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Assistance on the Northern Sea Route

Rosatom icebreakers help cargo ships travel the Northern Sea Route and free ice-bound ships. New icebreakers — Sibir, Ural, Yakutia and Chukotka — are under construction; new fuel is developed for advanced Lider-class icebreakers.

Through thin ice

Ice in the Arctic Ocean is relatively thin this winter, so oil tankers and LNG carriers often travel the Northern Sea Route (NSR) without being escorted by an icebreaker. They are assisted by the Marine Operation Center (MOC) of the Russian nuclear fleet operator Atomflot (part of Rosatom). Using an automatic system processing real-time data on the weather, currents, ice motion and other information, the MOC builds an optimal route for each ship. Captains receive information about hazards on the travel route and navigation recommendations.

Commissioned in August 2020, the system is part of the Northern Sea Route infrastructure that makes the navigation in the Arctic as safe and predictable as possible. During the summer navigation season, 11 convoys were escorted using the information system.

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Sparta rescued twice

It is not always possible for the ships to travel the NSR without an icebreaker escort. In late December and early January, Rosatom icebreakers rescued a cargo ship Sparta III trapped in the ice.

Sparta III and an ice-class tug Kigoriak were traveling from Dudinka to Arkhangelsk and got stuck in the Yenisei Gulf because of massive ice ridges. They could not get out of the ice trap; fuel and water were running short, and instruments froze.

The two ice-bound vessels were rescued by the icebreaker Vaygach working in the Gulf of Ob. It broke ice around the cargo ship and took it in tow. The short scope towing was the only option possible in those conditions, although the standard option is close towing. It could not be used for Sparta III, which has a specific design of the bow, and close towing would have damaged the propelling and steering mechanisms of the icebreaker. Long scope towing was not possible either since ice masses would have put too much load on the towline.

After Sparta III and Kigoriak were escorted by Vaygach through the ridged ice, they set for the mouth of the gulf. Kigoriak managed to make it out of the gulf, while Sparta III got stuck again in a day, with her steering mechanism broken. The crew spent the New Year waiting for help. On January 1, Sparta III was approached by Vaygach and the diesel icebreaker Admiral Makarov. Vaygach made a channel in the ice, while Admiral Makarov took the cargo ship in tow. On January 2, all the three ships passed by to the west of Bely Island in the Kara Sea, where the ice was thinner. Vaygach then returned to her work, while Admiral Makarov escorted

Sparta III into the Barents Sea. On January 12, the rescue vessel Spasatel Karev towed the cargo ship to Murmansk for repairs.

In February, the 50 Let Pobedy icebreaker escorted Sofcomflot's LNG carrier Christophe de Margerie eastwards through the thick winter ice.

Icebreakers under construction

The Baltic Shipyard in Saint Petersburg is building four Project 22220 nuclear icebreakers — Sibir, Ural, Yakutia and Chukotka.

Zvezda Shipyard (Russia's Far East) continues to build the first Project 10510 Lider-class nuclear icebreaker. Having a capacity of 120 MW, the icebreaker will be capable of traveling through 4-meter-thick ice and making a 50-meter-wide channel in the ice. Its design was developed at Aisberg Design Bureau. The Lider-class vessel will be equipped with a RITM-400 nuclear propulsion system developed at OKBM Afrikantov (part of Rosatom). The lead vessel's name is Rossiya (Russia).

A new fuel modification is developed for the Lider icebreakers. In January 2021,

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the Russian Research Institute of Inorganic Materials (part of Rosatom) finished designs of the startup neutron source, fuel elements and burnable absorbers for RITM-400. Another Rosatom Group company — Chepetsk Mechanical Plant — is preparing to begin the production of a zirconium alloy caisson pipe. The pipe will house reactivity compensation rods of the reactor control and protection system.

"Lider will need 1.4 times more fuel than Arktika because its reactors will have more fuel rods. Unlike RITM-200 reactors that have hexagonal fuel assemblies with spacer grids and cylindrical fuel rods, RITM-400 units will have a channel-type core with cylinder-shaped fuel assemblies and self-spacing complex-profile fuel elements," says Gennady Kulakov, Director for Fuel Research and Development at the Russian Research Institute of Inorganic Materials. In addition, the refueling interval will increase from 5–6 years (as existing icebreakers have) to 10 years.

Rosatom signing an agreement with EDF to extend its membership in MAI

Taking Care of Old Plants

In late December 2020, Rosenergoatom (part of Rosatom, Russian NPP operations subsidiary) signed an agreement with the French electric utility company Électricité de France (EDF) to extend its full membership in the Materials Aging Institute (MAI) for 2021–2024. The agreement enables Rosenergoatom to initiate research into the aging of nuclear structural materials and have unrestricted access to the results of research conducted by other MAI members.

Other Russian organizations participating in MAI research projects are the Russian Institute for Nuclear Power Plant Operation, Kurchatov Institute National Research Center and its subsidiary Prometey Central Research Institute of Structural Materials (all — Rosatom).

EDF and its partners — major industrial and utility companies — established the Materials Aging Institute in 2008. Its full members

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include KANSAI (Japan), EDF Energy (UK), CGNPC (China) and the Electric Power Research Institute (EPRI). The MAI aims to join efforts of the academic and engineering communities to study aging processes in structural materials applied in power engineering.

