Russian Grip on EU Nuclear Power

Report by Patricia Lorenz

May 4, 2022

January 25, 2024, Update

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Foreword

The Vienna Ombudsoffice for Environmental Protection (Wiener Umweltanwaltschaft - WUA) is very proud to present this updated report.

WUA has been working on the issue of nuclear power for the past decades. The currently ongoing developments need to be understood as a decisive phase for nuclear energy use in the EU and in the neighbouring countries.

The war against Ukraine and the economic sanction packages forced many countries and nuclear operators to re-assess their connections to Russia with its dominant nuclear company Rosatom.

The earlier version of this report already presented an overview over with it the EU industry's dependence on the Russian nuclear company Rosatom.

Now, after almost two years of Russia's brutal war against Ukraine, this updated report takes stock of the consequences nuclear business took in reaction. After first quick and urgent measures – cancellation of the Rosatom NPP Hanhikivi and return of Škoda J.-S. into Czech ownership – solving the dependence on Russian fuel was announced.

This update examines the status quo and again concludes that the idea of achieving energy supply security with nuclear energy a fatal mistake, because some type of nuclear fuel and maintenance for VVER reactors are irreplaceable. The ethical and political consequences of continued cooperation remain undeterminable.

In spite of high awareness, the countries with operating VVER reactors have not managed to change the situation. Obviously, the chosen strategy might be described as "Back-to-business-as-usual", risking enormous consequences for energy supply and EU political development due to strong dependence on Russia.

The situation in the countries operating VVER reactors this report found show that nuclear power is not the path to independence and reliability in electricity supply, not even in the long-term.

Phasing-out this high-risk energy production is the only reasonable action to take.

Raphael Zimmerl

Vienna Ombudsoffice for Environmental Protection (Wiener Umweltanwaltschaft)

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Executive Summary

This report maps out the situation in which the nuclear industry finds itself since Russia invaded Ukraine. Where discussions on sanctions, boycotts, and terms of payment for Russian gas and oil started immediately after the invasion, nuclear power has managed to largely stay out of the limelight – until today, two years into the war on Ukraine.

While compared to gas and oil the volumes are certainly smaller, Russia's nuclear export business is a factor in its foreign policy and part of the Russian war machine; the European Union's heavy reliance on Russian uranium and nuclear fuel has made this possible.

However, with the war continuing and war crimes an established fact, on April 7, 2023, the European Parliament agreed on another resolution demanding a full embargo on imports of Russian oil, coal, nuclear fuel and gas, believing that the Russian industry and its experts, namely Rosatom, can be replaced by Western equivalents.

Since that date, very little progress has been made, especially in the key area of nuclear fuel supply.

In the past two years, all countries with Russian VVER reactors (Ukraine, Bulgaria, Czech Republic) have claimed that they have started switching to Western suppliers. Media reports on the companies' and the governments' announcements have created the impression that deliveries of non-Russian fuels will commence as early as 2024. However, the facts show that this is impossible; a country-by-country analysis clearly indicates that this change will not happen in the next few years, or even in the next decade.

The conclusion of this very thorough investigation of the reports on operators, fuel suppliers and governments is that the situation is both highly confusing and contradictory. Despite vehement claims about new contracts and ending dependency on Russian fuel supplies, the situation is as follows:

Nuclear fuel supply situation as of January 2024

Rosatom/TVEL remained the almost sole supplier of nuclear fuel for the VVER reactor series in the EU. They use different fuel to that of Western-designed nuclear power plants, thus creating severe dependency for those countries still operating the nuclear power plants built in Communist times. The situation for VVER-440 units is different to the larger and newer VVER-1000 series, because no Western supplier can provide fuel for the smaller plants. Consequently, for Slovakia and Hungary, which operate only VVER-440 plants, around half of their domestic power generation is at risk. 2024 was claimed as the year in which deliveries of such fuel would be announced but, as this report shows, the fuel does not yet exist. Nor have the regulators received an application for such fuel, and thus have not even started the licensing procedures which take years to complete.

In the past two years, several countries with VVER reactors claimed that they had secured alternative fuel supplies.

The NPP operator in the **Czech Republic** has made major announcements: As early as 28 June 2022, the ČEZ Group reported that they "are strengthening the energy security of the Czech Republic: we have signed contracts with Westinghouse and Framatome for the supply of fuel assemblies." In March 2023, ČEZ signed an agreement with Westinghouse for the supply of VVER-440 fuel assemblies for Dukovany from 2024. What actually happened: Dukovany unit 4 was loaded with the new TVEL fuel PK3+ in October 2023. In September 2023, unit 2 Temelín started transitioning from a 12-month to an 18-month fuel cycle, a major change undertaken together with TVEL. The Czech nuclear regulator SÚJB confirmed that they were aware that Westinghouse and Framatome could supply the relevant fuel, but to date no applications had been submitted for a change to the new fuel types. In January 2024, ČEZ commented on this situation, saying there would be "a couple of months delay for Westinghouse fuel," and that "Framatome fuel deliveries are expected in 2025." It is fair to assume that there will be a few more "delays" in the coming years.

Bulgaria has two VVER-1000 units operating at the Kozloduj site. Bulgaria is grappling with dependency on Russian institutions, both for fuel diversification and the Kozloduj annual overhaul. But contrary to other VVER countries, Bulgaria started preparing for the switch from TVEL fuel before February 2022. In early 2021, a contract was signed between the Bulgarian government and Westinghouse for a safety assessment of Westinghouse nuclear fuel as a supplement to Russian-sourced fuel for the 1,000-MW Kozloduy-5. According to this decision, Framatome will start supplying nuclear fuel for the 6th unit of Bulgaria's only nuclear power plant. However, as Framatome has not yet developed any VVER fuel, and is only in the planning stage of producing fuel with its joint venture with Rosatom in Germany, this is unlikely to happen in the next few years.

In 2022, **Finnish operator Fortum** announced that although there are potential alternative suppliers of fuel for the NPP Loviisa they intend to continue with TVEL fuel for the two units as foreseen in the current contract until 2027 and 2030 respectively. Meanwhile, the rhetoric has changed, pointing out the need to diversify – but only after 2030, when a tendering process would be arranged for supplying fuel for the next operating license period until 2050.

