. On February 10, a PF1 poloidal field coil arrived at the ITER construction site. On February 13, D. Efremov Research Institute of Electrophysical Equipment (NIIEFA, part of Rosatom) sent this year's first shipment of Russian-made equipment for ITER.

Coil arrived

"We are glad Russia has done a good job with the manufacture and delivery of the poloidal field coil. Superconducting magnets for ITER require an unprecedented precision," ITER Director General Pietro Barabaschi said at the ceremony dedicated to the coil's arrival.

"The best Russian professionals were involved in the production of the PF1 coil. They developed advanced technology, processes and production solutions. The successful completion of the PF1 coil production and its delivery to the reactor construction site shows clearly that Russia has

been, and will continue to be, an integral part of the ITER project and, more generally, global thermonuclear research effort," Rosatom's Director General Alexey Likhachev pointed out.

Weighing 200 tons, the 9-meter round PF1 coil is one of the six poloidal field coils in the magnet system designed to confine plasma inside the thermonuclear reactor. The coil's journey started on November 1 last year when it was shipped from the Sredne-Nevsky Shipyard in Saint Petersburg to the French port of Berre. Then it was loaded onto a special flatbed trailer to be escorted to Cadarache via a special route dedicated for superheavy, oversized cargoes.

Final shipment of electrical equipment

This year's first shipment is also the final batch of electrical equipment that NIIEFA manufactured for the ITER project. The shipment included high-current busbars and switchgear components for the power supply system of superconducting poloidal field coils and the central solenoid.

NIIEFA is a leading contractor for the production of electrical equipment for the power supply systems of the ITER magnet windings. It consists of three equipment groups and a control and monitoring system.

The first group comprises switchgear equipment for the protective power output system. Plasma particles in the tokamak are confined by a powerful magnetic field that is induced by electromagnetic coils. Their windings are made of superconducting strands having zero electrical resistance at cryogenic temperatures. They are designed to carry an extremely strong current of 70 kA to create

magnetic fields. In case of a technical failure, though, there is a risk the windings of the ITER magnet system can switch from a superconducting state to a normal resistive state. If this happens, hundreds of tons of superconductors will overheat immediately and may 'burn', and the reactor will be damaged heavily. **"Our protective power output system ensures the safe operation of the ITER unit. If a technical failure occurs, it releases, quickly and safely, the energy accumulated in the coils of the tokamak's magnet system, protecting them from temperature and high voltage effects,"** explains Igor Rodin, Deputy Director General for Thermonuclear and Magnetic Technologies and Director of Sintez R&D Center at NIIEFA.

This group also includes on-line current switching systems initiating the discharge

> The magnet system of the tokamak consists of 39 superconducting coils, including 18 toroidal, six poloidal, six inductor, and nine correction coils. The magnet system is powered by 22 independent power supply systems.

What is ITER

ITER stands for the International Thermonuclear Experimental Reactor based on a tokamak design. The purpose of this megascience project is to demonstrate the possibility of controlled fusion for the production of 'cleaner' and safer energy. The project is a joint effort of the European Union, Russia, United States, India, China, South Korea, and Japan.

that creates plasma in the tokamak at the beginning of each operating cycle.

The second group consists of powerful high-current busbars that supply power to the superconducting coils. **"These are the most expensive components provided for in the supply contract,"** says Maxim Manzuk, Head of High-Current Switchgear Department at NIIEFA. In total, the busbars are 5 km long and, together with supports, weigh 900 tons. They are water-cooled and designed for continuous operation at direct currents reaching tens of thousands of amperes.

The third group of electrical equipment includes energy-absorbing resistors. They are needed to dissipate the energy accumulated in the magnetic field of the tokamak windings in the form of heat. NIIEFA will supply a total of 29 such resistors, weighing 1,300 tons. They will occupy an entire 3,000 sq m building and be able to dissipate over 50 GJ of energy. This amount of energy is extremely huge and comparable with kinetic energy of a 640-ton transport aircraft traveling at the speed of 1,400 km/h. **"This is the amount of energy our resistors can convert to heat and dissipate in 30 seconds by heating to 300 °C. A forced air cooling system will cool down the resistors to their initial temperature within an hour,"** Maxim Manzuk explains. Some busbars will be placed on 2 to 2.5-meter high supports; others will be suspended from the ceiling.