Rosatom takes part in several research projects led by the MAI. One of them is the RPV Integrity project dealing with integrity assessment issues underlying every feasibility study for the life extension of nuclear power plants. The project has three lines of research. First, a series of material studies intended to identify and clarify deterioration behaviors in VVER-1000 reactor structural materials subjected to radiation and temperature aging during an extended (up to 80 years) service life. Second, researchers analyze whether it is possible to use small amounts of samples to correctly assess cracking resistance of the structural materials both in the initial state and after the thermal and irradiation-induced aging. The third line of research is assessment of heat-affected zones and metal condition around weld joints in reactor pressure vessels. The goal is to identify the most affected areas adjacent to the melt front to simulate and forecast the condition of metal in long-term operation.

The Vessel Internal Project is the second major initiative supported by Rosatom. Its purpose is to identify and estimate dependencies of stress corrosion embrittlement in reactor internals. The dependencies will help define optimal annealing conditions for reactor internals to prevent embrittlement.

The third project is dedicated to the management of concrete structure aging. The participants of the project analyze changes

in structural behaviors of containment concrete under the influence of operating conditions, including temperature, humidity and radiation. The studies conducted by Rosatom as part of this project will help develop a formula to forecast concrete aging and calculate the service life of nuclear power plant containments.

The POLYAGE project studies the aging of polymer materials used at nuclear power plants, particularly new-generation cables, in operational conditions. Sheaths and jackets of these cables are made of halogen-free polymer composites. The studies will help monitor aging processes and estimate the service life of the cables.

Rosatom proposed a project on the increased reliability of Eddy current testing on scaled tubes of steam generators at VVER and PWR-based nuclear power plants. It is aimed at obtaining reliable data on the condition of heat-exchanging tubes with scale that distorts eddy current signals. The project provides for theoretical studies, numerical simulations and testing. The data to be obtained will improve the safety margin of steam generators installed at the VVER and PWR based nuclear power plants.

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“Thanks to information sharing and joint research into material aging, the project participants gain knowledge in forecasting changes in material properties and improve their research methodology to timely prevent serious damage to NPP parts and components in long-term operation,” said Vladimir Potapov, First Deputy Director at the Russian Institute for Nuclear Power Plant Operation, who is in charge of research and development and new research projects and sits on the MAI Program Committee.

Joint efforts

As a rule, each MAI project lasts four years. If the project is of interest for MAI members, it is extended for another four years. This duration of projects is an explanation to the four-year extension of the full membership agreement.

Each foreign member of the Materials Aging Institute has the right to make research proposals to the Program Committee. If other MAI members show interest in the proposal and if EDF approves it and finance is sufficient, the new proposal will be included in one of the existing projects. There is a rule that at least two companies have to participate in the project. With this approach, tasks are solved more effectively as the parties share their expertise. For instance, it was researchers from France first and then from China who took interest in the project on the increased reliability of Eddy current testing on scaled tubes of steam generators at VVER and PWR-based nuclear power plants. Researchers from the three countries developed terms of reference and an action plan for the project and received approval from the Program Committee.

“Participation in MAI projects gives us an opportunity to present results of our research on the international scale. In 2013–2015, proposals made by Rosenergoatom were treated with distrust by other MAI members, but the situation has changed and we are regularly invited as research partners. This is a well-deserved appreciation of the work done by the Kurchatov Institute, Prometey Research Institute and Russian Institute for NPP Operation,” Yulia Rumyantseva, Head of International Scientific Cooperation at Rosenergoatom’s International Cooperation Department, said. She coordinates contacts between Rosenergoatom and the MAI.

Participants of each project share information in the workshops held at least twice a year. The workshops are organized by responsible project officers. Each project participant presents an intermediate report to be published on the website. All participants have access to the reports while full members have access even to reports on the projects they are not engaged in. **“Cooperation on projects gives us access to the international database on material studies and community-approved results of research while saving time and money**

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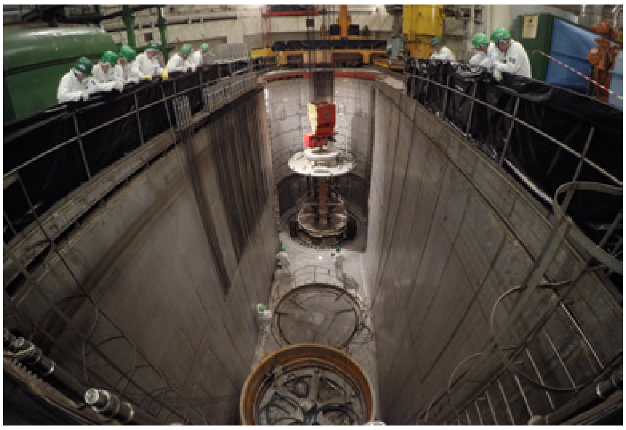

of the participants,” said Rosenergoatom Director for Technology Development Valery Bezzubtsev, Head of Cooperation and a member of the MAI Board of Governors.

The results obtained jointly with other MAI members are put into practice and incorporated into industry regulations. For example, feasibility studies for the extension of service lives of VVER-440 and VVER-1000 reactors have become less conservative thanks to the data obtained in the cracking resistance assessment project. What is more, this data was included in Rosenergoatom’s internal documents and the Russian national standard “Water-Cooled Water-Moderated Power Reactor Pressure Vessel. Embrittlement Resistance Calculations.”

