ROSATOM | NEWSLETTER

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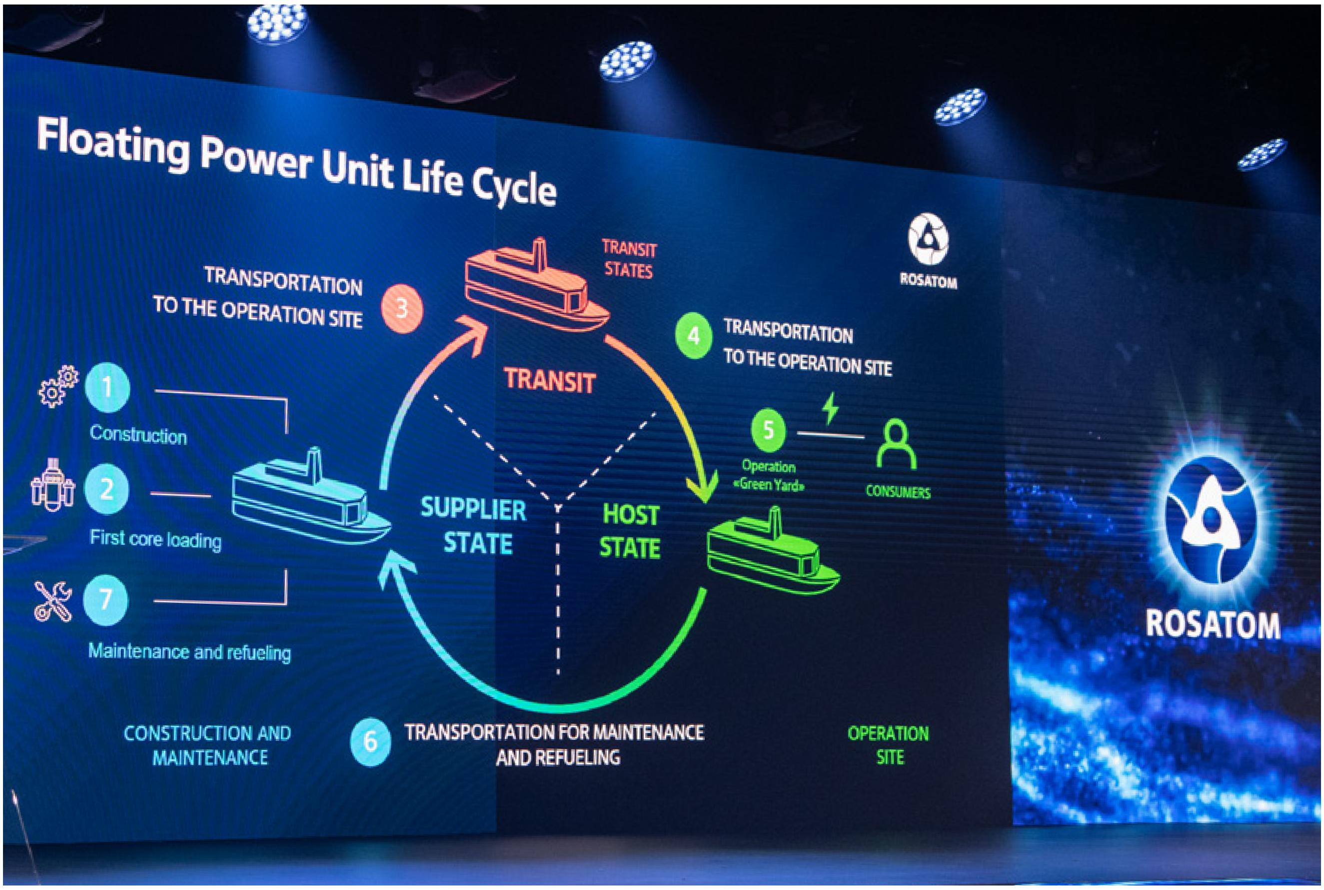

Grand Presentation of Russian SMRs

Small modular reactors (SMRs) have become a topic so significant for both Rosatom and the global community that the Russian nuclear corporation organized the SMR Day, a special event dedicated to small-scale nuclear power plants, at the UN Climate Change Conference COP28. Rosatom also conducts negotiations, makes agreements, develops designs and prepares documents for the construction of SMRs, and shares the specifics of SMR operation and maintenance with nuclear experts from other countries.