This year's first shipment with a total weight of 33.4 tons was loaded onto three trailers. It is planned that over 400 tons of equipment components will be shipped to France on about 50 trailers in this year.

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En Route to Myanmar

In early February, Rosatom Director General Alexey Likhachev and Prime Minister and Chairman of the State Administration Council of Myanmar, Senior General Min Aung Hlaing met in Yangon, Myanmar's largest city and former capital, to sign an intergovernmental agreement on cooperation in peaceful uses of nuclear energy. This brings Myanmar another step closer to building a new industry that will contribute to national development.

SMR+

"The new industry will undoubtedly have a positive effect on Myanmar's economy, industry and power production. Nuclear technology will ensure supply of clean and reliable power and give a strong impetus to the development of natural sciences, education and professional training. We value the fact that Myanmar has given preference to Russian nuclear technology," Alexey Likhachev said at the ceremony.

The agreement provides for Russia and Myanmar to collaborate on building a small modular reactor in Myanmar as part of a broader partnership program. **"This agreement starts our cooperation in carrying out a small modular reactor project and, more generally, in using nuclear technology across various applications. It will contribute to the social and economic development of the country,"** Min Aung Hlaing stressed.

History of cooperation

Diplomatic relations between the two countries were established as far back as 75 years ago. **"Our relations have traditionally been friendly and trusting throughout those 75 years. It so happened that the facilities symbolizing our bilateral cooperation and friendship had been built by the beginning of the sixties or in the second half of the sixties — they are a university of technology, a hotel in Yangon, a hospital in Taunggyi, and a dam in Chemoltau,"** Russian Ambassador to Myanmar Nikolai Listopadov said in an interview about joint projects.

Nuclear is a new area of cooperation. Myanmar grew interested in nuclear technology back in the 2010s. In June 2015, representatives of the two countries signed a memorandum of understanding at the Saint Petersburg International Economic Forum with an intention to cooperate in peaceful uses of nuclear energy. The key areas of cooperation set out in the memorandum were nuclear medicine, fundamental science, and radioecology.

In October 2016, a working group established pursuant to the memorandum held its first

meeting to discuss nuclear research projects and professional training. The work went on and reached a new level in 2022.

In July 2022, Alexey Likhachev and Myanmar Science and Technology Minister Myo Thein Kyaw met in Moscow to sign two memorandums of understanding between Rosatom and the Myanmar Ministry of Science and Technology in the presence of Min Aung Hlaing. The documents provided for the cooperation in professional education and staff training for the nuclear power industry and in raising public awareness of nuclear energy in Myanmar.

In September, Rosatom, the Ministry of Science and Technology, and the Ministry of Electrification of Myanmar signed a cooperation agreement on peaceful uses of nuclear energy for 2022–2023 at the Eastern Economic Forum. In addition to training the staff and raising public awareness, the agreement provides for the expansion of the bilateral regulatory framework and potential construction of an SMR.

In November, representatives of several Myanmar ministries were made familiar with the capacities of Russian universities, the National Nuclear Research University (MEPhI) and the Moscow Power Engineering Institute (MPEI), and visited Rosatom's Technical Academy. They learned that MEPhI and MPEI have been teaching students from Myanmar for several decades, offering degrees in power engineering, microelectronics, applied mathematics and other majors.

Prior to the Atomexpo International Forum that took place last year in the Russian city of Sochi, Myanmar representatives visited Rosatom's facilities in Obninsk and the Leningrad NPP in Sosnovy Bor and were demonstrated an analytical simulator for the VVER-1200 reactor unit, a 3D visualization and prototyping software package for nuclear power plant buildings and structures, and other nuclear facilities.

On November 22, when Atomexpo began, Rusatom Energy Projects and the Department of Electric Power Planning of the Myanmar Ministry of Electricity and Energy signed a memorandum of understanding to conduct a pre-feasibility study for the construction of a small modular reactor in Myanmar.

One more ICAT

On February 6, 2023, an Information Center for Atomic Technology (ICAT) was inaugurated in Yangon. The ceremony was attended by Min Aung Hlaing and Alexey Likhachev, high-ranking guests, and the first visitors, Myanmar schoolchildren and students. On the same day, Russia and Myanmar signed an intergovernmental cooperation agreement on peaceful uses of nuclear energy.