The results of the Concrete Structure Aging Management project will help update and harmonize concrete strength calculation formulas and be part of feasibility studies for buildings and structures of nuclear power plants.

Staff training is another focus area for the Materials Aging Institute. Each year, the MAI holds material deterioration courses for young engineers, researchers and post-graduate students. Rosenergoatom sent both students and lecturers for the training courses organized in 2018 (France) and 2019 (China). In 2020, the courses were to be held in Russia but, because of the pandemic, were rescheduled for 2021. The training courses are expected to take place in November both online and offline.

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Caring for Brazil

We continue writing about the countries where Rosatom operates. Our today's article is about Brazil, a country Rosatom supplies with isotopes. It also discusses a possibility of building a nuclear power plant in the country and using nuclear technology in the local agriculture industry. The most vivid event of the last month was Rosatom's participation in the reintroduction of rehabilitated animals.

In January 2021, employees of the Brazilian environmental organization Instituto Vida Livre and Rosatom Latin America released animals, which fell victim to poaching, accidents and other human activities in natural habitats, back into the wild. Before the release, the animals underwent rehabilitation. **"The moment of the release was very emotional — they had suffered from people so much. We are very glad to take part in the event and thus make a contribution to the sustainable development of Brazil. Environmental protection is one of Rosatom's priorities,"** noted Ivan Dybov, Director of Rosatom Latin America.

Instituto Vida Livre is planning to organize Espaço Vida Livre with financial support from Rosatom. Espaço Vida Livre will be a dedicated rescue and rehabilitation area for up to 5,000 wild animals, including rare and endangered species. Animals will be kept there until they are ready to return to their natural habitats. Rosatom Latin America assures that they will continue cooperation with Instituto Vida Livre throughout 2021.

Rosatom also supports Os Arteiros, a group of actors from one of the poorest neighborhoods in Rio de Janeiro. Last October, Os Arteiros produced and performed the Amores, a charity play dedicated to the Children's Day. The actors were children living in Cidade de Deus. The play is a series of sketches based on classic literature and stories from real life in the favelas where people suffer from domestic violence, crime and racism. The play was broadcast over the Internet.

In June 2020, amidst the pandemic, Rosatom financed food boxes and face masks distributed among 300 families living in Cidade de Deus. **"My name is João, and I represent Frente CDD. I would like to say thanks to Rosatom for the help it has provided. We are now giving food boxes to the residents of Cidade de Deus. We are thankful to Rosatom, and people are excited about the help they have received,"** says a representative of Frente Cidade de Deus, a neighborhood association, in a video address.

Besides, Rosatom supports the Bolshoi Theater School in Joinville, Santa Catarina. The school was founded twenty years ago by experienced ballet dancers from Moscow. School graduates dance in the Bolshoi Theater and many European and American theaters.

Isotopes supporting health

Isotope deliveries to Brazil is Rosatom's direct contribution to better healthcare and quality of life in the country. Brazil is the largest nuclear medicine market in Latin America. As a global leader in the production of isotopes, Rosatom accounts for more than 50% of total supplies to Brazil. Isotope deliveries to the country started in 2014. At present, Brazil receives iodine-131 and molibdenum-99 on a weekly basis for cancer diagnostics and treatment. Iodine-131 is used

to treat thyroid cancer and neuroblastoma, a malignant tumor forming in nerve tissues. Molibdenum-99 is used to diagnose tumors in different bodily tissues and analyze hemodynamics. Rosatom is preparing for deliveries of lutetium-177 and actinium-225. The two isotopes are used in treatments of prostate cancer. Actinium-225 is also reprocessed into bismuth-213, which treats many different forms of cancer.

Reactor combinations

Brazil has long been a nuclear country — it operates one nuclear power plant — Angra — with two power units having a capacity of 690 MWe (Angra 1, Westinghouse PWR) and 1,275 MWe (Angra 2, Siemens PWR). According to the IAEA, they generate around 15 TWh of electric power annually. Nuclear accounts for as little as 3% of the total energy mix, but the country plans to develop nuclear energy. Its national energy plan for the period until 2050 (PNE2050) provides for the construction of 8–10 GW of new capacity by 2050. The most important task is to finish Angra 3.

The first concrete for the power unit was poured in June 2010, but the construction was suspended and contracts terminated

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because of anti-corruption investigations. According to the plant owner Eletrobras Eletronuclear S. A., Angra 3 is 58% complete. Last November, President Jair Bolsonaro signed two laws providing around 744 million reals (149 million US dollars) in finance for Angra 3. The money will be used to carry out an independent technical and financial audit of Angra 3 and do some urgent work. When it is completed, Brazil is expected to tender out an EPC contract to finish the construction of the unit. Rosatom will make a decision whether to bid for the contract when audit results are announced.

Brazil is also considering the possibility of building small modular reactors (SMR). In 2019, Rosatom Latin America and Rusatom Overseas held several seminars at the request of the Brazilian party to present onshore and offshore SMR designs.

"Brazil also plans to construct a multi-functional research reactor, and we are considering our participation in the project," Ivan Dybov said.

Finally, the government of Brazil is studying the possibility of using nuclear technology in agriculture. The segment is also of interest for Rosatom. The Russian nuclear corporation has taken part in a public call from the state-owned company Amazul, which considers irradiation technology options available in the market.