The SMR Day was one of the key events on Rosatom's program at COP28. It began with an outstanding multimedia presentation of the onshore SMR under construction in Yakutia, which is being carefully integrated into the Arctic ecosystem.

The guests of the event also had the opportunity to take a virtual tour of the Akademik Lomonosov floating nuclear power plant that supplies Russia's northernmost city of Pevek in Chukotka with electricity and heat. As our readers may remember, we wrote in our last issue about the first refueling of this world's only offshore nuclear station.

"I am confident that Rosatom's small nuclear capacity solutions will become an effective and environmentally safe choice

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for those countries that, for a number of reasons, have never considered nuclear generation before," said Rosatom Director General Alexey Likhachev in a video message to the SMR Day visitors.

Agreements

Many countries are really interested in Russian SMRs. Dalaijargal Dorjbal, executive director of the Mongolian state-run company Monatom, was presented at COP28 with a concept of an onshore SMR that might be built in Mongolia.

Earlier, in mid-November, Alexey Likhachev and Vladimir Potanin, President of Nornickel, signed an agreement of intent and cooperation on the construction of an SMR in the Norilsk industrial region isolated from the national power grid. The parties will study available options, determine a priority site for the onshore SMR, its configuration, and the infrastructure required for the reactor construction and operation, and select an optimal project delivery scheme.

"Nornickel and the Norilsk industrial region are developing, so we will need more electricity after 2030," Vladimir Potanin commented.

"A high-tech nuclear power plant based on the latest RITM-400 reactor might be considered as a priority. Our low-power designs offer a reliable source of electricity for a long term and at predictable cost. In addition, nuclear power can make a significant contribution to the fight against climate change due to the absence of CO2 emissions. All these advantages make SMR technology a sought-after choice for large industrial facilities," Alexey Likhachev said.

10 small reactors

In early December, ZiO-Podolsk (part of Rosatom's power engineering division) manufactured the tenth RITM-200 reactor for the new generation of Project 22220 nuclear icebreakers. This reactor will be installed on the fourth serial icebreaker Chukotka, which is being built on commission from Rosatom at the Baltic Shipyard in Saint Petersburg.

"The RITM-200 reactors have proved themselves in powering our new universal nuclear icebreakers that make navigation on the Northern Sea Route more efficient. The same reactors will be installed on the fifth and sixth serial nuclear-powered icebreakers. The decision to build them has already been made by the Russian Government," Alexey Likhachev said.

Training

In November, an IAEA training course on the safety of small modular reactors was completed at the Saint Petersburg branch of Rosatom's Technical Academy. Professionals from 13 partner countries embarking on nuclear power programs learned about the SMR technology and related IAEA safety guidelines, and studied how to apply these guidelines to different types of small modular reactors.

The course was taught by experts from the Russian watchdog Rostechnadzor, RITM reactor designer OKBM Afrikantov, and Rosatom's Technical Academy. Russian experts shared their experience in the construction and operation of small modular reactors, answered questions on nuclear infrastructure, licensing, nuclear and radiation safety.

The course attendees took virtual tours of Akademik Lomonosov and OKBM Afrikantov, as well as a real tour of Rosatom's Emergency Center. They were shown nuclear accident prevention and management systems and learned about the interoperability of emergency response teams.

Critical design review

Technical designs of a RITM-200N reactor, an AS-14–15 core and its components presented by experts from AtomEnergoMash (Rosatom's power engineering division) passed a critical review by the Scientific and Technical Council of Rosatom. RITM-200N will be installed at the small-scale nuclear power plant in Yakutia.

The Council noted that the designs were thoroughly elaborated and met the scope-of-work requirements. Work is now underway to develop detailed design, operational and acceptance documents for the reactor equipment.

Lutetium-177 Cures

Important news is coming from the world of nuclear medicine: the first patients with prostate cancer have undergone radionuclide therapy with lutetium-177, and all of them have shown positive changes. Read more about this and other news on Rosatom's isotope business in our article.

Lutetium

The therapy was administered at the Federal Research and Clinical Center of Radiology and Oncology (FRCCRO) of the Russian Federal Medical and Biological Agency. A substance containing lutetium-177 for the treatment of neuroendocrine tumors and prostate cancer was developed using technology from the Research Institute of Atomic Reactors (RIAR, part of Rosatom's research division). The radiopharmaceutical passed all the stages of quality control.