The new information center was founded to educate the people of Myanmar and raise their awareness of nuclear technology, radiation safety, and innovation. ICAT will promote youth's interest in scientific research and dramatically improve the staff training needed by the country to develop the nuclear industry.

The Yangon Information Center for Atomic Technology is the latest and most advanced in Rosatom's ICAT network (it is the 25th center in succession and the 6th one abroad). Its interactive exhibition features unique exhibits: visitors can build a 'city of the future' using their knowledge, watch how the RITM-200 reactor works, measure their own radioactivity, learn about radiopharmaceuticals, and much more. ICAT also has an advanced video room. Students and schoolchildren have an opportunity to watch educational films and learn how the atom is structured, where nuclear energy comes from and how it is released, how the nuclear power plant works, and where else nuclear technologies are used.

During this year, ICAT will host seminars for Myanmar media and expert communities, the Science and Atom Festival, and lectures by Russian experts from MEPhI for Myanmar university students. NL

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Liquid Salt Burns Minor Actinides

In December 2022, N. Dollezhal Research and Development Institute (NIKIET, part of Rosatom) presented a draft design for a molten salt research reactor (MSRR). The new reactor is designed as a test facility to validate technologies for a full-scale minor actinide burner.

Purpose and principles of operation

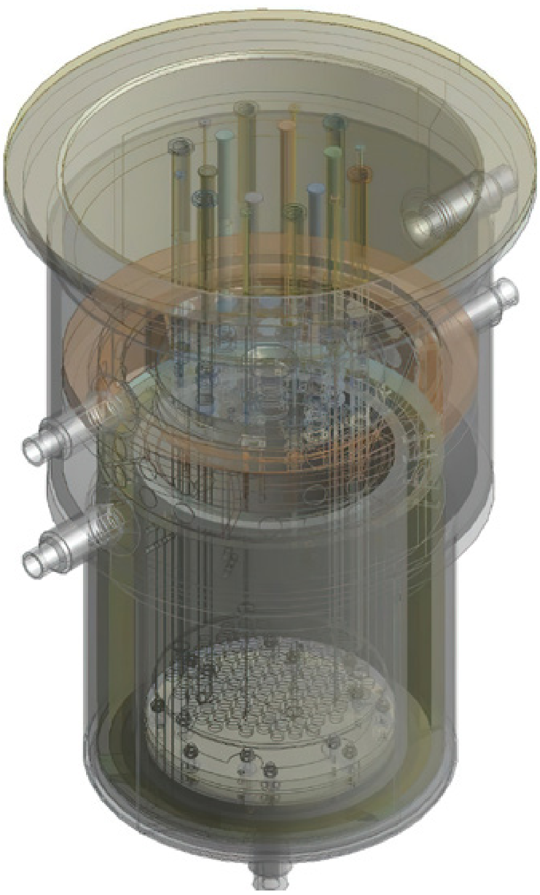
In molten salt reactors, nuclear fuel is dissolved in a metal fluoride salt medium, which also serves as a coolant, with a salt-and-fuel mixture forming a homogeneous reactor core.

Molten fuel salt reactors have a number of distinct advantages. First, unlike heterogeneous reactors, they need no fuel rods or fuel assemblies.

Second, molten salt reactors are much safer due to negative reactivity feedback for both temperature and density of the fissile medium. And since their temperature and void coefficients are negative, no severe accident can ever happen. The pressure in the fuel circuit is low but sufficient to pump the molten salt medium through. This minimizes the amount of potential energy that can be released if the circuit is damaged or broken. And if the temperature in the circuit rises to a dangerous level, a relief valve triggers, whose passive action is based on natural laws of physics.

The main purpose of a molten salt reactor is to enable continuous transmutation — or 'burning' — of minor actinides contained in spent nuclear fuel from thermal neutron reactors. Since molten salt reactors make it possible, Russia has returned to this concept after a long break (research activities into molten salt reactors were suspended in Russia in the early 1990s). Molten salt reactors are now seen as part of a closed nuclear fuel cycle and an important component of the spent nuclear fuel reprocessing and disposal technology.