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Uranium in Limbo

The latest edition of the Red Book published by the OECD Nuclear Energy Agency and the IAEA testifies to the crisis in uranium production, with mines mothballed, production reduced and exploration rolled back. The pandemic makes the situation even worse. But since forecasts of future demand for uranium vary twofold and uranium from mines is not the only feedstock for nuclear fuel, it is not easy to assess risks of the uranium industry.

The Red Book is published twice a year. Its informal name comes from the color of its cover. The purpose of the Red Book is to accumulate and structure the information about uranium exploration, resources, reserves, mining and demand in the reporting period. The report published in December 2020 analyzes processes taking place in the uranium market in 2018–2019 and compares them with the preceding two-year period. The publication also accounts for the extraordinary processes that occurred in 2020 on the back of coronavirus pandemic. The Red Book 2020 contains surveys covering 45 countries, but only 31 of them are based on official government data. The remaining 14 surveys were prepared by the NEA and the IAEA Secretariat.

Resources

In 2019, identified recoverable resources in the highest cost category (<USD 260/kgU) were estimated by the Red Book experts to amount to a little more than 8 million tons, which is 1% more than two years ago.

"Global uranium resources have once again increased, but much more modestly so than reported in recent editions," the report says.

The cost category of up to USD 260 per kilogram of uranium includes lower-cost categories. For example, resources in the cost category of <USD 80/kgU (USD 30/lbU3O8) were estimated at less than 2 million tons, while resources at the cost of <USD 40/kgU (USD 15/lbU3O8) amounted to a little more than 1 million tons.

In order to answer the practical question of how much uranium is available for reprocessing into nuclear fuel, one should use the Reasonably Assured Recoverable Resources (RAR) table and take a look at the lowest cost categories (<USD 80/kgU and <USD 40/kgU). Why those categories? Because only low-cost producers of uranium are sure-footed amidst an extended period of cheap uranium.

The lowest-cost resources (<USD 40/kgU) amount to 744.5 thousand tons of uranium. The cost category of up to USD 80/kgU) includes 1.24 million tons of uranium. The reality is much more complicated, though. According to the table, there is no cheap uranium in Namibia, but the Husab Mine has been launched and in operation.

Prices

The spot price of uranium did not exceed USD 29 per pound of U3O8, while long-term prices balanced around USD 32 to USD 32.5 per pound.

The Reasonably Assured Recoverable Resources table says that Kazakhstan is a leader in the cost category of up to USD 40/kgU. Its resources in the category are estimated at 305.8 thousand tons. Kazakhstan is followed by Canada (296.2 thousand tons) and Brazil (184.3 thousand tons). Other countries do not have more than 50,000 tons of uranium resources in this category.

Australia remains a global leader in terms of total resources, but its reasonably assured resources declined from 1.4 to 1.28 million tons following re-estimation of resources and depletion of stockpiled ore at the Ranger Uranium Mine. In Canada, RAR grew from 592.9 to 652.2 thousand tons. **"Overall decrease in identified resources in the low-cost categories [is] due to mining depletion. Increased RAR in the higher cost categories [is] due to new resources identified as the result of exploration activities (i. e. Arrow, Phoenix/Griffon, Triple R and Fox Lake deposits),"** the report says. In Kazakhstan, RAR grew from 434.8 to 464.7 thousand tons on the back of exploration results, particularly at the deposits of Budennovskoye (sites 6 and 7), Inkai (sites 1 and 4), Muyunkum and North Kharasan (Kharasan 1).

In Niger, RAR decreased from 336.4 to 315.5 thousand tons, although resources grew from zero to 9.9 thousand tons in the cost

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category of up to USD 80/kgU and from 237.4 to 238.7 thousand tons in the category of up to USD 130/kgU, according to the authors of the report. In Namibia, RAR went down from 368.5 to 320.7 thousand tons across all categories due to mining depletion and reclassification and removal of 'non-minable' Rössing mine resources. In Russia, RAR decreased marginally, from 260 to 256.6 thousand tons, driven mostly by the depletion of resources at the existing mines.

In general, the report describes the situation with uranium resources as follows, **"The most significant changes during this reporting period are observed in low-cost (<USD 40/kgU) RAR increasing by 4.4%, as well as increases in the higher cost categories (<USD 260/kgU, <USD 130/kgU) of IR by 5.5% and 3.5%, respectively. Reasonably assured resources comprise 59% of the identified resource total, a less than 1% decrease compared to the last reporting period."** In other words, there have been no major changes in global resources over the last two years.

Most of lower-cost (<USD 80/kgU) resources (439.84 thousand tons) can be produced by in-situ leaching (ISL) using acid (another method is alkaline ISL). Underground mining accounts for the second largest category of resources (402.88 thousand tons). Uranium as a by-product or a co-product is the third largest resource (255.17 thousand tons). All the three production methods correlate with Kazakhstan, Canada and Australia (specifically, Olympic Dam) as the countries of production.

Exploration

The Red Book testifies to a dramatic reduction in uranium exploration expenditures. In 2014, exploration and mine development costs amounted to more than USD 2 billion, but already in 2015 fell by more than a half to USD 876.5 million. The cuts continued — in 2018, investments in exploration and development were about USD 500 million. Non-domestic investments decreased from USD 420 million in 2016 to USD 54 million in 2019 (preliminary data).

