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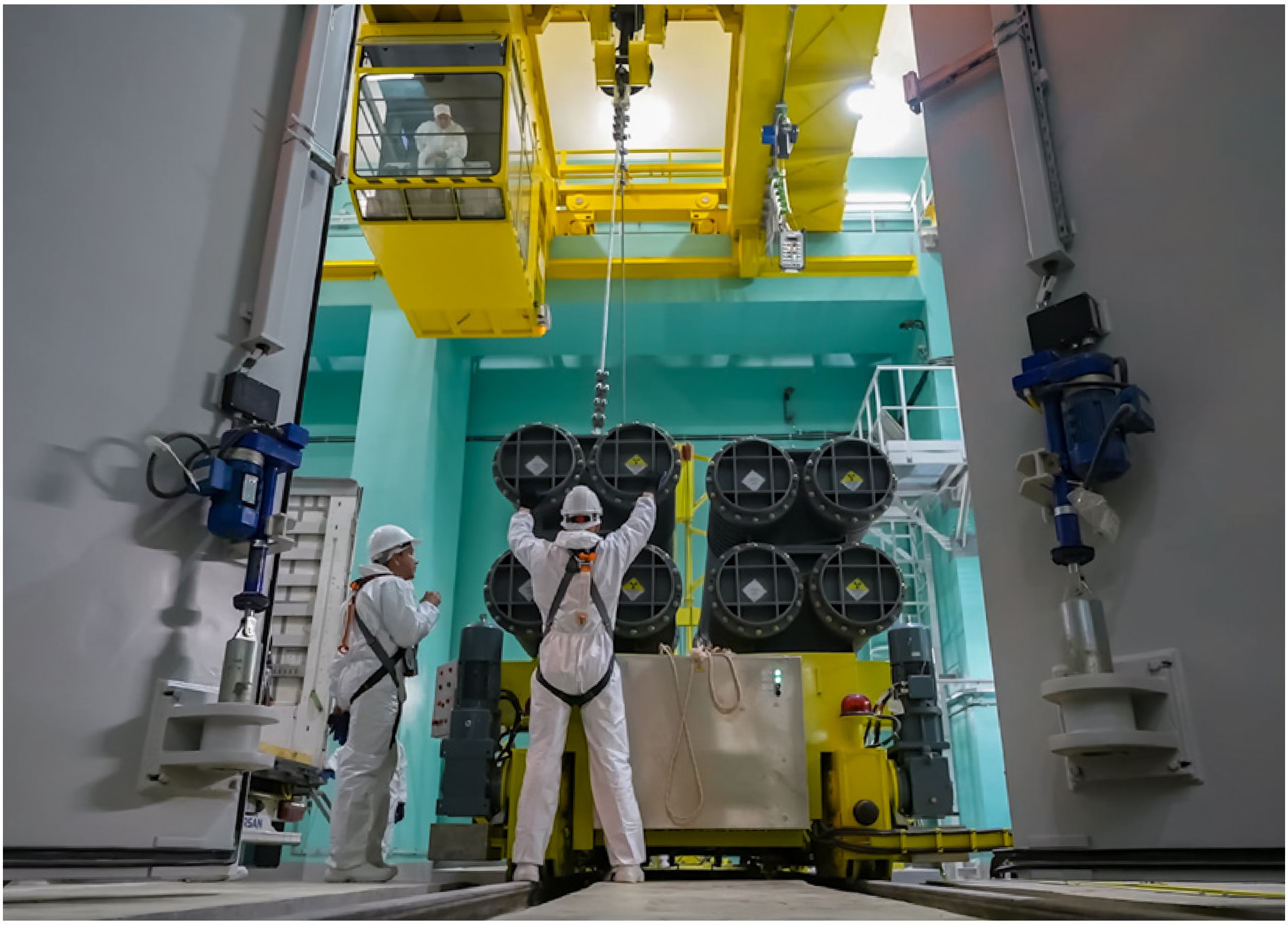

Akkuyu's First Breath

The first delivery of nuclear fuel for Akkuyu Unit 1 arrived at the construction site. Since then, the power plant has been considered a nuclear facility, and Turkey has become a nuclear nation. The fuel delivery ceremony was attended by IAEA Director General Rafael Grossi, Rosatom Director General Alexey Likhachev, and Turkey's Minister of Energy and Natural Resources Fatih Dönmez. Russian President Vladimir Putin and Turkish President Recep Tayyip Erdogan watched the event via video link.

“This is a very exciting moment for everyone. If compared with a human life, it is like the first breath of a child. There is still much ahead: the child will be given a name, learn to walk and talk. But the first breath has been taken and the world has been told: there is another nuclear facility on the Earth,” Alexey Likhachev said.

Fatih Dönmez received from Rosatom's chief a certificate confirming that the fuel had been delivered in full compliance with the applicable safety standards and regulations. The ceremony ended with a symbolic move: Gülnar District residents — a senior person, a schoolchild, and a young nuclear engineer — raised ‘peaceful atoms’ flag over the Akkuyu NPP as a token of Turkey joining the countries that use nuclear energy for civilian purposes.

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“It is fitting that Turkey joins the club of industrially, technologically advanced countries possessing nuclear energy precisely in 2023 when the Republic of Turkey celebrates its 100th anniversary,” Vladimir Putin commented.

Addressing the audience, Rafael Grossi said: “Nuclear energy gives good, but also responsibilities. That is why IAEA has been associated from the beginning with the project by providing assistance to follow safety standards required. We are doing this today with the spirit of hope, the spirit of success. In another 100 years’ time Akkuyu NPP will still be producing clean energy. You can always count on IAEA in every step in this way from now.”