The MSRR is planned to be built on the premises of the Mining and Chemical Plant (MCP, part of Rosatom) in the Krasnoyarsk Krai. The choice is not accidental since MCP specializes in the final stage of spent nuclear fuel management and nuclear decommissioning.



MSRR project timeline

Engineering studies and computations for the MSRR began in late 2019. By now, the R&D program for the project has been approved and, as part of this program, feasibility studies have been launched into MSRR structural materials, reactor unit, spent fuel reprocessing module and other equipment, as well as into the technology for the preparation of fuel and flushing salts and other processes. **"We are now working to make unparalleled high-temperature test benches to refine technical solutions for certain assemblies and verify software codes for this innovative reactor unit,"** says Igor Tretyakov, Chief Designer of Research and Isotope Reactors at NIKIET.

As part of the draft design, engineers developed basic technical, structural, schematic and layout solutions for the reactor unit and the equipment it will contain. Much of front-end engineering is still ahead, including justification of investments, development of the detailed design for the reactor and reprocessing module, completion of the R&D program, and, finally, development of detailed technical documents and licensing. MCP plans to be licensed as an MSRR site later this year. **"This means that a substantial portion of R&D feasibility studies should be done before 2024,"** Igor Tretyakov explains. It is planned that MCP will obtain a construction license by 2027, and the MSRR will be constructed by 2031.

MSRR features

The MSRR has a thermal capacity of 10 MW. Its primary structural material will be an

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alloy containing 80% of nickel. It is planned that this alloy will be used to make a reactor pressure vessel, pipes for the fuel (in more familiar terms, primary coolant) circuit, and thermal equipment. **"Researchers have studied how this material reacts with the fuel salt and its corrosion behavior, and have chosen it for now — the deadline for the engineering design is very tight, so we have to go the shortest way. It is quite possible, though, that R&D results will push us into considering other materials and other salts,"** Igor Tretyakov said.

It is assumed that around 10% of molten salt will be withdrawn from the fuel circuit at certain intervals, with a fresh fuel mixture added instead. Theoretically, it is not necessary to shut down the reactor for refueling, but this yet needs to be researched, analyzed and proved experimentally.

Presumably, the reactor will be built in the underground section of MCP. The rock massif will additionally isolate the reactor from the environment. Besides, the fuel circuit and some other pieces of equipment will be housed in a sealed box serving as a safety barrier.

In order to protect the personnel, most of the maintenance work on the MSRR is planned to be done with robotic mechanisms, which are also being developed now.

A few words about fuel

MSRR fuel and methods of its reprocessing are developed at A. Bochvar Russian Research Institute of Inorganic Materials (VNIINM, part of Rosatom). The MSRR will use molten fluorides of several metals as fuel. The fissile material in the melt will comprise

fluorides of minor actinides to be transmuted, and obviously, plutonium at the initial stage of operation.

One of the tasks VNIINM is working on is the production technology for minor actinide fluorides. **"The synthesis of fluorides is not particularly difficult — its methods have long been known. But in order to use these compounds as fuel in the MSRR, they should meet stringent technical requirements, primarily in terms of oxygen content,"** VNIINM Chief Researcher Alexey Ananyev noted in an interview for Strana Rosatom corporate newspaper.

VNIINM plans to use lithium and beryllium fluorides as a base for the fuel composition. They are less reactive to structural materials than sodium, lithium and potassium fluorides (FLiNaK). Obtaining salts of the required quality is the second task of VNIINM.

Its third task is to remove tritium, which is formed from lithium during irradiation. VNIINM has already selected sorbents for tritium extraction and developed a draft design for a gas purification system; experiments are currently underway. Meanwhile, designers are developing process equipment for the fuel preparation and reprocessing modules and gas purification systems.

The work to build the MSRR and fuel reprocessing module is progressing, albeit not without difficulties inherent in every new technology. The MSRR will be used to conduct experiments that will contribute to developing the technology for burning minor actinides from spent nuclear fuel, which will be a huge step forward to closing the nuclear fuel cycle.