"As a manufacturer of the original substance, we are able to meet all the needs of Russian medical institutions

and timely fulfill all the orders we might receive," says Oleg Andreev, one of the drug developers and Head of Radionuclide Sources and Substances at RIAR. In Russia, the radiopharmaceutical is supplied to four medical centers.

According to Pyotr Sychev, Head of the Nuclear Medicine Center and a radiologist at FRCCRO, the treatment was effective and none of the patients had adverse reactions.

The treatment procedure is as follows: doctors first make sure that the patient experiences no side effects and then inject the drug intravenously. The drug is administered once every two months. **"Our patients have completed the first course of treatment, and all of them showed a decrease in the blood level of prostate specific antigen protein. They feel well,"** Peter Sychev said.

As noted by Maxim Kushnarev, CEO of V/O Izotop (Rosatom's subsidiary supplying isotope products), in an interview with Vestnik Atomproma magazine, lutetium-177 medical isotope has been supplied to Brazil since 2021.

This September, the Leningrad Nuclear Power Plant obtained a license to produce lutetium-177, having added a new isotope to its product range consisting of iodine-131, molybdenum-99 and cobalt-60.

Cobalt

In mid-November, the Leningrad NPP met its annual target for the production of cobalt-60, which is used in gamma radiation sources for commercial irradiation plants. The target was reached faster than planned

thanks to the cooperation with Smolensk and Kursk nuclear power plants. **"We have no less ambitious cobalt-60 production plans for the next year,"** says Leningrad NPP Director Vladimir Pereguda. **"The share of sterilization cobalt produced in power reactors of the Russian nuclear plants will account for about 30% of the global cobalt-60 market this year,"** says Nikita Konstantinov, Deputy CEO for Business Development at RosEnergoAtom.

Cobalt-60 is obtained by placing cobalt absorbers into the reactor and irradiating them for 5 years.

International cooperation

This year, V/O Izotop has won a contract to supply the full needs of Belarusian clinics for technetium generators, increased supplies to Armenia and Kazakhstan, and is working to begin deliveries to Kyrgyzstan and Azerbaijan.

Rosatom is also expanding its footprint in non-CIS countries. In July, Moscow hosted a BRICS expert forum with offline and online attendance. Then, at another forum held in August in South Africa, a decision was made to create a BRICS working group on nuclear medicine. **"We expect Russia, and Rosatom in particular, to play a leading role in this working group. This is not only our assessment — we were very much pleased to hear from a South African representative that it is only Rosatom that possesses the end-to-end production technology, from source isotopes to radiopharmaceuticals, among the BRICS companies. And we are one of the few companies worldwide that has competencies in each production stage,"** Maxim Kushnarev commented.

Russian germanium-68/gallium-68 generators are now supplied to India and Kazakhstan. Besides, molybdenum supplies to India, which were interrupted for two years due to logistical issues, have resumed. Supplies of both medical and commercial isotopes to China are also growing. Among them is the helium-3 isotope used in airports. Isotope sales to China are expected to grow one and a half to two times for the current year.

As Maxim Kushnarev noted, European companies did not refuse to purchase Russian isotopes, and all the difficulties that had arisen were gradually overcome. Discussions are underway to provide contract manufacturing services. Deliveries to North America are also continuing.

Rosatom's isotope business development plans provide for the construction of a GMP factory in Obninsk. It will manufacture a wide range of radiopharmaceuticals and active substances, including both the most sought-after radiopharmaceuticals based on iodine-131, samarium-153 and molybdenum-99, and future-proven drugs containing lutetium-177, actinium-225, radium-223 and other isotopes.