It should be made clear, though, that development accounts for most of the exploration and development costs. **"China reported the development portion of total expenditures as 98% and 97% of total expenditures in 2015 and 2016 respectively, as the Husab mine was brought into production,"** the report says. And while China's CGNPC spent USD 378 million on the exploration and development of its Husab Mine in 2016, its expenditures decreased dramatically after the launch of the mine in the same year and amounted to USD 108 million in 2017, USD 41 million in 2018 and, according to preliminary data, USD 24 million in 2019.

It should be also noted that non-domestic investments in exploration and development include 'in-country' expenditures — this refers mostly to the data on Russia and China.

Canada, particularly the Athabasca Basin, remains a leader in terms of exploration. **"Expenditures in Canada alone exceeded the total spending of the remaining top five countries,"** the report reads.

Data on exploration and mine development expenditures in 2019 is incomplete because some of major producers, such as Australia and Canada, have not provided relevant information. The latest available data shows a 75% decrease over the period from 2012 until 2018. **"From 2016 to 2018, expenditures decreased in many countries, mainly because of persistently low uranium prices that slowed down many exploration and mine development projects,"** the authors of the report explain.

Production

Kazakhstan has been a leader in uranium production for the last ten years. **"Kazakhstan's production alone in 2018 totaled more than the combined production in that year from Canada, Australia and Namibia, respectively the second, third and fourth largest producers of uranium,"** the report says.

In general, production is decreasing globally. According to the report, almost 63,000 tons of uranium were produced in the world in 2016. The NEA and the IAEA estimated the production in 2019 to exceed 54,200 tons. Namibia was the only one of eight major producing countries to have increased the uranium output in 2016–2018. This was due to the launch of the Husab Mine and improvements in the ore grade at the Rössing Mine. In Canada, uranium production decreased twofold, from 14 to 7 thousand tons, following suspension of production at

Rabbit Lake, McArthur River and Key Lake due to depressed uranium market prices. Production cuts in the USA were even more dramatic, from 979 tons of uranium in 2016 to 277 tons in 2018. The reason was the same — an extended period of low market prices. Kazakhstan's Kazatomprom announced that it would also cut its uranium production. However, the cuts were expressed as percentage of the so-called subsoil use obligations. As a result, uranium production decreased in 2017 but then kept growing as those obligations were growing, too.

The report also accounts for the pandemic-caused reduction in the output in Kazakhstan and at the Rössing Mine, six months' suspension of operations at Cigar Lake, and problems with delivering workers to the Ranger Mine in Australia. **"At the time of writing, it is not clear how these temporary COVID-19 induced restrictions on mining and milling will impact uranium production in 2020 and beyond. Clearly, 2020 production targets will not be achieved and the disruption caused by the pandemic could ripple through 2021, constricting global supply of newly mined uranium,"** the report states.

Production expansion at existing mines and development of new mines will directly

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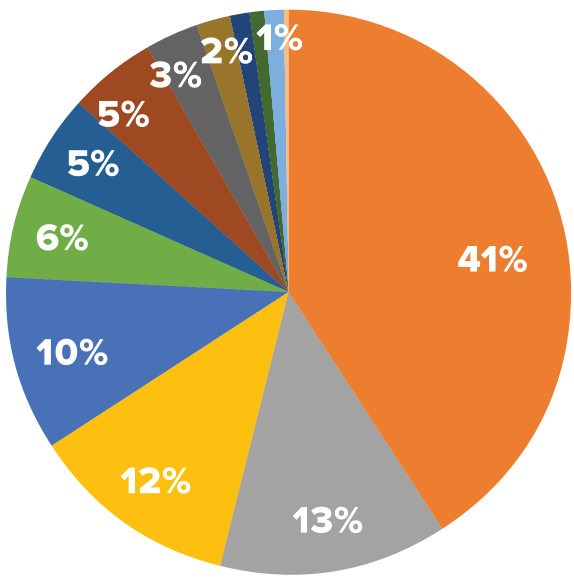
depend on the market, particularly prices, the possibility of rapidly resuming production at mothballed mines, and also whether the market perceives decommissioning of old mines as a threat to reliability of supply. **"Since these sites span several stages of approvals, licensing and feasibility assessments, it can reasonably be expected that at least some will take several years to be brought into production, whereas others may never be. Notwithstanding the time it takes to bring new deposits into production, these new mine developments may be timely since longstanding, significant production centers in Australia (Ranger), Namibia (Rössing) and Niger (Cominak), with cumulative production capacity of 7,900 tU/year) are preparing for closure between early 2021 and the end of 2025."**

Demand

Even the leading global organizations fail to give a clear answer what trend the nuclear power industry will follow. According to the IAEA, there were 450 nuclear power plants with a total capacity of 396 GWe operating as of January 1, 2019. In order to supply them with fuel, 59,200 tons of uranium is needed every year. By 2040, the total installed capacity will either decrease to 354 GW (low scenario) or increase to 626 GW (high scenario). The demand for uranium will, respectively, go down to 56,640 tons or up to 100,225 tons by 2040. **"Both short-term and long-term requirements are much more challenging to project following the accident at the Fukushima Daiichi NPP and the shift towards liberalization of electricity markets."**

The demand for uranium will also be influenced by such factors as installed capacity utilization and improvement in technologies that increase burn-up, extend the refueling interval and decrease uranium content in tailings.