The delivery of nuclear fuel is an indication that the reactor is in its final construction phase. According to Alexey Likhachev, general construction works at Unit 1 will be completed later this year. They will be followed by commissioning operations scheduled to begin in November. The reactor systems will be tested first separately and then as a whole. The next steps are preparing the reactor for going critical and fuel loading. “The entire process takes many months, but in any case we plan to bring the reactor to criticality next year and continue with gradual power ascension so that it can sustainably generate power by 2025 as provided for in the intergovernmental agreement signed between Russia and the Republic of Turkey,” Alexey Likhachev said during the media scrum.

The project is progressing on schedule and even ahead of it despite an immense number of ‘black swan’ events that occurred in recent years. These were the pandemic, international sanctions, and the disastrous earthquake in Turkey. Coordinated efforts of the united Russian-Turkish team and personal involvement of the presidents of the two countries are the factors that help continue the construction project, Alexey Likhachev noted.

“The significance of this moment extends beyond Turkey. With the global nuclear community committed to delivering new nuclear power plants at the speed and the scale required, the Akkuyu power plant is a powerful symbol of this shared commitment. And clearly the completion of this first unit in about 5 years is a testament to international collaboration and demonstrates that we as an industry can build nuclear reactors efficiently,” WNA Director General Sama Bilbao y León stressed in her greeting speech.

After the Akkuyu NPP is put in operation, its four reactors will annually generate 35 billion kWh of carbon-free power. This will be enough to meet nearly 10% of national electricity needs. With Akkuyu, Turkey will make a step forward to achieve the net-zero goal and strengthen its energy security.

The Akkuyu NPP is the first but likely not the only joint nuclear project of Moscow and Ankara as Turkey plans to build more large nuclear power plants, including one in Sinop. **"We are aware of the Turkish Government's plans. We endorse them and are ready to begin official negotiations. We have definitive proposals on the technical concept, degree of local content, project economics, and management approaches,"** Alexey Likhachev said. The Russian nuclear corporation is also ready to discuss small NPP projects, he added.

> **Akkuyu** is Turkey's first nuclear power plant that will feature four Generation III+ VVER-type reactors. Pursuant to the intergovernmental agreement, Rosatom holds a 100% stake in the project and may sell up to 49% to either one or several investors. The Akkuyu NPP is the first-ever nuclear power project carried out with the Build-Own-Operate model.

Reactors Come in Two

In late April, Atommash (part of Rosatom's power engineering division AtomEnergoMash) shipped two sets of core equipment — two reactors and eight steam generators — for the nuclear power plants. This was the first time in the history of the global nuclear industry that such a scope of equipment had been shipped from one manufacturing site.

Preparations in advance

It is but natural that Atommash started to prepare for such strenuous work in advance. The task was approached in a comprehensive and multi-dimensional manner: production facilities were upgraded and re-tooled, with manufacturing processes digitalized, business processes streamlined, and production teams re-skilled and enhanced.

Since 2018, Atommash has purchased and upgraded dozens of new welding and metal-cutting machines, testing and quality control devices. As an example, a 600-ton

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CNC horizontal milling and boring machine with a 40-meter long working table was put in operation in 2020. With the machine tools upgraded, Atommash has sped up the machining of billets and vessels of steam generators and reactors.

In 2016–2022, the employee headcount increased more than one and a half times. Along with new employees hired, they were also trained under professional development programs. Mentoring and proactive training techniques were used in conjunction with the production upgrade.

Atommash has also introduced 3D scanning to control the geometry of products and an information system to optimize in-plant logistics. The steam generator production flow uses simulation modeling to make production plans and schedules and monitor actual performance against them. Digital systems and solutions monitor the employee condition (movements, key health indicators, use of PPE, etc.).

Atommash also uses digital modeling tools: over 90% of its products have 3D models and can be checked for assemblability. Production processes are managed through the Director's Panel web application. This information system collects data on the key equipment utilization, monitors contract performance and fulfillment of the monthly production plans by section, and analyzes other performance indicators.

Efficient capacity management

It takes more than two years to manufacture equipment for a single reactor. This complex production process is managed through numerous critical control points. For instance, there are about 300 such points for a reactor pressure vessel. Only after one point is passed does the process move to the next one. These critical control points help assess equipment utilization and build an optimal plan based on the effective sequencing principle: after a product passes a manufacturing stage, another one can be taken in. The company's production capabilities allow a number of processes to be run in parallel and several pieces of equipment to reach the final stage at a time.

Where the equipment went

One of the equipment sets went to India's Kudankulam Nuclear Power Plant, to be installed at its Unit 5 under construction. The other went to China and is destined for Unit 7 of the Tianwan Nuclear Power Plant. The total weight of the cargo is 3,400 tons.

The Kudankulam NPP is located in the state of Tamil Nadu in Southern India. Four power units with VVER-1000 reactors are currently under construction on the site. The Tianwan NPP is located in China's Jiangsu Province. Rosatom is building two power units with Generation III+ VVER-1200 reactors at Tianwan.

AtomEnergoMash (AEM) is Rosatom's power engineering division and one of Russia's largest power machinery producers providing comprehensive solutions in design, manufacture and supply of machinery and equipment for nuclear, thermal, petroleum, shipbuilding and steel-making industries.

How the reactors were transported

First, the cargo was delivered by truck to a dedicated berth on the bank of Tsimlyansk Reservoir (Don River) in Volgodonsk. The trucks traveled only at night to avoid creating traffic jams. Municipal services had to block roads and cut power lines because of the cargo's large size. The speed of the trucks was only 2–7 km/h.

On April 27 and 29, the cargo was loaded onto barges to be delivered to Saint Petersburg by river. The barges would cover 3,500 km and pass by the cities of Saratov, Samara, Kazan, Nizhny Novgorod, Shlisselburg and others.

In Saint Petersburg, the barges would go down the Neva River at night under the raised bridges. From there, the cargo would travel to the destination ports through the Baltic and North Seas, Gibraltar, Mediterranean Sea, Suez Canal, Red and Arabian Seas.