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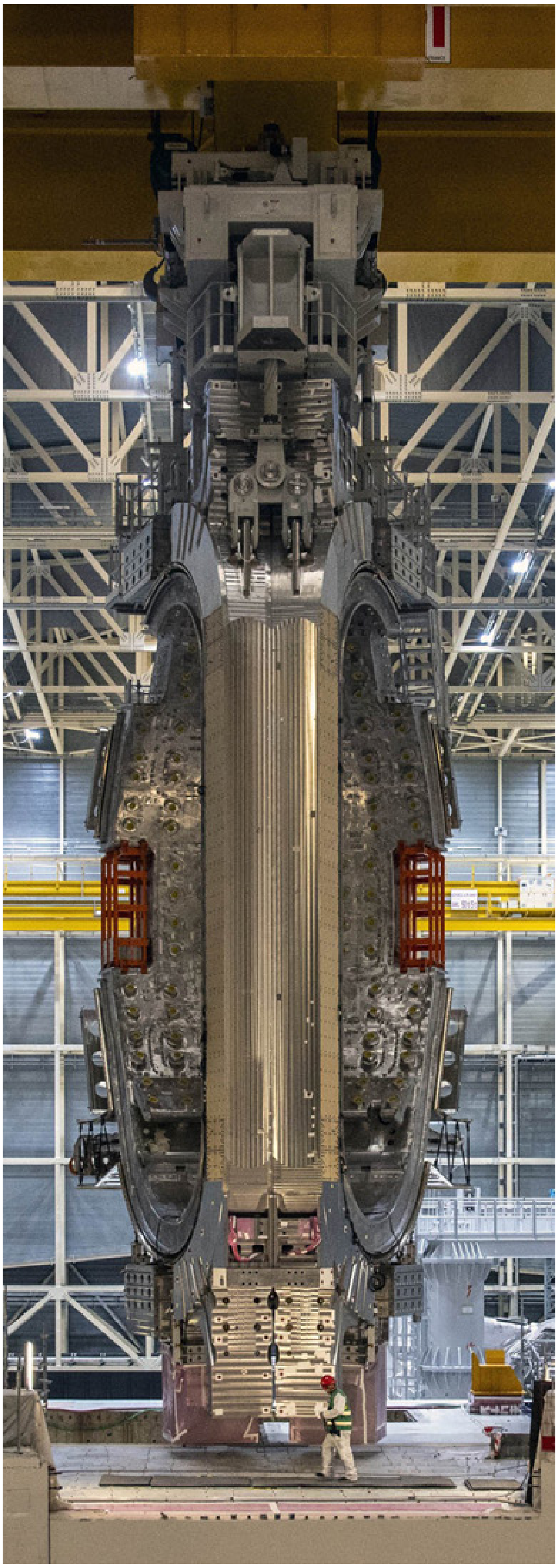
Many Faces of Nuclear Fusion

Throughout the year, we have been informing our readers about the latest developments in reactor technology with input from Rosatom. We will finish up our Reactor Technologies series with an article about fusion projects.

ITER

The International Thermonuclear Experimental Reactor (ITER) is the largest thermonuclear project carried out with Rosatom's input. The Russian nuclear corporation is involved in the production of reactor systems, research, and other aspects of the project.

In late October, Rosatom made the thirtieth shipment of electrical equipment for ITER. Twenty trailers left the Research Institute of Electrophysical Equipment (NIIEFA, part of Rosatom) for Cadarache, France to deliver a large set of fast discharge resistor elements for the switching network units and protective make switches to the ITER construction site. They belong to the power supply and distribution system that makes it possible to obtain the first plasma. The project timeline depends on the early delivery of these components. **"The development and manufacture of the entire set of electrical equipment for the system supplying power to the ITER magnets would not**



have been possible without many years of painstaking work by the NIIEFA research and production team. This testifies to its undeniable authority in the international thermonuclear community," Moscow's ITER Center Director Anatoly Krasilnikov commented on the shipment.

Further, in November, Rosatom took part in a discussion of prospective lining materials for the first wall of the reactor's vacuum chamber at the 33rd Meeting of the ITER Council (the project's governing body). The Council decided to conduct research into the properties of various materials to select the best one. Institutes of Rosatom and the Russian Academy of Sciences are expected to participate in the experiments. The Council also assessed the progress of construction, discussed collaboration with the French nuclear regulator, and reviewed technical aspects of the construction process.

T-15MD and TRT

T-15MD is an upgraded version of the T-15 tokamak operated by the Kurchatov Institute in 1988–1995. T-15MD is installed on the foundations of its predecessor. The new tokamak was energized in May 2021, and the first plasma was obtained in the spring of 2023. By now, power generation tests have

Thermonuclear reaction

A controlled thermonuclear reaction differs from a nuclear reaction in that the former is based on fusion of lighter nuclei into heavier nuclei, while the latter is based on fission of heavy nuclei.

been conducted. As noted by Viktor Ilgisonis, Director for Research and Development at Rosatom, the tokamak is being upgraded to yield results that will meet international standards.