Stock availability of uranium inventories is another important factor. There are no exact estimates of commercial uranium inventories, but they are known to decrease in Europe and the USA. **"In the United States, as of 1 January 2019, total commercial inventories (utilities and producers stocks)**



URANIUM PRODUCTION IN 2018
(NEI/IAEA data)

- 41% Kazakhstan
- 13% Canada
- 12% Australia
- 10% Namibia
- 6% Uzbekistan
- 5% Russia
- 5% Niger
- 3% China
- 2% Ukraine
- 1% India
- 1% South Africa
- 1% USA
- 0,1% Others

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were 50200 tU, a 8% decrease from the 54488 tU of inventories held in 2017 (EIA, 2019)… In the European Union, uranium inventories held by utilities at the end of 2019 totaled 42912 tU, enough for an average of three years' fuel supply, a slight decrease of 5% since the end of 2018 and a 17% reduction since 2015."

Finally, the demand for uranium might be affected by spent fuel refabrication. As you may know, the first commercial fuel assemblies containing mixed uranium plutonium oxide (MOX) fuel were loaded into the BN-800 reactor of the Beloyarsk nuclear power plant (Russia) in 2020. Replacement of conventional fuel with MOX fuel in the BN-800 reactor will be completed in 2022. Refabrication makes it possible to repeatedly use the initial material and reduces demand for natural uranium. However, this technology will begin to produce effects on the market only in the second half of the 21st century.

According to the Red Book experts, the identified low-cost (<USD 80/kgU) resources are enough to meet even the high-case demand until 2040. **"The currently defined resource base is more than adequate to meet low and high case uranium demand through 2040, but doing so will depend upon timely investments to turn resources into production. Nonetheless, meeting high case demand requirements to 2040 would consume about 87% of the total 2019 identified resource base recoverable at a cost of <USD 80/kgU (equivalent USD 30/lbU3O8)."**

It should be made clear that identified resources include both reasonably assured resources and inferred resources, which need to be confirmed yet. If we divide RAR by

annual demand for uranium, we will see that these resources will suffice for approximately 22 year in the low-case scenario and 12 years in the high-case scenario. Yes, we should consider other sources as well. In 2018, uranium from mines accounted for 90% of the total demand (95% in 2017), but even in this case the extension will not exceed one or two years.

And even if we take an average term and assume that resources are not replaced at all, the industry will have 15 to 17 years until the existing resources are totally exhausted. Exploration continues at the existing mines, and depleted reserves are replaced with identified resources, so the total amount of resources will not change much. The key question is then as follows: how easy will it be to bring new resources into production? **"Challenges remain with depressed market prices and other concerns in mine development include geopolitical factors, technical challenges and legal and regulatory frameworks,"** the report summary says. NL

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Energy for Future

The Akkuyu NPP will make a large contribution to the Turkish economy and also improve the scientific and intellectual potential of the country. The plant will be one of the safest nuclear facilities in the world. This is confirmed by independent audits and proved by expertise of Russian engineers. The Akkuyu project has already benefitted the region where the Turkish first nuclear power plant is located.

Joining the 'nuclear club' gives Turkey a chance to become a technology leader, Anastasia Zoteeva, Chair of the Board and CEO of Akkuyu Nükleer, said in an interview to Bloomberg. **"The nuclear power plant will, of course, contribute to the local economic development because nuclear secures a reliable energy supply at a predictable price. Technology and science will also develop at pace. (…) Needless to say, this will improve the intellectual potential of the country,"** Zoteeva stressed.

The CEO noted that there were 8,000 people working on the construction site with 80% of them being Turkish citizens. This number will grow up to 12,000 people at the peak of construction. After the nuclear power plant is commissioned, it will employ 4,000 people. Turkish employees will be able to replace Russian workers in many areas — their training is already underway.

Anastasia Zoteeva also said that, despite the pandemic, all the operations scheduled for the previous year were completed on time. For example, a core catcher and an internal containment of the reactor building were installed at Unit 1. At Unit 2, workers also installed a core catcher in its permanent position and completed the first tier of the

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internal containment. Construction works are going on at three units simultaneously. Turbine buildings and other auxiliary facilities of the nuclear power plant are also being constructed. **“We did not stop working during the pandemic — not for an hour. We took every step to ensure safety of our employees. The Turkish government gave us much support. We managed to continue work on the site even in the most difficult situations,”** Anastasia Zoteeva stressed.

The plan for this year is to obtain a license for Unit 4 and continue construction at the first three units, she said.

The Akkuyu NPP is an advanced reliable plant built in full compliance with Turkish, Russian and international standards of quality and safety, Sergey Butskikh, First Deputy CEO at Akkuyu Nükleer and director of the under-construction nuclear power plant, said earlier. **“Akkuyu will be one of the safest nuclear power plants in the world. Safety is and will be our top priority throughout the service life of the plant. The safety culture pierces every aspect of the project and determines every stage and form of the work we do. Safety systems account for about 40% of construction costs,”** Sergey Butskikh stressed.

He reminded that the construction is supervised by Akkuyu Nükleer and its contractors, as well as by independent auditors, such as the French engineering group Assystem and Turkey’s Nuclear Regulatory Authority (NDK).

Russian companies continue to manufacture and ship machinery and equipment for the nuclear power plant right on schedule. In late January, the Petrozavodsk branch of AEM Technologies (part of Rosatom’s mechanical engineering division) shipped a set of embedments and mounting hardware for the pressurizer and emergency core cooling system tanks. The embedments are 4-meter 6-ton steel rings embedded in the concrete foundations and slabs to be connected with the mounting parts of the equipment. The company has started to assemble spherical casings of the primary coolant pumps for Akkuyu Unit 2. All four guide vanes for the pumps are ready for shipment to the construction site.