Setting new records

AtomEnergoMash will continue to set records in 2023. The companies of Rosatom's power engineering division are planning to ship three more nuclear reactors (again from the Atommash site) and other key and auxiliary equipment for nuclear power plants and icebreaker reactors, as well as dozens of other items of equipment. All in all, AtomEnergoMash's backlog of work includes contracts for the nuclear island equipment for 23 reactors in different countries, in addition to equipment for the LNG projects, shipbuilding, petrochemical, oil refining, steel-making and other industries. NL

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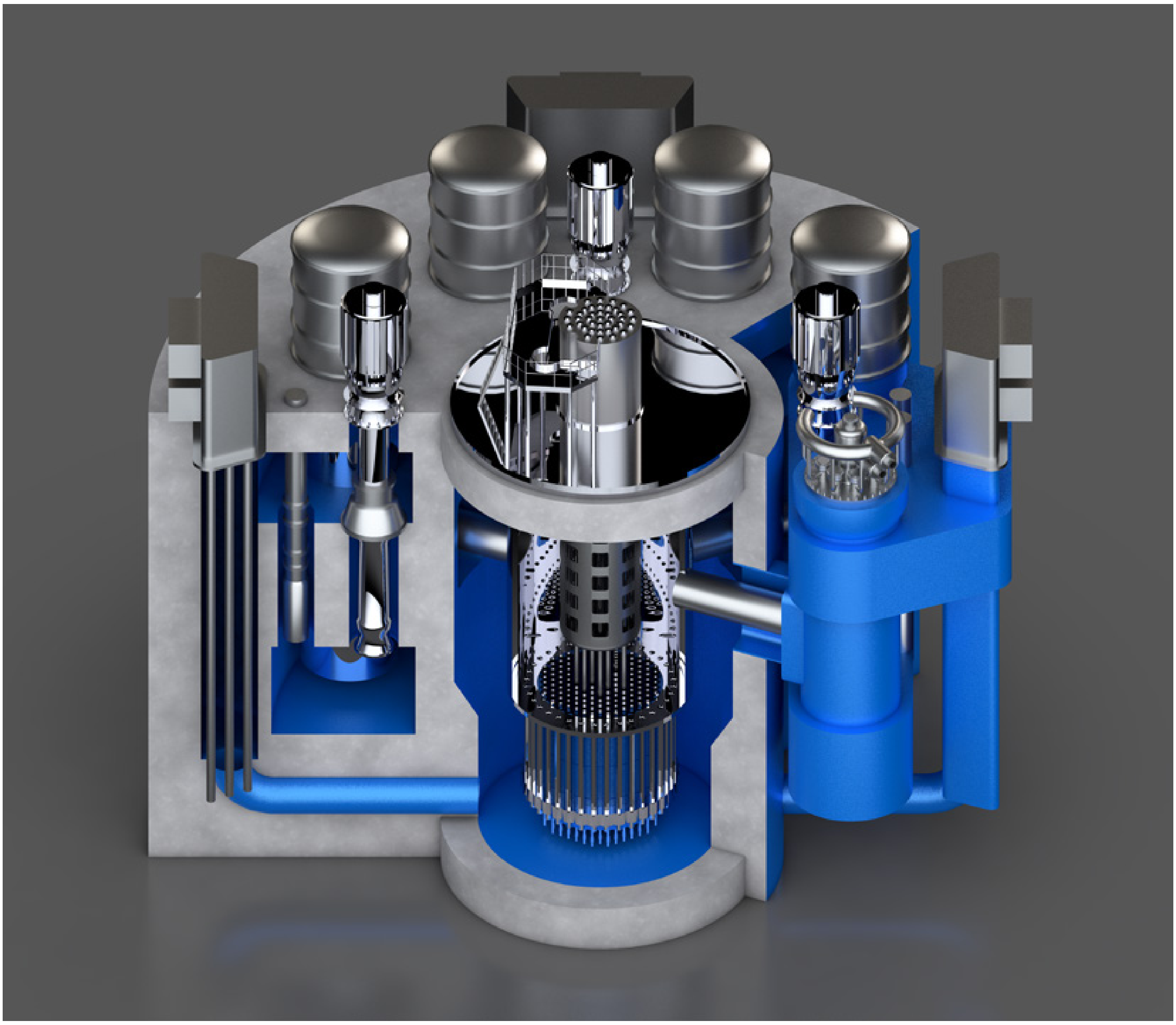

Lead-Cooled Reactor Made Tangible

BREST-OD-300 is the first lead-cooled nitride-fueled fast neutron reactor that brings theory into reality. Its key objective is to demonstrate the feasibility of the latest reactor technologies and the tangibility of closing the nuclear fuel cycle.

Reactor design and operation principles

BREST-OD-300 is a Russian acronym for a "300 MW passively safe pilot demonstration fast neutron reactor." It uses molten lead as a coolant and a mixture of uranium and plutonium nitrides (MUPN) as a fuel. The first concrete for the reactor's basemat was poured in June 2021.

The new type of coolant necessitates a specific design: the core of BREST-OD-300 is located in the central section of a reinforced concrete pool filled with molten lead. Its peripheral sections house steam generators and circulation pumps.

The melting and boiling temperatures and other physical properties of the coolant and the reactor design make it possible to omit the core catcher and many of the auxiliary systems and reduce safety requirements for the out-of-pile equipment. The integral design and physics of the BREST reactor exclude the possibility of accidents that would require evacuation of people.

The reactor has a two-circuit design: nuclear fuel heats molten lead in the primary circuit; molten lead then flows through a steam generator and transfers heat to water in the secondary circuit; water turns into steam and rotates a turbine generator to produce electricity.