Slovakia is only operating VVER-440 reactors and has indicated no haste to replace TVEL as the sole fuel supplier. As of early 2024, its status remains the same: the switch to an alternative supplier is not seen as urgent; the newly elected government's Minister of Economy raised the topic and confirmed that "the switch to non-Russian fuel" will continue. Meanwhile, the state-controlled Slovak utility SE concluded a TVEL delivery contract for the years 2022 – 2026. According to the SE website (only published in Slovak), this contract with TVEL has the option of being extended to 2030. Another fuel contract was also signed with Westinghouse (WEC) in August 2023. The timeline may be considered highly flexible, but also realistic, because the "first WEC fuel will be delivered one year after approval" by the Slovak

Nuclear Regulator (UJD). Again, no hastiness: The approval procedure takes a few years, but the regulator UJD confirmed no application has yet been filed.

Hungary is known for its open support of Russia and refusal to cut business ties, in particular when it comes to nuclear power. The Hungarian government made it clear that it has no intention to diversify from TVEL/Rosatom and find an alternative nuclear supplier for the four VVER-440/213 units operating at the Paks site. Instead, even future fuel supply contracts for the Paks 2 units have been signed with TVEL. It was only due to pressure from the European Commission that the contract was shortened to 10 years from the intended 20 years.
Currently, Hungary is operating four VVER-440/213, each with 500 MWe, at the Paks site. At the end of 2023, Hungary gave in to the European Commission's pressure for fuel diversification, and during a session on 23 November 2023, lawmakers approved the following amendment proposed by the government: "The NPP may use a different, alternative fuel from another company, including during the extended period of its operation." However, this will have no practical consequences in the near future.

Status on the supplier side
For geopolitical and economic reasons, as a French and thus European company, Framatome has supposedly started developing VVER fuel, with contracts even signed with several utilities. This report examined the situation and discovered that no Framatome VVER fuel will be delivered in the near future. Both the Czech and the Slovak nuclear regulators confirmed in November 2023 that they had not received any application to license a new type of fuel.

- Westingshouse continues production of its VVER-1000 fuel.
- Westinghouse VVER-440 fuel development has either been unsuccessful, halted, or scrapped, and certainly Westinghouse currently has no VVER-440 to deliver to the Dukovany, Mochovce, or Paks NPPs.
- Framatome cannot deliver any VVER fuel, and there are no convincing signals that Framatome is developing this kind of fuel.
- Instead, Framatome has chosen another path, which consists of manufacturing VVER fuel under a licence with Rosatom/TVEL at Lingen/Germany.
- The Framatome – Rosatom joint venture to manufacture VVER-440 fuel at the ANF factory in Lingen/Germany is currently stuck in the licensing process. It might never be realized because the German authorities have strong doubts regarding safety and internal and external security issues.

This report also quotes experts confirming that switching nuclear fuel, which is connected to a range of further changes in technology, takes five to ten years.

With regard to fuel diversification and energy supply security, the European Commission has repeatedly pushed the countries to take action and claims that progress has been made, but again, not giving any details. This report gives a clear overview of the status. In short: progress is very slow, deliberately non transparent,

and clearly intended to avoid public and political scrutiny.

The report also offers an overview of the possible alternative vendors for new reactors, although very limited. On top of the usual construction time and costs overruns, both the French EPR and the US AP-1000 have encountered several design failures. The South Korean APR-1400 is not recognized as a Gen III+ reactor in Europe, and Chinese reactors have already been excluded in the UK and the Czech Republic for security reasons.
Nearly two years into the war on Ukraine, the EU has not yet managed to agree on sanctions in the nuclear sector. The respective countries with their fuel dependencies have not undertaken any real steps towards either securing an alternative supplier or phasing out the VVER reactors.
On top of this, the Russian state's nuclear giant Rosatom is planning to cement its presence in the EU nuclear fuel market: with the help of French state-owned Framatome, a joint venture intends to manufacture VVER fuel in Germany at the Lingen factory, unless the German authorities recognize the pressing reasons to refuse a permit for a joint venture with a foreign state-owned (Kremlin-controlled) company. Such a joint venture could be subject to political and military influence, affecting the internal and external security of the Federal Republic of Germany. Rosatom employees would have access to this sensitive production facility in Germany. Industrial espionage, acts of sabotage and blackmail cannot be completely eliminated by rules or laws, and knowledge of internal operational procedures makes abuse even more likely.
Ukrainian officials have pleaded with world leaders to sanction Rosatom and punish Putin for launching the invasion, for capturing the Zaporizhzhia nuclear power plant, and for placing large parts of Europe under the constant threat of a major nuclear accident.

Introduction

This report was prepared to map out the situation the nuclear industry finds itself in since Russia invaded Ukraine in 2022. When compared to gas and oil from Russia, where discussions on sanctions, boycotts, terms of payment started right away, nuclear power has managed somewhat to stay out of the limelight.

However, with the war continuing and war crimes a fact, on April 7, 2022, the European Parliament agreed on another resolution, demanding a full embargo on imports of oil, coal, nuclear fuel and gas from Russia, believing that the Russian industry and experts, namely Rosatom, can be replaced by Western ones:

> 17. Calls for an immediate full embargo on Russian imports of oil, coal, nuclear fuel, and gas, for Nordstream 1 and 2 to be completely abandoned, and for a plan to continue ensuring the EU's security of energy supply in the short-term to be presented; […]
>
> 19. Urges the Member States to terminate collaboration with Russian companies on existing and new nuclear projects, including in Finland, Hungary and Bulgaria, where Russian experts can be replaced by Western ones, and to phase out the use of Rosatom services; calls for an end to scientific cooperation with Russian energy companies, such as Rosatom, and other relevant Russian scientific entities; demands that sanctions on Belarus mirror those introduced against Russia in order to close any loopholes allowing Putin to use Lukashenka's aid to circumvent sanctions;

Regarding the gas supply, Germany and Austria in particular, and to a lesser extent Italy, were quickly blamed by other EU member states for their refusal to cancel their gas delivery contracts. Reluctantly, the most dependent countries made clear that they are not going to sanction Russian gas.

Two years later, this updated report summarizes the actual development in the nuclear field. Again: Nuclear power so far managed to avoid Western embargoes for manifold reasons. Among those many reasons is certainly the heavy reliance on uranium and nuclear fuel.

Key issue is nuclear fuel for the VVER reactors, where the situation at first glance is confusing. The respective states and their utilities keep reaffirming that they are looking for new fuel suppliers to rid themselves of their politically unwanted dependence from Rosatom/TVEL. They claim to be negotiating and most have already contracts with Western companies in place; these are Westinghouse and Framatome. But how believable are those plans? Or are ČEZ, SE, MVM only hoping that the war and sanctions will soon end, and they can continue business as usual? Another player entered the tricky game: The nuclear fuel factory in Lingen/Germany for which its owner Framatome is hoping to receive a permit for the production of VVER fuel in a joint venture with Rosatom. This could be more a problem than a solution, as the first analysis in the report showed.