With a multi-level safety system, the Akkuyu NPP will be able to withstand a 9-magnitude earthquake. The plant is designed and constructed accounting for specific landscape and climate in the Mersin province. Seismic surveys around the current construction site started back in the 1970s. According to the environmental impact assessment (EIA) report approved by the Ministry of Environment and Urbanization of Turkey, the Akkuyu site is recognized as one of the seismically safest areas in Turkey. The EIA report is based on 250 technical surveys conducted by universities and government organizations in 1974–2010. In 2011–2012, four independent research teams from the Boğaziçi University Kandilli Observatory and Earthquake Research Institute (KRDAE), the Russian Academy of Sciences Institute

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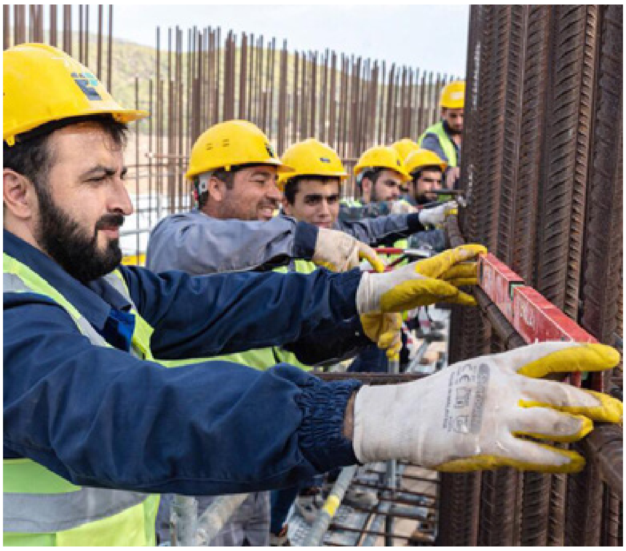

of Earth Physics, Worley Parsons (EU) and RIZZO (USA) carried out seismic hazard assessment studies for the Akkuyu nuclear power plant. In addition, the Civil Engineering Department of the Middle East Technical University and the Naval Engineering Research Center carried out a comprehensive assessment of tsunami hazards for the Akkuyu NPP.

The Akkuyu nuclear power plant is already changing the local life for the better. New houses are built and new stores opened in the neighboring communities of Silifke and Taşucu. Before the project launch, the population of Taşucu was about 10,000 in winter months and has grown to nearly 50,000 since then. **"Construction in the region is going on a large scale. For example, we are preparing a development plan of a residential area for Russian workers. It will be built between Silifke and Taşucu and consist of 3,000 houses,"** said Nurettin Kaynar, Chairman of the Silifke Chamber of Commerce and Industry. The services segment is also seen to rebound. Kaynar explains, **"For example, a car rental company is preparing to open an office in Taşucu. Our economic and social life becomes more active. I think the region will benefit from those changes."**

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Personnel is Key

In late January, 13 students from Egypt defended their graduation theses at the Tomsk Polytechnic University (TPU, Russia). They completed a 5-year graduation course in Design, Operation and Engineering of Nuclear Power Plants.

Classes were taught in two languages, English and Russian. This year, a total of 48 students completed the course. Along with Egyptians, there were students from Vietnam, Kazakhstan and Russia.

The students from Egypt started education in their home country. For the first three years, they studied theoretical sciences at the Egyptian-Russian University and then continued their studies at I. N. Butakov Center for Science and Education of the TPU Power Engineering School. Their education program was taught fully in English.

"Russian universities offer about 10 graduation courses in nuclear power engineering, but our program is unparalleled in its comprehensiveness. We teach the best engineers for the nuclear power industry — they do not specialize in a narrow field like a reactor, a steam generator or turbines alone. Our graduates can manage all operations of a nuclear power plant," Sergei Lavrinenko, an education program coordinator, explained.

The students studied not just the fundamentals of physics and kinetics and neutronic calculations, but also the principles of design, operation and engineering of nuclear power plants. Practical classes were held at a human resource training center in Volgodonsk.

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"I liked the Russian education system very much. The subjects we were taught were very useful and gave us much theoretical and practical knowledge. A lot of practical training is what makes the study at the Tomsk Polytechnic University different. This is very important for our profession. I am going to return to my home country and work at El Dabaa nuclear power plant, which is now under construction," said Mina Sami Bules Tawadros, a graduate from Egypt.

As part of their graduation exams, the students presented projects covering many different aspects of nuclear power technology, including design and engineering of nuclear power plants, performance improvements in reactors, heat exchangers, steam generators, condensers and turbines, and disposal of radioactive waste.

"Since our graduates have comprehensive knowledge about nuclear power plants, they are in great demand. There were up to four jobs per program graduate in 2020," Sergei Lavrinenko said.

The tuition of Egyptian students was paid by the Russian Ministry of Science and Higher Education. The graduates will have a chance to take a job at Rosatom's companies in Egypt or nuclear research centers.