BREST-OD-300 is part of the so-called ‘pilot demonstration power production facility’ (abbreviated ODEK in Russian) that also includes a uranium-plutonium fuel fabrication unit and a spent fuel reprocessing unit. New fresh fuel will be produced there

from reactor-grade plutonium and depleted uranium by carbothermal synthesis.

The three ODEK units are meant to demonstrate the sustainability of spent fuel recycling into fresh fuel, that is, the feasibility of a ‘closed’ on-site nuclear fuel cycle.

Multi-dimensional engineering

In late April, the Siberian Chemical Plant (SCP, part of Rosatom’s TVEL Fuel Company), ODEK’s host site, began to assemble a prototype pump for molten lead. Weighing over 30 tons, the pump is made of high-alloy steel grades and ceramic materials. Its parts were delivered to the site in late March 2023. When assembled, it will be tested on a dedicated test bench, in a column filled with molten lead. The pump is capable of pumping 11 tons of molten lead per second through the reactor’s primary circuit, which is comparable to the load of a medium-sized truck.

In 2023, the pump will be tested for pressure and flow performance. Based on the results obtained, the prototype design may be modified to manufacture four pumps for the reactor.

The Novosibirsk Chemical Concentrates Plant (part of Rosatom) is developing dummy fuel assemblies for the mock-up reactor core. They are planned to be ready at the end of 2024 and will be shipped to ODEK.

Fuel rods and fuel assemblies for BREST-OD-300 have been thoroughly studied and tested boforehand. As a recent example, dummy fuel rods were tested in the IGR pulsed reactor (Kazakhstan). Completed in September 2022, the tests and subsequent

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post-irradiation studies confirmed the estimated performance of fuel rods in beyond-design-basis conditions, such as positive reactivity addition.

Meanwhile, researchers study new materials that could improve fuel performance. This February, VNIINM (part of Rosatom) produced a pilot batch of bimetallic tubes with a 0.3 mm thick ferritic steel protective layer. Such tubes can be used as fuel rod cladding in lead-cooled reactors and as a base material for the spacer grid cells in the reactor core. New structural materials will potentially increase the MUPN fuel burn-up in the lead-cooled fast reactors by 20–25% and, consequently, make the reactor operation more cost-efficient.

Much work is also underway to improve employee qualifications. In March, over 30 employees of the ODEK fabrication/re-fabrication unit finished an analytical simulation course. They practiced operational skills, studied production processes and learned emergency procedures.

Later this year, SCP employees will do a two-week internship at the Beloyarsk NPP.

Reactor construction, equipment installation, development of the SNF reprocessing module and other works are fully on schedule. ODEK is planned to be commissioned in its entirety in 2030.

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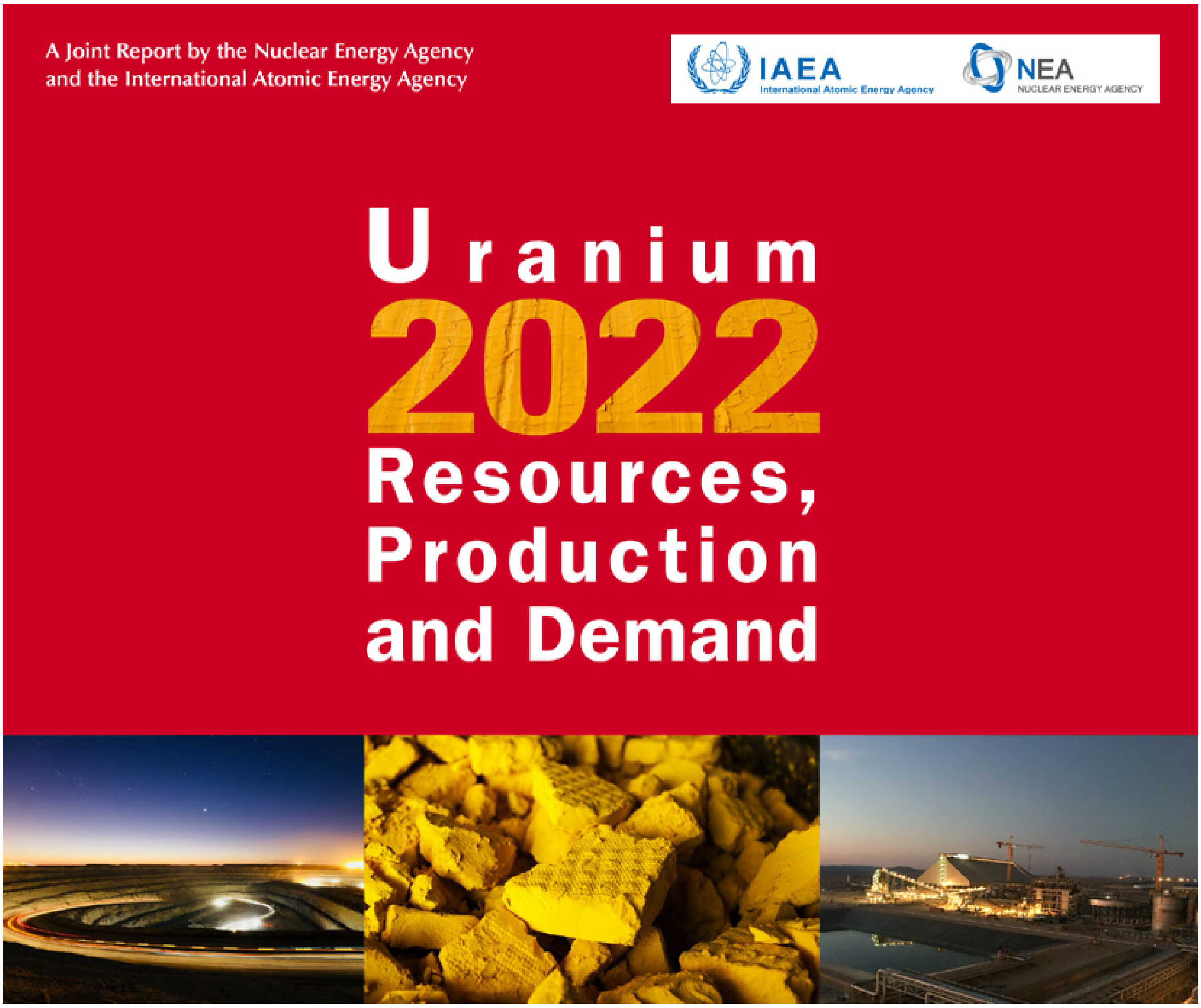