Also in this report is an assessment of whether it is possible to replace Russian nuclear services in the near-term. This report was probably the first to gather a comprehensive picture of the Russian nuclear industry's deliveries, supplies and services for the European nuclear industry, and provides one example of a mutual dependency.

On top of the dependencies which already exist and put strain on the EU energy policy and the attempt to have a unified foreign policy position vis-à-vis Russia, reports show that Rosatom is involved in Putin's war machinery. This is not only the terrifying action of endangering and seizing the Zaporizhzhia NPP, but also developing weapons systems and hardware for military use. The Washington Post reviewed documents showing that the company has offered to provide goods to military units and weapons, including missile systems, unguided bombs and multiple missile launch systems, as well as several carriers and tanks.[1]

In combination with the shocking picture of Russian troops shelling and threatening nuclear power plants and the fact that most Soviet-built nuclear power plants in CEE countries have already reached the end of their original lifetime, non-Russian fuel is only a long-term option. Overall, the well-prepared phase out of nuclear power would be the economically and politically most sustainable answer.

[1] Russian nuclear conglomerate has aided war effort: documents | The Hill (Accessed January 16,2024).

1. Russian Nuclear Companies

The nuclear sector is exposed to high risks all over the world because the industry is heavily dependent on Russian-mined uranium, VVER fuel supplies, servicing and maintenance of nuclear power plants and new-build plans.

The EU's latest sanctions on Russia do not include the nuclear sector, but new-build projects, pushed back for years and relatively advanced in the planning or preparation stages, have already been, or may be cancelled, while sooner or later others could turn out to be very problematic, in one way or another.

At the centre of this is Rosatom and, of great importance for CEE countries, the former Czech company Škoda JS and the technical support organisation (TSO) Řež ÚJV.

1.1 Rosatom – The nuclear giant

Rosatom Holding, with around 300 companies, was created by Vladimir Putin in 2007. It is an economic as well as political power to reckon with. As the Czech nuclear regulator SUJB's chairwoman Dana Drábová said in 2021: "Rosatom is a company under Kreml control."2

This is also confirmed by Rosatom's development program, which had to be approved by the Russian President. Putin approved a rise in funding under the program, known as the Development of Equipment, Technologies, and Scientific Research in the Nuclear Industry, from Rb 349.5 billion (USD 4.77 billion) to Rb 552.7 billion, of which Rb 119 billion are expected to be allocated from the Russian federal budget.3

Created by Putin in 2007, state company Rosatom now produces nearly 20 percent of the world's nuclear fuel — providing an important revenue stream for Moscow, just like fossil fuels. According to its 2020 Annual Report, Rosatom produced over 1,000 tons of heavy metal (tHM) of nuclear fuel and 7,100 tons of uranium.4

TVEL is the supplier of nuclear fuel for the VVER reactor series. They use different fuel to that of Western design nuclear power plants, thus creating severe dependency for those countries still operating the nuclear power plants they built in Communist times. The situation for VVER-440 units is different from the larger and newer VVER-1000 series, because no Western supplier can provide fuel for the smaller plants.

The EURATOM Supply Agency (ESA) in its 2019 and 2020 Annual reports already warned against the continued dependence of VVER reactors operators on a single

[2] iDNES.cz podcast, April 27, 2021.

[3] Platts Nucleonics Week August 19, 2021.

[4] Rosatom Annual Report 2020.

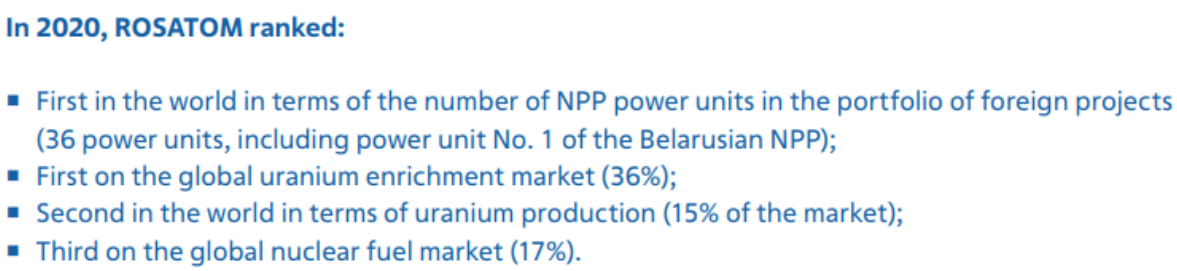
foreign supplier for nuclear fuel. This remains a matter of concern and is considered a significant vulnerability, in stark contrast with the situation elsewhere."5

Table 1: VVER units in the EU and Ukraine

Country	Nuclear power plant	Type of unit
Bulgaria	Kozloduj 5 & 6	VVER-1000
Czech Republic	Dukovany 1-4	VVER-440
	Temelín 1 & 2	VVER-1000
Finland	Loviisa 1 & 2	VVER-440
	Hanhikivi 1 (under construction)	VVER – 1200
Hungary	Paks 1 – 4	VVER – 440
	Paks 5&6 (under construction)	VVER – 1200
Slovakia	Bohunice 3&4	VVER-440
	Mochovce 1&2	VVER- 440
	Mochovce 3&4 (under construction)	VVER-440
Ukraine	Khmelnitsky 1&2	VVER-1000
	Rivne 1&2	VVER-440
	Rivne 3&4	VVER-1000
	South Ukraine 1-3	VVER-1000
	Zaporishskaja 1-6	VVER-1000

According to Rosatom's website, the corporation includes about 300 enterprises and organisations employing a total workforce of more than 290,000.6

Figure 1: The Rosatom 2020 Annual Report on market shares7



The following scheme shows that through its subsidiaries Rosatom covers the complete "nuclear fuel cycle" of the nuclear industry, from mining to burial:

[5] ESA 2019, https://euratom-supply.ec.europa.eu/publications/esa-annual-reports_en.

[6] https://rosatom.ru/en/about-us/.

[7] Quelle?

Figure 2: Markets served by ROSATOM and value chains8

Its political importance can be easily demonstrated by the following "staffing decisions": In 2016, Russian President Vladimir Putin appointed Rosatom Director General Sergey Kirienko as the First Deputy Head of the Presidential Administration with immediate effect. Before becoming the head of Rosatom, Kirienko led the Russian Federal Atomic Energy Agency for two years.9 Currently, he is the Chairman of the Supervisory Board of Rosatom.