The Troitsk Institute of Innovative and Thermonuclear Research (TRINITI) is preparing the necessary infrastructure for a reactor technology tokamak (TRT) construction project. TRT is expected to become a full-scale prototype of a future fusion reactor or a neutron source. It will be used to study plasma behavior in quasi-stationary modes close to ignition and improve methods of additional plasma heating, fuel supply, and blanket technologies. The device will also be helpful in developing new diagnostic techniques and tritium technologies. TRINITI plans to complete the first phase of the thermonuclear facility retrofitting project by the end of 2024, which is the prerequisite for creating the power generation infrastructure for the TRT.

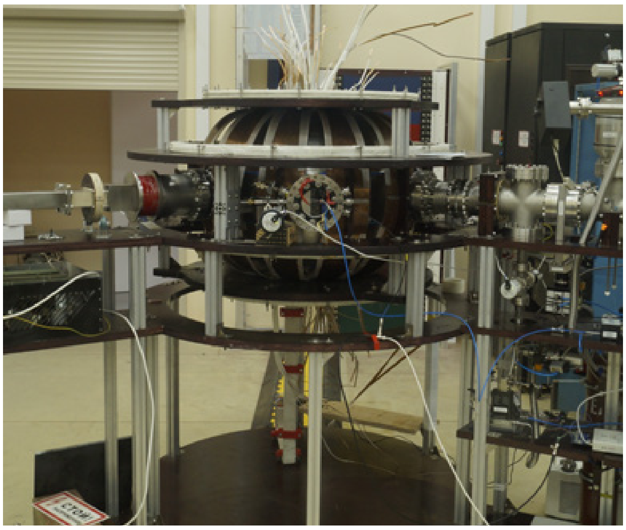
Plasma focus

Scientists from the National Nuclear Research University (MEPhI), one of Rosatom's backbone universities, and the Dukhov Russian Research Institute of Automatics (VNIIA, part of Rosatom) developed a dense plasma focus neutron generator capable of initiating miniature fusion reactions.

Its emitter consists of a small (a few centimeters in diameter) plasma focus discharge chamber, an energy storage device, and a high-voltage switch. To create plasma, gaseous hydrogen isotopes are pumped into the plasma focus chamber, then high voltage is applied to two electrodes. When the voltage is applied, the switch is triggered, and all the energy from the storage device is transferred to the chamber. The current of hundreds of kiloamperes ionizes the gas in the chamber and forms a plasma sheath, i. e., hot plasma of a specific configuration. The sheath accelerates between the electrodes under its own magnetic field and is compressed into a point called 'pinch.' This is the plasma focus where fusion reactions take place. They last for several tens of nanoseconds. At that moment, the emitter generates various types of radiation, including neutron radiation, X-rays, plasma jets, electron and ion beams. When the voltage is removed from the electrodes, the gas returns to its normal state.

This device can be used to calibrate neutron and gamma ray detectors for mega science projects. It can also be employed to test detection system components for radiation resistance. Such tests are necessary for on-board equipment of spacecraft and radioelectronic components. Another potential application of the device is to study the impact of various types of pulsed radiation on living organisms and conduct neutron activation analysis of different substances.

"All the equipment used to be calibrated using pulsed sources, reactors and accelerators. These are multi-tonne jumbos with numerous control systems. Our unit weighs as little as 150 kilograms and can be moved by two trained engineers," says Elena Ryabeva, Deputy Director at the MEPhI Institute of Cyber Physical Systems. The dense plasma focus neutron generator is already in use by students in the laboratory.



As Rosatom chief Alexey Likhachev said at the Russian Energy Week, the Russian nuclear corporation does not yet have a concept of fusion commercialization. Nevertheless, he promised to continue the work and invest money and effort in the idea. Speaking at the Conference of Young Scientists, Russian President Vladimir Putin also promised to allocate funds for fusion research.

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The Reactor Future At a Glance

Ahead of the COP28 conference, the IAEA released its Nuclear Technology Review 2023 report covering the key events of 2022 and the trends that the agency's experts believe will shape the future of the global nuclear industry.

The review outlines 26 aspects defining the latest industry developments and trends. We will consider the most significant and interesting of them below.