Enough Uranium for 100 Years to Come

In early April, the IAEA and the NEA published their joint Uranium 2022: Resources, Production and Demand report. Also known as the Red Book, it captures the results of 2020 and changes over the two years that passed since the previous edition and also analyzes more recent events having affected the uranium market. These include the energy crisis in Europe, supply chain disruptions, and a price increase to around USD 50–51 per pound of U_3O_8. All combined, they make it economically feasible to mine higher-cost reserves, thus securing nuclear fuel supply for up to 100 years.

The OECD and NEA global uranium industry report was due to be published in late 2022, but the publication was delayed. Despite the delay, the reporting year remained unchanged.

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Resources

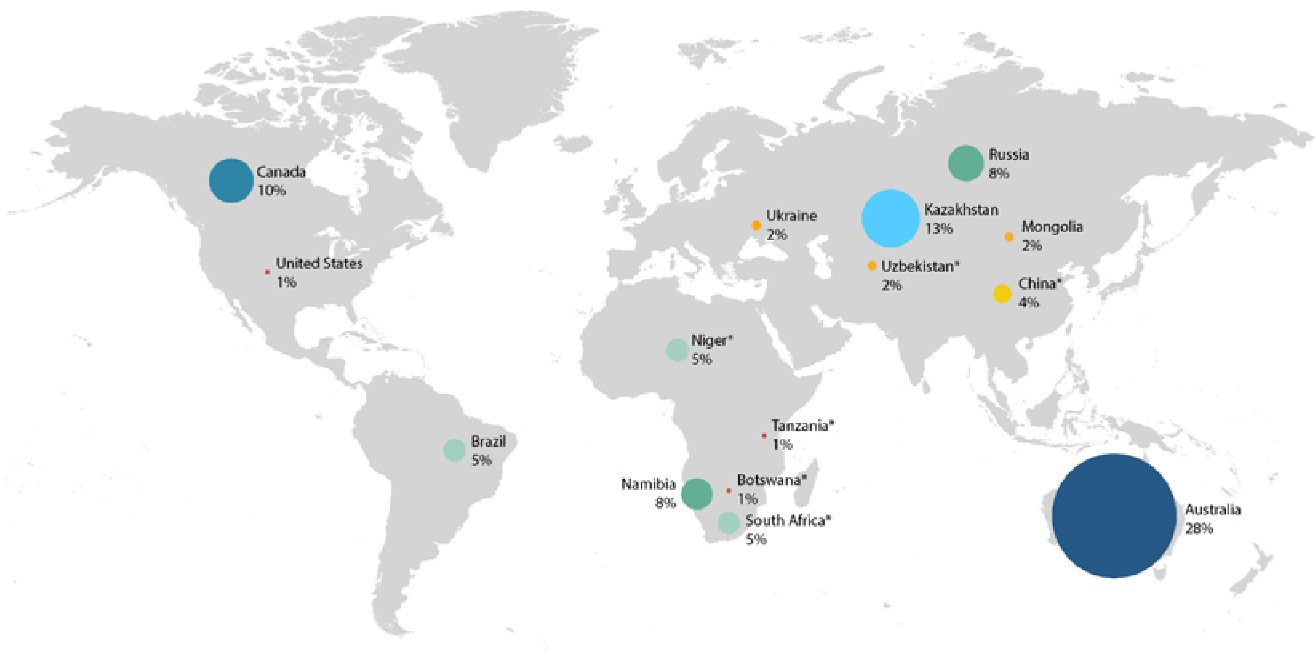
In 2019–2020, global uranium resources decreased by 2% in contrast to an increase of about 1% in the previous two years. Identified resources in the cost category of up to USD 260/kg of uranium (USD 100/lb U_3O_8), which also comprise lower production cost resources, decreased by 152,900 tons (1.9%) from a little over 8 million tons of uranium to just under 7.92 million tons. The resources in the <USD 40/kg U (USD 15/lb U_3O_8) cost category dropped the most, from nearly 1.1 million tons to little under 776,000 tons, down by 28.2%. The <USD 80/kg U (USD 30/lb U_3O_8) category demonstrated only a 0.8% decline, while the resources in the <USD 130/kg U (USD 50/lb U_3O_8) category decreased by 1.1%.

The most dramatic decline occurred in reasonably assured resources (part of identified resources), with the <USD 40/kg U category resources having dropped 38.6%, from 744,500 tons to 457,200 tons. The other category resources showed a much less notable decrease of 2.6% in the <USD 80/kg U category (down to 1.21 million tons), 0.6% in the <USD 130/kg U category (down to 3.81 million tons), and 0.7% in the <USD 260/kg U category (down to 4.69 million tons).