Rosatom became the leader of the USD 500 billion global nuclear energy market, building 37% of all reactors in the world, eclipsing the United States' meagre 7% share.10 However, claims about the status and progress of the new nuclear power

[8] Rosatom 2020 Annual Report.

[9] WNA, https://www.world-nuclear-news.org/Articles/Kirienko-leaves-Rosatom-to-join-Presidential-Admin#:~:text=Russian%20President%20Vladimir%20Putin%20has%20appointed%20Rosatom%20director-general,minister%20of%20economic%20development%20and%20trade%20since%202010. (Accessed April 17, 2022).

[10] https://thebulletin.org/2015/10/russian-nuclear-power-convenience-at-what-cost/ (Accessed January 21,2024)

plant project should be taken with a grain of salt, as an analysis by an independent Russian expert has shown.11

At the time, the Russian side also offered interesting incentives. One was financing in the form of loans, as applied for the Hungarian nuclear power plant Paks II, where Russia covered 80% of the (assumed) construction costs with a loan. To enter the market even more convincingly, Rosatom offered Turkey the BOO (build-own-operate) option: providing uranium fuel, running the reactors, and taking back the generated nuclear waste to Russia. However, similar offers were not made for projects such as Dukovany in 2020, with the funding having dried up.

BOO Akkuyu

Turkey, a country with no nuclear power plants and no nuclear experience, ordered four units from Russia. Turkey had no nuclear safety regulator, nor any nuclear legislation. There the BOO model seemed to make sense; however, the drawback is complete dependence on Russia during construction and operation. The project is progressing only slowly.

1.2 Nuclear industry key companies owned by Rosatom

A full list is available on Rosatom's website: https://rosatom.ru/en/all-enterprises. Most of the information listed in the following interview stems from the Rosatom website but was confirmed by other sources; only key companies are included.

Atomenergomash (AEM)

AEM delivers reactor islands, turbine islands and owns the well-know OKB Gidropress. AEM is involved in constructing reactors at the following sites in Russia: Kurskaya NPP, Leningradskaya NPP, Novovoronezhkaya NPP. Abroad, AEM is involved in new construction and modernisation: Astravets / Belarussia, Akkuyu / Turkey, Kudankulam / India, Tianwan / China, Hanhikivi / Finland, Temelín NPP, Paks II / Hungary, Kozloduy / Bulgaria, Bushehr / Iran, Mochovce /Slovakia and Metsamor / Armenia.

JSC Atomenergoprom (AEP)

The group comprises around 50 nuclear industry enterprises. Atomenergoprom (AEP) provides the full production cycle of nuclear power engineering — from uranium production to nuclear power plant construction and energy generation. AEP companies already includes large enterprises such as Rosenergoatom Concern (#2 in the world by nuclear electricity generation), TVEL (17% of the world nuclear fuel market), and TENEX.

Atomstroyexport (ASE, Engineering Division of Rosatom), JSC

Atomstroyexport (Engineering Division of Rosatom) unites the leading companies of the nuclear industry, namely: JSC Atomstroyexport. ASE is involved in the following NPP projects:

[11] Ecodefense, Vladimir Slivyak, Dreams and Reality of Russian Reactor Export. https://ecdru.files.wordpress.com/2019/03/rosatom-report2019.pdf.

Astravets/ Belarus, Hanhikivi/ Finland, Akkuyu/ Turkey, Paks II/ Hungary, El-Dabaa/ Egypt/, Kudankulam/ India, Rooppur/ Bangladesh, Tianwan/ China, Xudapu / China and Kursk in Russia.

Mayak Production Association

Mayak in Ozersk, in the Chelyabinsk Region, is infamous. Mayak produced plutonium as early as the 1940s and later became known worldwide for several accidents and radioactive contaminations. Spent fuel reprocessing is a service offered at the Mayak facilities, also to Western countries' utilities.

Nukem

The well-known market leader in storage and transport containers for the nuclear industry, the German company Nukem Technologies GmbH, has only one shareholder: ASE Group ("Atomstroyexport"). In October 2019, Nukem was integrated into TVEL/Rosatom.12 It provides services related to the management of radioactive waste and spent nuclear fuel (SNF), as well as the decommissioning of hazardous nuclear and radiological facilities. AEA is handling projects such as three projects in Bulgaria: Construction of Dry Storage Facility for Spent Fuel at Kozloduy Nuclear Power Plant, Construction of a Near-Surface Repository for Low Level and Short-Lived Intermediate Level Waste in Bulgaria, Design for Dismantling of Equipment in the Controlled Areas of Kozloduy Nuclear Power Plant Units 1 to 4. In Austria, Nukem has three projects with the Nuclear Engineering Seibersdorf GmbH, and a total of 22 countries have contracts for Nukem's casks and services. At the Ignalina NPP site, it is responsible for the RBMK-1500 SNF storage facility as well as conditioning and storage facilities. Nukem is constructing the conditioning centre at the Bohunice site in Slovakia, and at Chernobyl. In France, Nukem is decommissioning Brennilis NPP, and NPP Philippsburg 1 in Germany.13 More information on the projects can easily be found on the company's website.14

OKB Gidropress

OKB Gidropress is the designer of the VVER reactors, of which 21 NPP were built in a number of countries (Russia, Ukraine, Armenia, Finland, Bulgaria, Hungary, Czech Republic, Slovakia, China and India), and 22 WWER-440 units. As the plant designer, Gidropress plays a key role in modernisations and life-time extensions.

Project Centre ITER

Russia is involved in the international ITER project.

TENEX

Uranium products, including conversion and enrichment of uranium, also for Western PWR (Pressurised Water Reactors).

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[12] https://www.nukemtechnologies.de/news/nukem-wird-teil-des-back-end-bereichs-von-rosatom (Accessed April 29,2022).

[13] https://rosatom.ru/en/rosatom-group/back-end/nukem-technologies-gmbh/.

[14] https://www.nukemtechnologies.de/en/projects.

TITAN-2

The TITAN-2 Holding represents a group of Russian companies involved in constructing nuclear power facilities. Organisations within the Holding perform the whole cycle of works, from development of basic design documentation to facility commissioning. It is the General Contractor responsible for construction of new units at the Leningrad NPP/Russia, as well as the Main Contractor for Hanhikivi-1 NPP in Finland and Akkuyu NPP in Turkey.