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Cooperation in Nuclear Energy

This column is usually dedicated to the global trends in nuclear technology and power generation, but this time we will talk about Rosatom in the context of a (largely imaginary) trend of 'gaining independence' from anything associated with Russia. In late February, the British journal Nature published an online article on the levels of the world's dependence on Rosatom. The facts show, however, it would be more correct to talk about pragmatism and goodwill-based cooperation.

The article was published on the website of Nature Energy, a **'monthly, online-only journal publishing the best research on energy, from its generation and distribution to the impacts energy technologies and policies have on societies.'** We could not ignore an analytical article in such a high-ranking publication.

The most reasonable point made in the article concerns the significance of the Russian nuclear corporation for the global nuclear power industry. Since its inception, Rosatom has become increasingly active in the international nuclear power market, and has become a leading provider of key services, the article says. Construction of as many as ten reactor units started between 2007 and 2017, and

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between 2009 and 2018, the company accounted for 23 of 31 orders placed and about a half of the units under construction worldwide. Through its subsidiary TVEL, Rosatom also provides fuel supplies, controlling 38% of world's uranium conversion and 46% of uranium enrichment capacity in addition to decommissioning and waste disposal. **"In sum, Russia was the supplier in around half of all international agreements on nuclear power plant construction, reactor and fuel supply, decommissioning or waste between 2000 and 2015. Its main nuclear power competitors — China, France, Japan, Korea and the United States — accounted for another 40%, combined,"** the authors emphasize. Neither the Fukushima accident nor political turmoil has affected Rosatom's market position.

It is curious, though, that the authors did not cite any data after 2018. Let us fill in the gap. According to the 2021 annual report of AtomEnergoProm (Rosatom's holding company for its civil nuclear assets), the company was the global leader in terms of international NPP construction projects (35 reactors) and uranium enrichment (38% of the world market), and also ranked second worldwide uranium reserves and uranium mining (15% of the world market) and third in terms of nuclear fuel production (17% of the world market). Since then, despite thousands of sanctions imposed on Russia, only Finland suspended a power plant construction project with Rosatom, decreasing the corporate portfolio to 34 power units in the pipeline.

It is also stressed in the article that Rosatom's main advantage lies in its capacity to be a 'one stop nuclear shop' for all needs, the only supplier providing an 'all-inclusive package.' **"The way Rosatom designs its projects also makes it a convenient partner for**

nuclear newcomers. While details of contractual agreements vary from case to case, the developer takes care of the entire process until the plant is ready to use and can be handed over to local (Russian-trained) nuclear experts to operate," the article says. True.

Logic lost

If we follow the authors' argument, those strengths give Rosatom an opportunity to use its nuclear construction projects '**to exert political pressure and to project power globally.'** But first, 'Russia exerts political pressure' does not directly ensue from 'Rosatom has strengths' — there should be some logical transition from one statement to the other, at least for the sake of decency. There isn't one, however. More than that, the very next sentence says a completely opposite thing: **"Minin and Vlček, having studied the behavior of Rosatom and its relationship with the Russian state, argue that the company is primarily a profit-seeking entity with a high degree of autonomy and growing self-sufficiency."** And the quoted summary of S. Thomas' article on Rosatom's 'inability' to complete all of its projects neither confirms nor refutes the above statement — it is simply a talk on a different topic. Thus, it could be argued that the article is logically incoherent and, at times, contradictory.

Errors and inaccuracies

There are factual errors in Nature's article. For example, it lists the Tarapur Atomic Power Station as one of Rosatom's projects. In fact, its first two power units with boiling water reactors were built by the US companies. The other two units with heavy water reactors were built by Indian companies.

The article first claims that 'Rosatom boasted as many as 73 different projects in 29 countries' and then, just a few lines below, that 'Russia's nuclear energy diplomacy has been formalized in 54 countries.' The second figure is closer to the truth.

The authors also claim that hostilities in Ukraine in 2022 caused the cancellation of NPP construction projects in Finland and also in Jordan and Slovakia. False. Jordan made a decision back in 2018 that they needed a small modular reactor (SMR) rather than a large nuclear power plant and last May signed an agreement with Rusatom Overseas (part of Rosatom) to develop an SMR project. The negotiations are continuing. Slovakia's nuclear community would probably be surprised by the claim because Mochovce 3 with a VVER-440 reactor was brought online on January 31. Connection of Mochovce 4 with the same-type reactor is expected soon. This means that Slovakia spent the whole of 2022 completing the construction of Russian-designed units.