“The decreases were primarily the result of mining depletion and cost category re-assignments of resources in Kazakhstan and Canada. Also contributing to decreases in these and other uranium producing countries were changes in

Figure 1.1. **Global distribution of identified recoverable conventional uranium resources**

(<USD 130/kgU as of 1 January 2021)



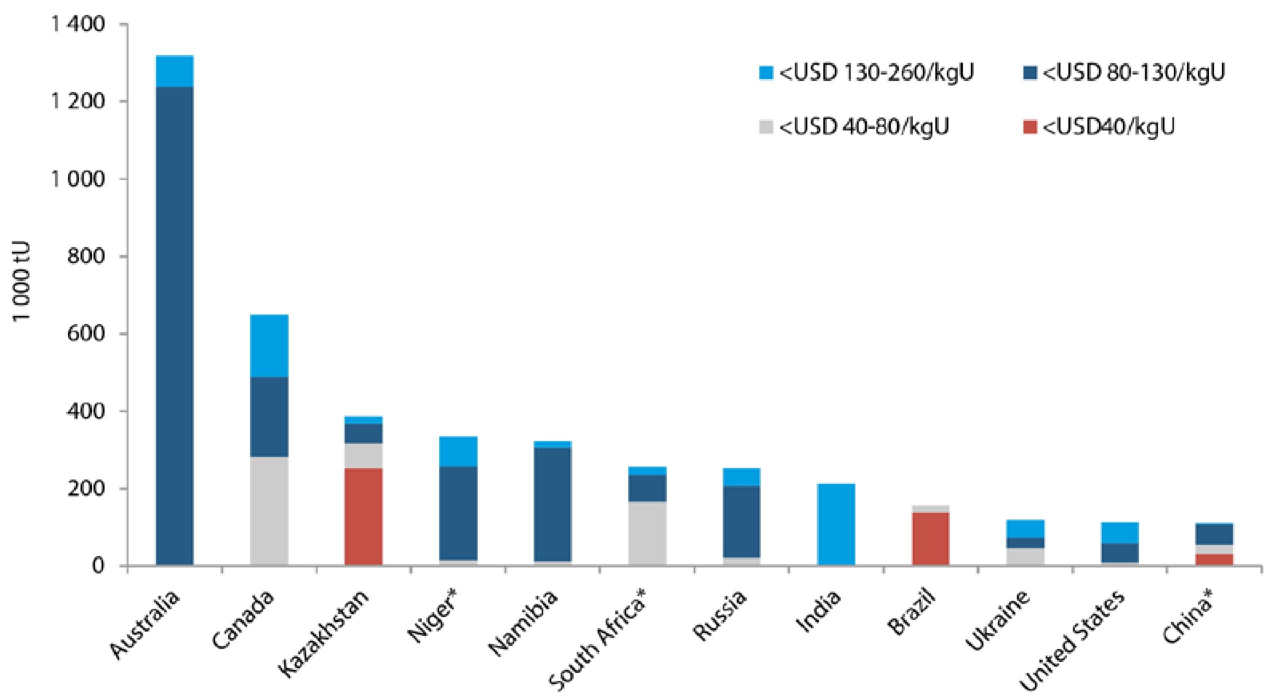
* Secretariat estimate or partial estimate.
The global distribution of identified recoverable conventional uranium resources in the <USD 130/kgU cost category among 15 countries, which are either major uranium producers or have significant plans for growth of nuclear generating capacity, illustrates the widespread distribution of these resources. Together, these 15 countries are endowed with 95% of the global resource base as specified above (the remaining 5% are distributed among another 24 countries). The widespread distribution of uranium resources is an important geographic aspect of nuclear energy in light of security of energy supply.

cut-off grades, updated recoverability information, currency inflation effects and re-evaluations of previously identified uranium resources," the authors of the report explain. In particular, the re-evaluation left Canada with no resources in the <USD 40/kg U cost category. These resources are claimed to be only in Argentina (2,400 tons), Brazil (138,100 tons), China (73,200 tons), Kazakhstan (502,000 tons), Spain (8,100 tons), and Uzbekistan (52,100 tons). However, the report urges to treat the data in the two lowest cost categories with caution **"since some countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently, hosted uranium mining may be underestimating mining costs."**

As for the resources in three higher-cost categories (USD 40 to USD 260/kg U), they decreased in Russia, Ukraine, Kazakhstan, and the Central African Republic. Resource estimates were revised in Mongolia, China, and Turkey. Guiana, Hungary, India, Malawi, Mauritania, Mongolia, Namibia, Niger and Paraguay reported increases in the same resource categories due to the ongoing exploration and new discoveries.

The lowest-cost category of reasonably assured recoverable resources is dominated by the ISL-amenable resources (291,560 tons out of 457,300 tons). The role of underground mining is growing in the three higher-cost categories: 549,600 tons out of 1.21 million tons in the <USD 80/kg U category; 2.14 million tons out of 3.81 million tons in the <USD 130/kg U category, and 2.62 million tons out of 4.69 million tons in the <USD 260/kg U category. The share of heap leaching is also growing in the two upper categories, with resources amenable to this technology

Figure 1.2. **Distribution of reasonably assured recoverable conventional uranium resources among select countries with a significant share of resources**



* Secretariat estimate or partial estimate.

estimated at 268,220 tons and 323,570 tons, respectively.