TVEL Fuel Company of ROSATOM

The TVEL Fuel Company of Rosatom incorporates enterprises for the fabrication of nuclear fuel, conversion and enrichment of uranium, production of gas centrifuges, as well as research and design organisations. More information on fuel production can be found in the chapter on Nuclear Fuel and TVEL´s website: http://www.tvel.ru/en/.

1.2.1 TVEL´s four enrichment and conversion companies

1. Angarsk Electrolysis Chemical Complex

Angarsk, Irkutsk Region

Uranium enrichment since 1957; a host facility for the International Uranium Enrichment Centre (IUEC) operating under the auspices of the IAEA.

2. Siberian Chemical Combine

Seversk, Tomsk region

The facility supplies Russia's low-enriched uranium fuel and enriches reprocessed uranium for foreign customers. It is one of the largest sites that stores low and intermediate level nuclear waste from reprocessing, with more than 30 million cubic metres.15

3. Production Association Electrochemical Plant

JSC PA ECP, Zelenogorsk, Krasnoyarsk territory

The company produces low-enriched uranium.

4. Urals Electrochemical Integrated Plant

JSC UEIP, Novouralsk, Sverdlovsk region

The company provides uranium enrichment.

1.3 Gazprom and OMZ – former owner of Škoda JS and Řež ÚJV

Less well-known are the many companies active in nuclear services. Among them is Škoda JS, a former Czech nuclear company, which in 2004 was bought by OMZ, the

[15] https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-fuel-cycle.aspx (Accessed, April 29, 2022).

Russian heavy machinery manufacturer, itself owned by Gazprombank, a private bank owned by Russian gas monopoly Gazprom. A look at the board of directors16 showed many Russian names with some also on the Škoda JS board of directors17 and thus under direct control of Russian capital. OMZ is also linked to Gazprombank (managing fonds) and has already been placed under sanctions.18 At the same time, Škoda JS owns 17.39% of the Research institute and TSO ÚJV Řež.

The amount of highly specialised and unique information and data gained over decades working in all fields of nuclear infrastructure is enormous, as the following overview shows.

Škoda JS is currently responsible for maintenance of both NPPs (units at Bohunice, and Mochovce-1 and 2), and the construction of Mochovce-3 and 4 where it serves as the main contractor Škoda JS is also contracted for maintenance of the two Czech NPPs Dukovany and Temelín. Škoda JS is already responsible for Paks 1-4 (maintenance and modernisation, including inspections of the reactor pressure vessel at units 2, 3 and 4) and has signed contracts with MVM ERBE within a framework contract for the Paks 2 units for document evaluations, and inspections of the primary circuits.

On top of this, through Škoda JS the Russian nuclear giant owns about 20% of the nuclear research institution ÚJV Řež which is also a TSO. That means they enjoy access to sensitive safety documentation on reactors in both countries.

According to their November 15, 2022, press release “the ČEZ Energy Group became the 100% owner of ŠKODA JS, a traditional Czech company operating in the field of nuclear energy. With the purchase, ČEZ solved the problem of its major supplier, which several years ago became part of the Russian engineering group OMZ, controlled by Gazprombank. This put the company at risk of sanctions, which had a potential impact on securing key supplies for the ČEZ Group's nuclear power plants. “What cannot be perceived as progress for independence of the Czech nuclear TSO ÚJV Řež is the fact that ČEZ will also acquire further shares in the scientific research facility ÚJV Řež, which Škoda JS currently owns. The ČEZ Group's ÚJV Řež shareholding will therefore increase from 52.46% to 69.85%.”19

Russian hand in EPR (European Pressurised Reactor) - NPP Hinkley Point C / UK

Since July 2018, Škoda JS has had a contract with France's Framatome to manufacture two sets of EPR reactor pressure vessel internals (core basket, heavy reflector and the upper internals) for the two units currently under construction at Hinkley Point C, as well as for the two other EPR reactors in the EU: for the one recently completed in Olkiluoto (Finland) and for the still much delayed Flamanville-3 (France).

[16] http://www.omz.ru/en/company/direction/.

[17] https://www.koda-js.cz/struktura-spolecnosti/.

[18] https://www.reuters.com/article/ukraine-crisis-russia-usa-sanctions-corr-idUSL8N1BD4CB.

[19] ČEZ, Press Release, November 15, 2022.

2. Nuclear fuel by Rosatom and status of fuel diversification and sanctions

Twelve EU sanction packages later, nuclear business with Russia is still kept out of the restrictions. In the run-up for the ninth sanction package, Poland and the Baltic States have come forward with their proposals to include a ban on cooperation with Russia in the field of nuclear energy and fuels. However, Hungary – with French support - still insisting that nuclear business with Russia will not be included in this or any upcoming package. This is unlikely.

In August, after the NPP Zaporizhia shelling, the Ukrainian president Volodimir Selenskiy tweeted that he "talked with @eucopresident Charles Michel, told about the situation on the battlefield, in particular at the Zaporizhia NPP. Russian nuclear terror requires a stronger response from the international community – sanctions on the Russian nuclear industry and nuclear fuel."[20]

Still, even the next attempts to stop financing Putin's war with European money for nuclear services which were undertaken by the Baltic states Poland, Ireland, Germany and Austria encountered fierce resistance, mostly by Slovakia, Bulgaria, Hungary and of course France. Finland seems not to exclude this option altogether, though fuel supply for Lovissa NPP is coming from Russia.

The preparation of the most recent (12th) package was delayed, reasons most likely the diamond trade. Again, only the usual group of the "Eastern European sanctions hawks (…) would like to include Russia's nuclear sector, liquefied petroleum gas (LPG), liquefied natural gas (LNG) and steel. There is also a whole list of components made in the EU that can be used in Russian military hardware (…) EU officials and diplomats are also increasingly questioning whether labelling future measures as "packages" makes sense in the long-term and contemplate a transition towards a "more flowing" sanctions regime."[21]
The EU has appointed a special envoy, David O'Sullivan to make sure European sanctions are implemented. Also, the EU's special envoy's intention seem to head towards strengthening existing sanctions instead of including more items on the list. Already earlier in March 2023, he said to "ensure that they are effectively implemented and not circumvented via third countries," and that he is "cooperating and engaging in a dialogue with third countries that could be used as a platform for circumvention is vital," he said. "I have already started my outreach by visiting the United Arab Emirates, together with my U.S. and U.K. counterparts. Further visits are in the making."[22]

[20] August 7, 2022, on Володимир Зеленський (@ZelenskyyUa) / Twitter.