Pressure from the other side

The article in Nature contains another blooper associated with Slovakia. The authors remind that Slovakia permitted Russian planes with nuclear fuel to land in its airport despite the flight ban imposed by the EU. This example is meant to prove that **'dependencies on nuclear fuel imports from TVEL/Rosatom (which also continues to supply Bulgaria, Czechia and Finland and Poland's research reactor), combined with power-system inflexibility and overreliance on a single large nuclear power plant, exacerbates the vulnerability to supply disruptions.'** But it shows exactly the opposite. Slovakia's vulnerability was exacerbated not by its dependence on TVEL supplies but by anti-Russian EU sanctions that closed the skies to aircraft from Russia.

As for fuel supplies for the research reactor in Poland, the contract was signed in 2015 (i.e., after Crimea's accession to Russia). Prior to that, the Polish reactor had been running on nuclear fuel from France. Given these details, it should be recognized that the fuel supply contract is definitely not a legacy because Poland was free to choose a supplier, and it chose Rosatom.

The authors of the article found a single example of Rosatom's failure to deliver nuclear

fuel. They refer to an article on The Insider website: **"There was also an incident in 2005 that went unnoticed by the Ukrainian and Russian media amid the 'Orange Revolution': Ukraine received a batch of defective TVEL assemblies filled with tiny spheres. Loading them into the reactor would have provoked deformation, but the Ukrainian specialists detected the defect in time and sent the assemblies back to the manufacturer. The defect was officially explained by failures of the assembly line in Russia, after which the investigation halted."**

This quote shows that it is impossible to attribute anything beyond a technical fault to the event — even in the article devoted to 'energy weapons.' No attempt — not even the slightest — to exert political pressure in the energy industry, much less in the nuclear industry, would have gone unnoticed on the back of the Orange Revolution. Referring to that delivery now (the article was published in the fall of 2022) is nothing more than a shadow theater.

To sum it up, the article in Nature and its sources of information fail to cite even a remotely convincing example in Rosatom's entire history of how Russia applies political pressure through the nuclear power industry.

Is it even real?

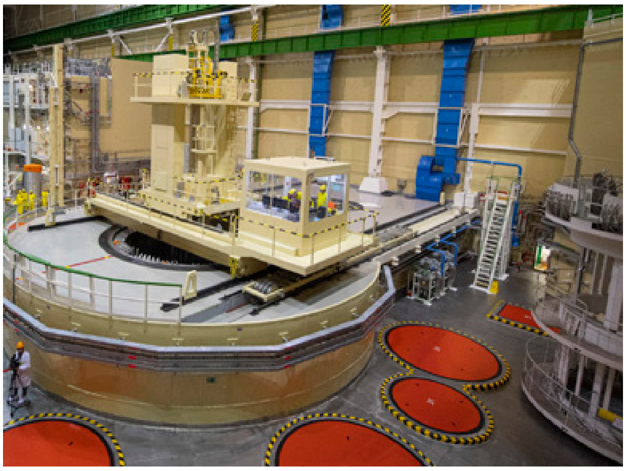
The article is built around infographics about a potential share of power that Russian-designed nuclear power plants will be able to generate if all the announced projects are completed by 2040, and around a ranking table titled 'Levels of Nuclear Cooperation with Russia.' This table is laughable for anyone with the slightest knowledge of the situation. How can Turkey where Rosatom is building a four-reactor nuclear station at Akkuyu under a BOO contract be compared to Spain where Rosatom has no construction projects? And how can the level of cooperation with Spain be higher than cooperation with Armenia that operates a Russian-designed nuclear power plant and considers construction of another one?

As for the infographics, it is no less curious. And notes to them raise questions, too. It is said in a paragraph about the countries generating much of their electricity at Russian-designed nuclear power plants that there is a **'substantial concern among its partners in the European Union and the North Atlantic Treaty Organization.'** In a paragraph about the countries receiving some of their electric power from Russian-designed plants, it is said there is **"some international concern, primarily in Israel and the United States."** It appears from the text that the degree of dependence is determined not so much by the share of Russian-sourced nuclear in the energy mix as by the degree of concern of third parties.