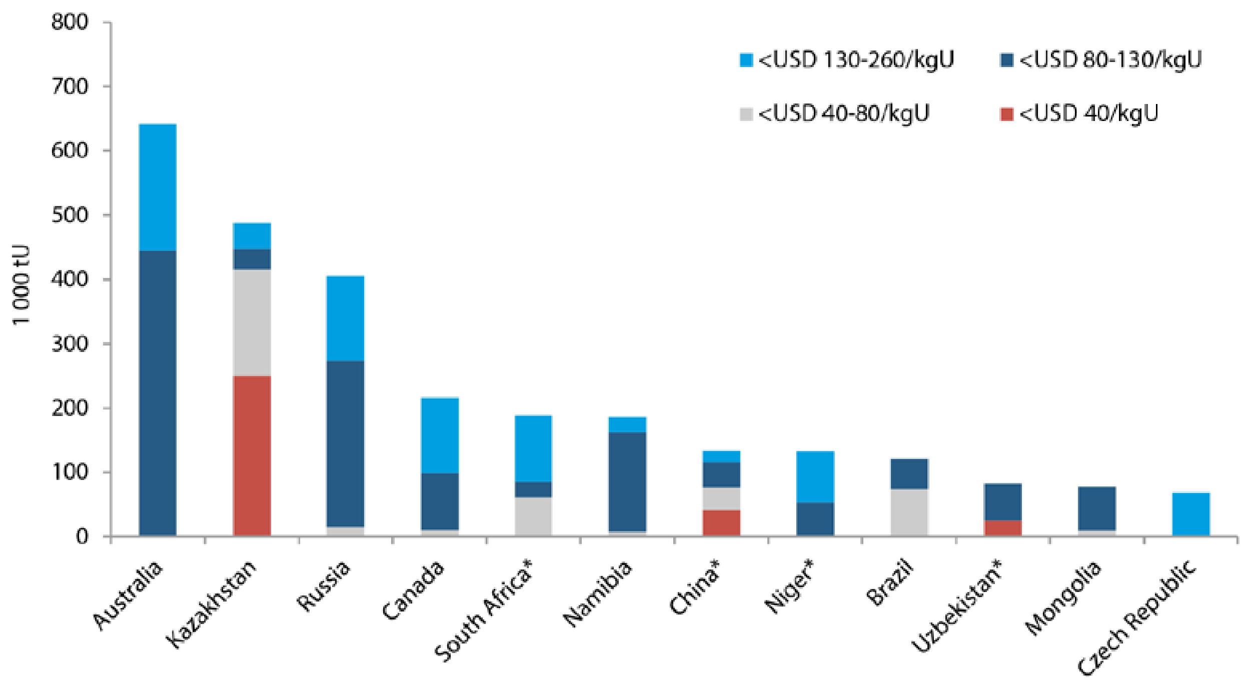
Exploration

Making reliable estimates of exploration costs is not an easy task as not every country shares the necessary data. **"Several countries do not report non-domestic expenditures or have not reported these expenditures recently, and thus the data are incomplete. Private companies in Canada and Australia are known to make non-domestic investments and are likely leading investors in foreign uranium exploration and development activities, but no information has been reported by these governments for the past several years,"** the authors of the report point out. Since 2008, only four countries (China, France, Japan, and Russia) have disclosed their non-domestic uranium exploration expenditures, but China has not reported this data for the current edition. In 2019 and apparently 2020, investments in foreign uranium exploration activities were at their lowest since at least 2014. That year, foreign exploration expenditures were nearly USD 801 million, having dropped 14 times to as little as USD 56.82 million in 2019.

Information about domestic exploration expenditures in 2019 and 2020 was updated by 19 countries. Compared to 2015, investment was down 71%, from USD 876.5 million in 2015 to USD 251.3 million in 2020. However, the latter figure does not include China's expenditures as the country has not reported this data for 2020. In 2019, China ranked second in terms of investment in domestic uranium exploration (USD 154 million).

Among 19 countries, Canada is the leader in uranium exploration expenditures, with USD 210.7 million invested in 2019 and

Figure 1.3. **Distribution of inferred recoverable conventional uranium resources among select countries with a significant share of resources**



* Secretariat estimate or partial estimate.

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USD 140.88 million in 2020. India ranked third in 2019 and second in 2020, having invested USD 66.17 million and USD 47.81 million, respectively. Total known expenditures worldwide amounted to USD 508.47 million in 2019 and USD 251.31 million in 2020.

The new edition of the Red Book features a table presenting drilling data by country. This data was reported by 15 countries, though by nine of them only in part. The table shows that only Namibia and Egypt increased their drilling activity in 2018–2021, while the rest of the countries either decreased it consistently or showed little change. The data, while fragmentary, still suggests a decline in drilling "on the global average" in the period under consideration.

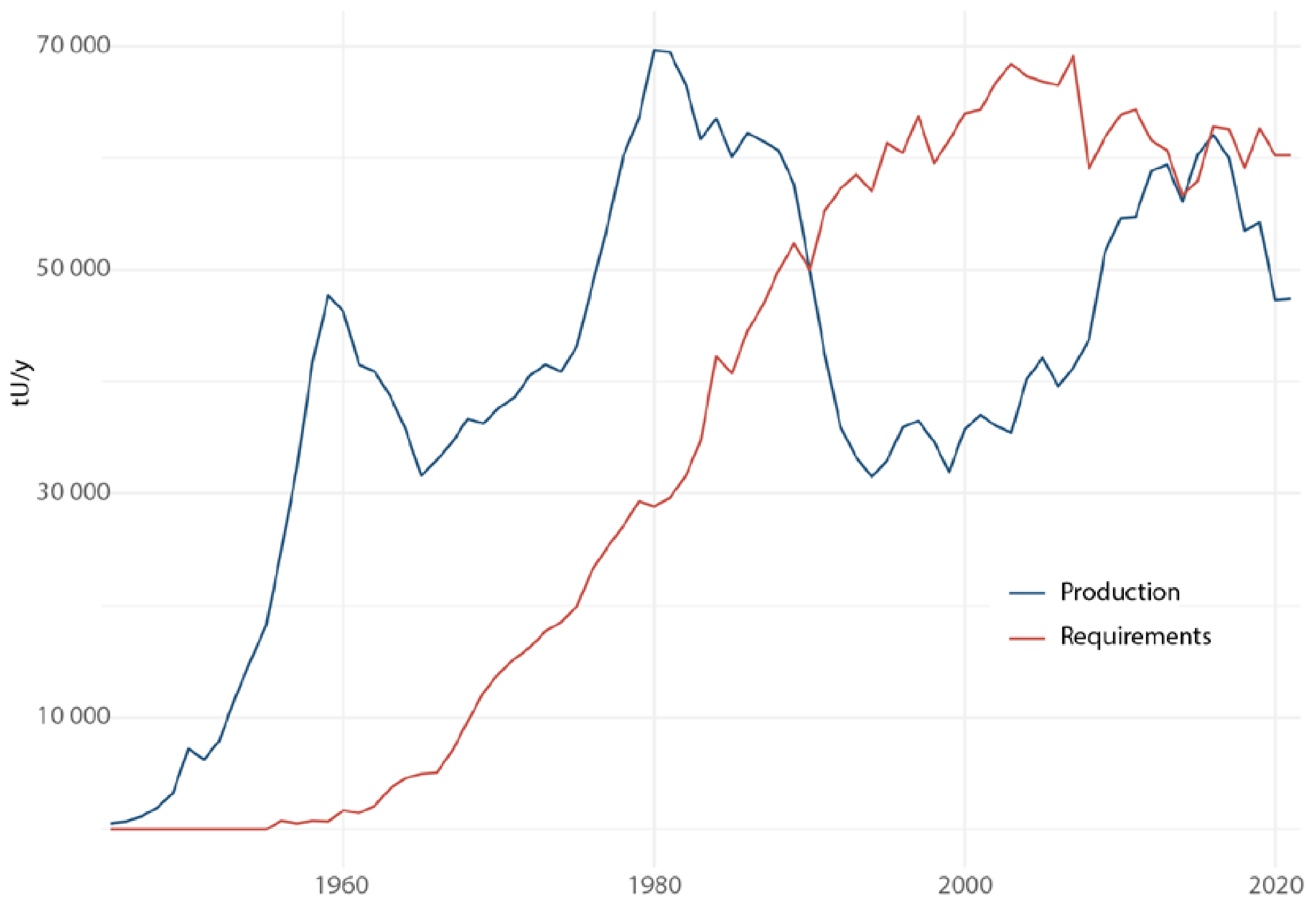
In addition, the report presents information on uranium exploration and drilling expenditures in 2021. Even the preliminary and incomplete data still suggests that both more money was invested in uranium exploration and more meters drilled than a year before.