[21] https://www.euractiv.com/section/global-europe/news/whats-next-for-eu-sanctions-on-russia/?utm_source=Euractiv&utm_campaign=c7e6a56788-RSS_DAILYUPDATE_EN&utm_medium=email&utm_term=0_24f4b280c0-b00d8877da-%5BLIST_EMAIL_ID%5D (Accessed November 19, 2023).

[22] https://www.politico.eu/article/eus-new-sanctions-envoy-set-to-fight-sanction-cirvumvention/ (Accessed November 20, 2023).

2.1 Status of fuel diversification

The nuclear industry or rather the utilities operation VVER reactors have come under severe pressure to diversify their fuel supply and end their dependency. Many claims have been made in the past 1,5 years that the solutions are under way.

European Commission's view on sanctioning Russian nuclear business and fuel diversification

European Commission's responsible Commissioner for Energy, Kadri Simson, addressed this issue whilst accepting that nothing will change by saying at the pro-nuclear ENEF event on November 10, 2022: "We still find ourselves in a situation where we have a critical dependence on Russia for nuclear fuel supply to Russian designed reactors operated in five of our member States. And many other member States rely on Russia for services – conversion and enrichment. This needs to change, because, as it is with gas, we cannot be fully secure of our energy supply if we are dependent on an unreliable source. For the past few months, the five countries with active Russian designed reactors have been in discussions on what can be done to licence alternative fuels that don't compromise on energy security. Nuclear energy can offer useful solutions in the current crisis and at the same time presents to us important security of supply challenges of its own."23

Other voices also were reported from the European Commission: "There is no reason that they [Russia] are closing our gas supplies and keeping open our nuclear fuel supplies," Massimo Garribba, deputy director general of the European Commission's Energy Directorate was quoted as having said. "This is a risk we must tackle...urgently."24

One year later, same place, same problem, when the Energy Commissioner at the nuclear promotion event ENEF 2023 in Bratislava explained: "Nearly two years after the full-scale Russian invasion of Ukraine, we are now much less dependent on Russian fossil fuels than before. This is also true in the nuclear energy sector. Five utilities from the concerned Member States – Bulgaria, Czechia, Finland, Hungary, and Slovakia – which operate Russian designed reactors have made progress in securing alternative nuclear fuel contracts. We have seen tangible results in diversifying nuclear fuel supplies for some reactors, and alternative fuel designs will now be delivered in those cases."25 She also mentioned the need "to look beyond fuel cycle". She announced that "the Commission is now assessing further dependencies related to spare parts, components, and maintenance services for Russian-designed reactors. It is crucial to evaluate the possible impact of any dependencies and address them swiftly." This was the Commissioner's speech at the pro-nuclear propaganda event ENEF, which is co-organized with the governments of the Czech and the Slovak government.

The Energy Commissioner was quoted making a clearer statement on the actual situation only a few days later back in Brussels: "Our clear request to them is that like

[23] https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_6804.

[24] www.Politico.eu/article/europe-just-cant-quit-russia-for-nuclear-power/

[25] https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_23_5603/.

other member states, who are still using Russian technology, that nuclear fleet, they have to prepare a plan how to diversify," Simson said. This certainly does not sound like the situation was be settled. The Commissioner also said that “Hungary should stop relying on “war criminal” Putin for gas, EU energy chief warns and continues that “Even Hungary knows that by continuing this activity, they grant Russia the right to manipulate their market”, Energy Commissioner Kadri Simson said at a POLITICO event.[26] At the same time, the energy commissioner said it was regrettable that Hungary is proceeding with construction on the Paks II nuclear reactor, which depends on support and nuclear fuel from Russia. Budapest has vowed to oppose any sanctions that would impact atomic energy.[27]

The Royal United Services Institute (RUSI) presented an analysis showing that the VVER-440 countries’ nuclear business with Russia has not decreased during the war in Ukraine, rather the contrary: “The value of imports of Russia-related nuclear technology and fuel worldwide rose to more than $1 billion (€940 billion) last year, according to the Royal United Services Institute (RUSI). In the EU, the value of Russia's nuclear exports fell in some countries like Bulgaria and the Czech Republic but rose in others, including Slovakia, Hungary, and Finland, RUSI data shared with POLITICO showed.”[28]

Actual status of Western companies’ VVER-440 fuel development

The VVER-1000 fuel by Westinghouse has been in use, the VVER-440 fuel has not been developed by any Western company (Framatome and Westinghouse). Westinghouse has invested substantial effort in the development of the VVER fuel, Framatome has not developed fuel assemblies for VVER reactors. The first loaded batch was reported at the Rivne NPP (Ukraine) in September 2023.[29] No information was yet provided on whether Westinghouse managed to overcome problems which had occurred in earlier attempts at replacing the TVEL fuel. NEI magazine recalled that “Finland had sourced fuel from Westinghouse (then part of BNFL) for its two VVER-440 units at Loviisa from 2001 to 2007 but decided to switch to TVEL. Westinghouse then shut down its manufacture of VVER-440 fuel and has rushed to redesign it in collaboration with Spain’s Enusa. A production line for the new fuel at Enusa’s Juzbado factory is being developed.”[30]

With respect to other VVER-440 operators, the question arises whether it is commercially viable for Westinghouse to produce fuel for a few VVER-440 reactors needing fuel with different characteristics.

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[26] https://www.politico.eu/article/hungary-stop-rely-war-criminal-vladimir-putin-gas-eu-commission-energy-chief-kadri-simson/ (Accessed November 15, 2023).

[27] https://www.politico.eu/article/hungary-stop-rely-war-criminal-vladimir-putin-gas-eu-commission-energy-chief-kadri-simson/.

[28] https://www.politico.eu/article/europe-just-cant-quit-russia-for-nuclear-power/.

[29] https://world-nuclear-news.org/Articles/Westinghouse-VVER-440-fuel-loaded-into-reactor (Accessed January 16, 2024).

[30] https://www.neimagazine.com/news/newswestinghouse-vver-440-fuel-loaded-at-ukraines-rivne-npp-11140465.