Generally speaking, dependence estimates are discrepant. For instance, the share of supply may be high but the level of cooperation is medium. There seems to be some dependence but the example of Ukraine shows dependence can be overcome. Another example has a high level of cooperation but a low share of electricity supply. This information allows us to make the only reasonable conclusion: the degree of cooperation, that is, a potential impact on nuclear energy security does not correlate with the future amount of electricity supplies from Russian-designed reactors and even less so with political influence.

Finally, let us focus on the most important point, energy weapons. The authors of the article in Nature based their understanding of nuclear energy weapons on the definition given by Karen Smith Stegen: “The term ‘energy weapon’ denotes that an energy supplier state uses its resources as a political tool to either punish or coerce (or sometimes a combination of both) its customers.”

But the current situation regarding the construction of nuclear power plants and supply of nuclear fuel is different. Weapons as a political tool of punishment and coercion have been used by third parties against both the customers and suppliers. The EU closes the skies, and the countries buying fuel face supply problems. The USA imposes sanctions, and no ship carrying cargo for the Rooppur Nuclear Power Plant can enter Bangladeshi waters. But thanks to the high professionalism of Rosatom employees and the nuclear



communities of other countries, nuclear power plants continue to be built and fuel continues to ensure clean energy generation by Russian-designed reactors.

The political instrument of punishment and coercion was used, for example, against the freight forwarders who delivered fuel to the Rivne Nuclear Power Plant. They were held hostage for a month and, although they were civilians, were finally exchanged as prisoners of war. Worthy of note is that the fuel on which the Rivne NPP ‘depends’ was not returned.

Speaking about the hypothetical problems with supplies, which are assessed to have the highest risk, we should keep in mind some important points. Firstly, we have stressed more than once that the nuclear fuel cycle moves at a different speed than the hydrocarbon market or the decision-making process in politics. Refueling takes place once every 12 to 24 months. Fuel is usually delivered to the site about a month before the scheduled refueling, so it is always possible to wait out the most acute phase. Besides, there is a possibility in principle of rearranging fuel assemblies in the reactor core to extend the time in operation by several months. Secondly, the critics have never been able to dig up any case of Rosatom intentionally creating problems for the sake of political pressure or achieving political results — neither after 2007, nor before, because it never happened.

Some conclusions

The article in Nature is a pure linguistic manipulation: business-like and profit-making cooperation is called ‘dependence,’ a word with a trail of negative connotations. The article contains estimates and calculations but

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presents no facts showing Rosatom's malice or political pressure. In the absence of facts, the ideas in the article jump from 'Rosatom is dangerous' to 'dependence on Rosatom is exaggerated' and concentrates on 'getting rid of Rosatom is possible but will take a lot of time.'

And money, we would add. The words of Rosatom's customers prove that supplies and, in general, cooperation with Rosatom are beneficial for them, first and foremost, in terms of business and technology. Here is a recent example. Janne Wallenius, Professor at the Royal Institute of Technology (Sweden) and CTO at Blykalla developing a lead-cooled SMR, told Radio Ekot they had suspended cooperation with Rosatom in testing structural materials for the reactor. A research reactor in Belgium is an alternative to conducting tests in Russia but this will be longer and three times more expensive. However, Swedish nuclear engineers hope to resume cooperation with Russia. **"We are waiting for the war to end,"** the Swedish scientist said.

It should be admitted that there are only a few countries with developed nuclear technology in the world. If a country wants to have this clean and reliable source of power, which also stimulates the economic development, it can develop it on its own — or buy ready-made technology. The first option, however, implies cooperation, too. China's history and the above mentioned example of Sweden show that the nuclear industry develops in partnerships. If you cut ties with a supplier, you do not become independent — you just become dependent on another supplier, often to your detriment. Gas is an example of how this works: the European countries refused to buy Russian gas and were forced to buy more expensive US LNG, exacerbating the political and military dependence on the United States with energy.

Lastly, the article in Nature demonstrates clearly that a wide variety of countries across continents — all having different levels of technology, political systems and cultures — see Rosatom as a partner. Some partnerships started years ago, and some start today — we regularly inform our readers about the new agreements signed. And these are the most convincing facts showing that cooperation with Rosatom is a conscious and free choice. NL

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