Nuclear capacity additions

For the second straight year, the IAEA has revised its outlook for global nuclear generation upwards. The installed nuclear capacity could increase to 873 GW by 2050 in the high case scenario, up 10% from the previous year's high case projection. The share of nuclear power could therefore grow from the current figure of 9.8% to 14% of the global electricity mix. For this scenario to come true, systemic transition to long-term operation through life extension would be required across the existing fleet and nearly 600 GW of new capacity would need to be built in the coming 30 years.

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Rosatom makes a substantial contribution to this goal. The Russian nuclear corporation is building 22 power units in seven countries, with a total of 33 units in 11 countries in the pipeline. For 18 years since its foundation, Rosatom has built 18 large power units, including nine reactors outside Russia. Fresh nuclear fuel has been delivered to the Akkuyu NPP in Turkey and the Rooppur NPP in Bangladesh this year.

According to the report, financing new-build nuclear capacity remains a challenge, though some positive developments are on the way: in 2022, nuclear power was included in the European Union's sustainable finance taxonomy, as well as in other taxonomies around the world. In general, the IAEA notes an improvement in the policymakers' attitudes toward nuclear due to its input into the reliable supply of low-carbon electricity. Turkey and Egypt, where nuclear power plants are being built by Rosatom, have included nuclear power in their national contributions to a carbon-free future under the Paris Agreement.

Small modular reactors

Interest in small-scale nuclear generation is one of the latest trends outlined by the IAEA. **"Together with advanced large water cooled reactors, SMRs are expected to make up the bulk of capacity additions over the next three decades,"** says the report.

Rosatom was the first in the world to commission a floating nuclear power plant, the Akademik Lomonosov, and proceeded with another three SMR projects. The first of them is the construction of four offshore power reactors to supply electricity to the Baimsky GOK mining site. The second one

is an onshore small-scale nuclear power plant in Yakutia. These two projects will use RITM-200 reactor technology in various modifications. Besides, Rosatom is working on the construction of a small NPP with a Shelf-M reactor, which will supply power to the Sovinoye deposit and adjacent ore fields. All in all, Rosatom is developing about ten reactor designs for small-scale nuclear power plants. Discussions are underway between Rosatom and governments of other countries, particularly Mongolia and Myanmar, on the construction of small modular reactors.

New technology

As noted in the report, several countries are increasingly considering, studying and implementing advanced versions of existing water-cooled reactors for the gradual deployment of advanced and more efficient partially or fully closed fuel cycles: **"In the Russian Federation, conceptual studies on innovative water cooled, water moderated power reactors of supercritical pressure are ongoing, including the possibility of a fast-spectrum core. The recent designs are focused on small modular versions**

[…], emphasizing enhanced safety, security, economics, and sustainability.” In addition, Rosatom has entered an advanced development stage with a spectral shift control reactor VVER-S (we wrote about it in our previous issue).

Molten salt reactors are also named in the report among promising coolant technologies. This technology is pursued by Rosatom as well, but not for power generation purposes. A research reactor with molten salt as a coolant is intended to pilot a transmutation technology for minor actinides to obtain less radioactive fission products. The reactor is scheduled to go critical in 2030.

A separate section of the report is dedicated to fast neutron reactors. There are five sodium-cooled fast neutron reactors in operation worldwide: one is located in China, another in India, and three are situated in Russia. Rosatom plans to build another fast sodium-cooled reactor, BN-1200, with a capacity of 1200 MWe. The first concrete for the reactor is scheduled to be poured in 2027. Another sodium-cooled fast-neutron unit — a 150 MWe multi-purpose research reactor MBIR — is now under construction.

Technologies employing heavy liquid metal as a coolant are attracting increasing interest. Rosatom is also ahead of the curve here as it is the first in the world to be building a pilot lead-cooled fast neutron reactor, BREST-OD-300, with a capacity of 300 MWe.

Non-electric applications of nuclear ower

The Nuclear Technology Review names the generation of heat (independently or in co-generation with electricity) for district heating or commercial purposes, water desalination and hydrogen production as the most promising non-electric applications of nuclear power. Rosatom is active in all these areas, too. For example, Akademik Lomonosov in Chukotka supplies the nearby town of Pevek with heat. A desalination plant designed and manufactured by Rosatom is being installed at Akkuyu to provide water for reactors, sanitary, drinking and firefighting needs. The Kola Nuclear Power Plant plans to launch a test bench facility for the production of hydrogen by electrolysis. More than that, Rosatom is working on the design of a 200 MWt high-temperature gas-cooled reactor combined with a hydrogen production plant with an annual capacity of about 110,000 tonnes. The first unit is expected to be built in 2032.