Another aspect is the necessary licensing of new fuel in the respective plants, which is a lengthy process as many experts agree. “This is a time and money consuming effort”, as José Emeterio Gutiérrez, a nuclear engineer who led Westinghouse's efforts to compete with Rosatom, pointed out: “Westinghouse started in Ukraine because of the government-to-government agreement with the U.S.”, said Jose Emeterio Gutierrez, the Spanish nuclear engineer who formerly led the company’s decade-long effort to compete with Rosatom. “But nuclear-fuel market peculiarities, along with a Soviet technological legacy, makes diversification difficult”, he said. “It takes at least five years for a country to license a new supplier and as long as a decade before it can start receiving tailor-made fuel”, said Gutierrez. “Fuel licensed in one country can’t automatically be transferred to another because of regulations and differences in reactor designs. For the operators of Russian-made units in Eastern Europe, many of which are running on borrowed time, it may not be worth spending the hundreds of millions of dollars needed to switch fuel sources.”31 Similar aspects were raised by the Hungarian expert Zsolt Hárfás in early 2024. He confirmed that no Western supplier has licensed VVER-440 fuel assemblies on the market; even if this fuel existed already, switching to another supplier’s fuel would take the operator 5-7 years.32

In this light it is necessary to understand the claims made by Framatome: “For several years now, Framatome has been developing an industrial solution to support the short- and mid-term needs of VVER nuclear operators, for both VVER 1000 MW and VVER 440 MW reactors.”, highlighted Lionel Gaiffe, senior executive vice president of the Fuel Business Unit at Framatome. “In the short-term, Framatome will provide the proven and incumbent design and in the mid-term, Framatome is the only fuel supplier able to guarantee a sovereign European solution, with a fully European design, manufacturing and components supply chain, thanks to our longstanding, proven expertise and track records.”33

2.2 Framatome and Rosatom seeking a licence to manufacture VVER fuel in Lingen/Germany

The fuel assembly manufacturing factory at the Lingen site in Germany has been operating since 1979, producing nuclear fuel for Western reactors. The production capacity of the plant is limited by the valid licence for converting 800 tonnes of uranium per year, and the other facilities to 650 tonnes of uranium per year.

The plant is now owned and operated by Advanced Nuclear Fuels GmbH (ANF) and manufactures fuel elements for light water reactors in several West European countries. ANF is a wholly owned subsidiary of Framatome GmbH, a subsidiary of the French company Framatome, majority-owned (75.5%) by Électricité de France (EDF).

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[31] https://www.mining.com/web/europes-other-energy-problem-relying-on-russian-nuclear-fuel/ (Accessed January 16, 2024).

[32] Ungarnheute.hu, January 15, 2024.

[33] Framatome press release. https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-hungary-to-extend-long-term-cooperation-in-nuclear-power/(Accessed January 16, 2024).

ANF filed an application for changes to its nuclear fuel factory with the Lower Saxony Environmental Ministry (Germany) on March 10, 2022. This is because it needs a permit to switch to manufacturing hexagonal fuel assemblies for VVER reactors. These are to be produced under licence, with the licence owned by Rosatom. European Hexagonal Fuels S.A.S., based in Lyon (France), was founded to handle the licenced production. According to several German media reports and official sources, Rosatom/TVEL is expected to hold a 25% share in the joint venture.

The Lower Saxony Ministry for the Environment, Energy and Climate Protection, in its role as the competent licensing authority, is overseeing the process of changing the licence for the ANF fuel element production plant in Lingen to allow the production of VVER fuel. In an unusual step, the German authorities opened a public participation process in accordance with the German Atomic Act and is making the documentation available to the public on its site from January 4 to March 3, 2024.34

In the factory itself, some equipment and production processes such as assembly, cladding, washing, and storing will be replaced or modified. The high sensitivity of this project does not stem from environmental concerns – an Environmental Impact Assessment (EIA) was not required by the German authorities – but rather from security, both internal and external, and geopolitical issues arising from the planned Rosatom participation.

Issues at stake: Nuclear safety, security, dual use

There are several open questions which the authorities and the public will need to respond to before the joint venture is approved or refused:

1. Possible impact of the fact that this joint venture with a foreign state-owned (Kremlin-controlled) company could be subject to political and military influence, affecting the internal and external security of the Federal Republic of Germany
2. The relevance of granting Rosatom employees access to this sensitive production facility in Germany when providing the equipment, conducting quality control etc.
3. The potential difficulty in deciding on future sanctions against Rosatom and/or the Russian state when the Russian - French joint venture is operating in Germany.
4. The potential impact on German and EU policies when considering the dependence of European countries on this fuel production.
5. The threat of "industrial espionage". With participation in this joint venture, Rosatom could gain know-how when operating in the EU.
6. The wide field of conducting acts of sabotage and blackmail cannot be completely eliminated by rules or laws; knowledge of internal operational procedures makes abuse even more likely.

34 https://www.umwelt.niedersachsen.de/brennelementfertigungsanlage_lingen/sachstandsinformation-bfl-8451.html.

Rosatom is a Russian state-owned corporation which is been openly used for Russia's foreign policy interests. Currently, Russia is leading a war against Ukraine, and even once it ends, political observers agree that this military attack against another state is not likely to be the last one.

Regarding nuclear safety, it is important to understand that the fuel assemblies, particularly the fuel rod cladding, is the first protective barrier against the release of fission products created in the pellet.

While the German authorities are obviously bound by the valid legal regulations including EU law, in this case they have some discretion in decision-making and are legally in a position to refuse the authorization of a French joint venture with Rosatom/TVEL.

German politicians have made it clear that they oppose this project: "Doing business with (Russian President) Putin must stop, and this also, and especially, applies to the nuclear sector," Lower Saxony's Energy Minister Christian Meyer said in March 2023.35 The final responsibility lies with the German Environmental Ministry at federal level, which is also not in favour of the project. However, the big neighbour France might apply diplomatic and less diplomatic efforts to make the Lingen VVER production possible. The European Commission might prove a reliable ally in this battle as it has been pushing for VVER fuel diversification for years and would prefer this market share going to a French company rather than the US company Westinghouse.

In conclusion: The Lingen site is far from producing VVER fuel. If ever, it might take several years until production could start. Clearly, a joint venture with Rosatom cannot be seen as independent, diversified nuclear fuel production. The announced Framatome-developed fuel would take many more years and might never happen. All parties involved probably hope that attention will diminish, and Rosatom will expand its business in the heart of the EU.

What might be another hidden agenda: Does it make sense for companies and operators to develop VVER fuel assemblies with costs of millions of dollars for operating Russian-made reactors in Eastern Europe – in particular those few VVER-440 - many of which are closing in on the end of their operational lifetimes. This could be another reason for Framatome simply hoping that they can "make a quick buck" with the Rosatom licence in its factory after a few technological changes.