Demand

The existing 442 nuclear power reactors with a total installed capacity of 393 GWe need about 60.1 thousand tons of uranium per year (about 150 tons per 1 GW of capacity in operation). The low case scenario for the global nuclear power industry assumes that there will be 394 GW of installed capacity in operation by 2040. The high case scenario

Figure 2.6. **World annual uranium production and requirements**

(1949-2021)



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puts this figure at 677 GWe, up 70% from 2020. Accordingly, demand for uranium will also grow to reach 63,000 tons per year in the low case and 108,200 tons in the high case. The biggest growth in installed capacity is expected in East, Central and South Asia, and in the Middle East. In Europe, nuclear capacity will remain at its current levels at best, dropping by a quarter in the low case scenario. Africa, Central and South America are expected to show modest growth. In North America, expectations range from a capacity reduction of 42% to a 3% growth from the 2020 levels.

Supply/Demand

This section of the Red Book answers the question of whether and for how long there is enough uranium to meet the needs of nuclear power plants.

One of the trends noted by experts is that the share of natural uranium in total reactor needs is decreasing. For example, this share was 86% in 2019, having dropped to 79% in 2020. However, the declining production did not affect the supply of fuel for nuclear power plants. The shortage was covered by the so-called secondary supply. Such secondary supply includes excess government and commercial inventories, spent fuel reprocessing, underfeeding and uranium produced by the re-enrichment of depleted uranium tails, as well as low-enriched uranium produced by blending down highly enriched uranium. It is difficult to estimate such secondary supply since this information is not disclosed.

Another driver behind the increase in supply was the growth of prices to about USD 50/lb U_3O_8. Its impact was first felt after the two years in question but was taken into account in building a forecast for the period untill 2040. In addition, supply chain disruptions caused by the pandemic in 2020, the energy crisis in Europe in 2021, and the sanction pressure on Russia in 2022 made the buyers favor long-term contracts to secure uranium supplies. All these factors combined made it economically viable to produce uranium at a higher cost. While mining uranium for the nuclear fuel production used to make sense only at a cost of USD 40/kg to maximum USD 80/kg, now it is economically sound to produce uranium at a cost of up to USD 130/kg. According to the author’s estimates, if the price of uranium remained at the level of 2019–2020 (below USD 78/kg), 80% of the identified recoverable resources in the <USD 80/kg U category would have been mined by 2040. Since the current price makes it possible to mine uranium at a higher cost, the identified recoverable resources in the <USD 130/kg U category would decrease by as little as 26%. **“Hence, given those market and economic conditions, identified recoverable resources at a cost category of <USD 80/kg U (equivalent to USD 30/lb U_3O_8, the average price of uranium in early 2021) would be sufficient for only about 30 years of global**

reactor-related uranium requirements, considering 2020 uranium requirement figures. At average market prices of about USD 50/lb U_3O_8 (USD 130/kg U), beginning in mid-2021 and sustained through the beginning of 2023, approximately 75% of the recoverable resource base could be economically brought into production, representing about 100 years of uranium requirements," the authors of the Red Book conclude.

They stress, though, it is not enough to only increase the price of uranium. We need timely investment in exploration, development and production and a high level of expertise to secure sufficient supply of uranium.

The rapidly changing political and economic environment has caused nations around the world to reconsider their attitude to nuclear power. **"Noting that this was also due to the dramatic European energy crisis of 2022 brought by the shifting geopolitical situation, the 2024 edition of the Red Book will aim to provide a fuller picture of the implications of these developments on uranium demand and supply,"** the authors promise.

Meanwhile, the ongoing changes benefit the nuclear energy industry: **"After a period of reductions in uranium production, slowed investment and comparatively low prices, it remains to be seen whether the quickly evolving market and policy environment will provide incentives for the uranium market to expand substantially in the coming decades."**

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