Natural uranium

The IAEA experts quoted global forecasts in their review, indicating that uranium demand over the next five years would increase from about 160 million pounds of U_3O_8 per annum to about 190 million pounds. **“In anticipation of further increases in the spot price for uranium, it is predicted that NPPs’ procurement departments will be looking to forward purchase uranium ore concentrate and to develop once again long-term contracts with uranium suppliers. This has the potential to further increase the spot price for uranium, which is expected to increase from about USD 52.00/lb U_3O_8 to about USD 65.00/lb U_3O_8 by 2027,”** says the report. Reality has outperformed the forecast for now: the spot price as of December 4, 2023 was USD 81.45/lb.

“It is anticipated that new uranium mines will open in the next five to ten years,

including in Australia, Brazil, Canada, Mauritania and Namibia. However, forecast production from these new operations will not be sufficient to make up the supply gap that is currently filled with secondary sources. As such, it is anticipated that exploration activity for uranium will increase in the coming years, including in conventional and unconventional deposit types," IAEA experts predict.

It should be recalled, Rosatom is developing deposits and conducting explorations in Russia and Kazakhstan, and has mining projects in Tanzania and Namibia.

Fuel

The following trends were identified by the IAEA experts in the fuel segment: improvement of fuel safety for the existing large-scale reactors, development of accident tolerant fuels, higher burnup and enrichment, and extension of fuel cycles through higher average burnup.

Besides, new reactor designs require the development of advanced fuels. **"[…] HALEU (high-assay low-enriched uranium enriched up to 20% in U-235 — RN) will be required to manufacture many of the innovative nuclear fuel concepts,"** says the review. The United States has plans to establish a HALEU infrastructure for advanced reactors, but currently only the Russian Federation has a supply chain for HALEU fuel production.

Rosatom is working systematically on developing new fuel compositions and structural materials to make nuclear fuel safer and more cost-efficient. Fabrication technologies for the new — composite in particular — cladding materials are being

studied to improve fuel performance. For example, composite silicon carbide cladding samples passed the first stage of in-pile tests in the BOR-60 research reactor earlier this year.

Development of new methods for the spent nuclear fuel (SNF) management and disposal is becoming increasingly important. Rosatom's activities cover several areas in the SNF segment. The first of them is the fabrication of new fuels from SNF. These are primarily mixed uranium oxide (MOX) and uranium-plutonium fuels. For example, the BN-800 reactor has been operating for a year now with a core almost fully loaded with MOX fuel. Rosatom is also working to obtain commercial quantities of mixed uranium-plutonium nitride (MUPN) fuel.

Second, the Russian nuclear corporation is developing the concept of a balanced nuclear fuel cycle, which provides for SNF reprocessing, extraction of valuable components and subsequent transmutation of the most radioactive elements (minor actinides). The transmutation concept has reached the in-pile testing stage. In December, the first three fuel assemblies with MOX fuel containing minor actinides,

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americium-241 and neptunium-237, passed acceptance tests at the Mining and Chemical Plant (part of Rosatom's fuel division). The fuel assemblies will be loaded into the BN-800 reactor at the Beloyarsk NPP in the spring of 2024. As expected by the researchers, americium and neptunium will be bombarded by fast neutrons and decay into lighter elements, which will have lower radioactivity and shorter half-life than the original isotopes.

Third, Rosatom is developing methods, tools and techniques for the safe management of various types of spent nuclear fuel and radioactive waste, applying them effectively in nuclear legacy management. These efforts have been taken successfully for many years, for instance, in the northwest of the Russian Arctic.

Fourth, Rosatom is deploying infrastructure for the ultimate disposal of spent nuclear fuel and radioactive waste. Finally, Rosatom is involved in many rehabilitation initiatives at former mining sites. One of such initiatives was completed this autumn at the former Taboshar uranium mine in Uzbekistan, the first in the USSR, where mining operations started in the middle of the last century.

Summing up the above, Rosatom's activities are not only in line with, but in many cases at the forefront of, the nuclear industry trends.

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