Employees for El Dabaa are also trained in Egypt. One of such training centers is a Nuclear Technology School in El Dabaa. As reported by the Ministry of Education of Egypt in January, its curriculum for senior year students was updated in cooperation with the Nuclear Power Plants Authority (NPPA) of Egypt. The new curriculum provides for more classes to be held in the English language. Some subjects will be

taught by external nuclear experts. According to Mohamed Megahed, Deputy Minister for Technical Education, in 2020, 60 students out of 3,700 applicants were enrolled in the Nuclear Technology School for the next year.

The importance of training was stressed by Amged el-Wakeel, Chairman of NPPA. In an interview to Al Gomhuria daily, he reminded that Egypt had been training technical staff for the nuclear industry since 1976. **"According to the agreement between Egypt and Russia, Egyptian engineers are trained and take refresher courses in Russia. The agreement with Rosatom provides for 2,150 Egyptians to be trained in nuclear reactor operation and maintenance,"** Amgad Alwakeel said.

El Dabaa project will affirm the role of Egypt as a leading country in the Middle East and North Africa and bring it to the ranks of the few countries possessing advanced nuclear technology, he stressed. Egypt started working on its civil nuclear program back in 1955 and stood at the origins of the IAEA, he added. The head of NPPA reminded that the contract for the construction of a nuclear power plant between Russia and Egypt came

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to force in December 2017; the site license was obtained in March 2019. The next step is to issue a construction license that will enable the contractor to begin concreting of the basemat for Unit 1. In the meantime, according to Dr. Amged el-Wakeel work is nearing completion to build a pier for seagoing cargo. Residential facilities for local and foreign staff are also about to be completed.

The importance of El Dabaa project has been repeatedly stressed by the authorities of Russia and Egypt. In late December 2020, Egyptian President Abdel Fattah al-Sisi said at a meeting with Rosatom Director General Alexey Likhachev that Egypt saw El Dabaa as a new milestone in the Russian-Egyptian cooperation. The nuclear project is a symbol of friendship between Russia and Egypt, he stressed. President al-Sisi expressed confidence that, with the Russian expertise in the construction of nuclear power plants, El Dabaa would be built to the strictest safety and efficiency standards.

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Nothing but Best for Rooppur

Construction of the Rooppur nuclear power plant has entered its most active phase. There are more and more workers on site with the majority being locals. The nuclear plant will use the latest technology and most advanced solutions developed by Russian engineers.

The Rooppur nuclear power plant, which will be the first in Bangladesh, has entered the most active construction phase, according to Igor Tupilov, Director of Atomstroyexport (ASE, Rosatom engineering division) branch in Bangladesh. The work is generally on track, he added. A short delay was caused by the pandemic, but the on-site team is working to catch up with the schedule. **"We have brought COVID-19 cases on the site under full control so the infection has almost no influence on the construction process"**, Igor Tupilov stressed.

He said that the number of on-site workers was growing to exceeded 18,000 as compared to the average of 12,000 working on the construction site in the previous years. More than 80% of the workers are Bangladesh nationals. Igor Tupilov said, **"The contribution of Bangladeshi workers, surveyors and engineers to the construction of the country's first nuclear power plant cannot be overestimated. The figures speak for themselves: there are about 2,500 people from Russia and 16,000 from Bangladesh working on the site."**

Igor Tupilov reminded that Rosatom was also heavily engaged in staff training. Every

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month, around 60 to 100 workers complete vocational courses for welders, steel fixers and concrete layers at a dedicated staff training center in Bangladesh.

He explained that the most difficult part of the project was to coordinate all construction-related processes and meet the project schedule in full accordance with the contract.

The director stressed that the Rooppur NPP was the largest infrastructure project in Bangladesh, **"The construction of Rooppur is under the spotlight of attention from the Russian nuclear corporation Rosatom and the Russian government, which considers the project to be of extreme importance."**

The nuclear plant will use the latest technology and most advanced solutions developed by Russian engineers.
A remarkable example is the Russian Tongue and Groove Walls (TGW) technology used by Rosatom's engineering division to shore the pits for water intake facilities and a pump station at the Rooppur construction site. TGW is a Lego-like set of tongue-and-groove elements with reinforcing beams. Other construction pit sheeting solutions could not be used because of complicated hydrogeological conditions on the site.

TGW has a number of advantages over similar solutions, such as faster and easier assembly and high durability at a lower cost. TGW also needs less time to sink. Besides, TGW elements can be stacked up easily, thus reducing logistic costs. The TGW technology reduces installation time twofold and installations costs and materials by up to 30%.

While the work is going full tilt on the construction site, Russian manufacturers continue sending machinery and equipment

to Bangladesh for the under-construction nuclear power plant. In late January, the Volgodonsk-based production facility of AEM Technologies (part of Rosatom's mechanical engineering division) manufactured and shipped a set of internals for the reactor pressure vessel of Unit 1. The vessel internals include an 11-meter core barrel, a core baffle and a protective tube unit, all together weighing more than 210 tons.

The products were first taken by road from Volgodonsk to the port of Novorossiysk and then will be shipped by sea and river to the construction site in Bangladesh. The water route is about 14,000 km long.

The Rooppur nuclear power plant is constructed to the Russian design. The Rosatom engineering division is in charge of design and construction of the plant. The plant will have two power units with VVER reactors. Their design life is 60 years extendable by 20 more years. Each power unit will have a capacity of 1,200 MW. Rooppur 1 will be commissioned in 2023, to be followed by the second unit in 2024. AEM Technologies (part of Rosatom) manufactures key equipment for the nuclear islands of the two power units.

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