2.3 VVER 1000 fuel

The issue of Russia being the sole nuclear fuel supplier for the VVER reactors, also in EU countries, has been a topic for decades, and in particular the issue of whether the TVEL fuel can be replaced with fuel made by Western companies; information on why fuel deliveries were substituted by other suppliers cannot always be fully verified. In addition to technical issues, economic, political, and geo-strategic interests may have played a role.

[35] Germany criticizes Russian role in French nuclear fuel plant | AP News (Accessed January 16, 2024).

Westinghouse was also only delivering fuel for VVER-1000, not for VVER-440, although with one exception, when from 2001-2004 fuel for delivered for Loviisa reactors in Finland.

One interesting result found during research for this report is that TVEL is not only continuously improving the fuel assemblies for its VVER series but is also designing specific fuels for individual plants which could later be used by other plants; for Paks in Hungary, fuel with characteristics other than those for Loviisa (enrichment level) was recently loaded in the core. In 2019, Dukovany started operating on modified RK3 Plus VVER fuel.36 This constitutes an additional problem when it comes to non-Russian companies supplying VVER reactors with assemblies.

It was reported in 2016 that TVEL intends to standardize the construction of its VVER-1000 fuels for use in all VVER plants.37

First Westinghouse fuel for VVER-1000 in 2000

An attempt to rid power generation from its dependence on fuel deliveries from Moscow has already been made. When, following the Velvet Revolution in the **Czech Republic**, the decision was taken to complete the VVER-1000 Temelín reactors, the intention was to achieve a Western safety standard and Western fuel supply. Therefore, the US company Westinghouse helped to finish the plants and promised to develop the necessary fuel. When Temelín unit 1 went into operation in 2000, Westinghouse had developed nuclear fuel for this special East-West engineering cooperation, Temelín 1 & 2. Later this fuel turned out to be inadequate.

With its fleet of 13 VVER-1000 units, **Ukraine** has consistently led the way in trying to diversify its TVEL fuel and demonstrates the realistic options available. Development of the first Westinghouse VVER-1000 fuel for delivery to Ukraine started in 2001. Westinghouse had earlier designed and delivered VVER fuel to the Temelín nuclear power station in the Czech Republic, but without having considered the mixed core conditions. Developing VVER-1000 fuel for mixed cores presented an additional challenge, especially since compatibility data on the resident fuel was not easily accessible to Westinghouse. Westinghouse shipped the fuel in 2005 and it was loaded in South Ukraine 3 the same year.[4] Later it turned out that the US nuclear fuel assemblies did not fulfil the requirements and revealed mechanical scratches and rub marks, grid damage, and that the fuel rods were not sufficiently stable. Bent fuel rods pose a safety risk if they cannot be moved properly in and out of the reactor core. The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) did not approve loading of any subsequent Westinghouse fuel assemblies of this design. Both the Czech Republic and Ukraine reverted to TVEL fuel deliveries, but after the 2014 annexation of Crimea, Ukraine re-started its fuel diversification. A constant issue is the difficulty of accessing the required technical data and information which are owned by TVEL, Rosatom and Škoda. Meanwhile, Westinghouse has been able to deliver an improved design – the Robust Westinghouse Fuel Assembly (RWFA). The first reload batch of this design was inserted in NPP South Ukraine 3 in March 2015.

[36] Nuclear Fuels, August 12, 2019.

[37] https://oenergetice.cz/elektrarny-cr/cez-nakoupi-pro-temelin-opet-americke-jaderne-palivo (Accessed April 29, 2022).

In 2014, Energoatom, the operator of all Ukrainian NPPs, extended the fuel contract to also include assemblies for the Zaporishskaja plant. When the Russian army occupied the NPP Zaporishskaja in March 2022, observers claimed they had taken with them fuel samples both fresh and spent.

As hinted earlier, another issue is political influence and the fact that the Russian fuel assemblies are cheaper. This might have played a role in a surprising U-turn in Ukraine, when it was reported that the Russian state-owned nuclear fuel company TVEL will supply fuel to eight out of 15 Ukrainian reactors between 2021 and 2025, as announced by the Ukrainian state-owned nuclear power generator Energoatom on January 10. TVEL supplies fuel to nine reactors, while the remaining six use Westinghouse fuel. Energoatom disclosed the plans after revelations that the company, without a public announcement, had signed an agreement with TVEL in September 2018 to extend Russian fuel supplies for five years through 2025. Foreign Minister Pavlo Klimkin, who said he was not aware of the agreement, has urged Energoatom to explain the continued dependence on the Russian supplier. "I believe those who were involved in this decision-making at least owe an exhaustive explanation to Ukrainian society," Klimkin wrote on his Facebook page December 21. Ukraine accuses Russia of waging a war against the country following annexation of the Black Sea peninsula of Crimea in March 2014 and continued military support for separatists in parts of the Donetsk and Luhansk regions in eastern Ukraine.38 A 2021 report said that the Rivne nuclear power plant received its first-ever shipment of fuel assemblies from Westinghouse on July 21.39 On February 23, 2022, Rosatom completed a fuel delivery for NPP Rivne.40 Rivne-3 will begin loading Westinghouse assemblies in early 2022 after inspecting the shipment, and it is expected to take four years to completely phase out TVEL fuel for the unit; in 2025 Rivne-3 will operate entirely on American nuclear fuel.

Table 2: TVEL fuel in Ukraine as of April 2022

Ukraine	Khmelnitsky 1&2	VVER-1000 *TVEL*
	Rivne 1&2	VVER-440 *TVEL*
	Rivne 3&4	VVER-1000 WEC unit 3, TVEL unit 4
	South Ukraine 1-3	VVER-1000 1 TVEL, 2 & 3 units WEC
	Zaporishskaja 1-6	VVER-1000 4 WEC, 2 units TVEL

However, Ukraine also intends to receive VVER 440-fuel from the US company. In 2021, a contract was signed between Energoatom and Westinghouse for the

[38] Nuclear Fuels January 28, 2019.

[39] Nuclear Fuels July 26, 2021.

[40] NIW, March 25, 2022.

development and delivery of licensing documentation for fuel assemblies fitting VVER-440 reactors. The first reload of Westinghouse fuel in a Ukrainian VVER-440 nuclear fuel is expected at Rovno-2 in 2024, according to Energoatom. However, it was already expected for 2022.

On top of likely technical problems, it is clear that Westinghouse will not be able to handle the large number of new customers asking for fuel – Westinghouse will first need to create new production capacities.

Bulgaria switching to Western produced fuel, dependences remaining

Bulgaria has two VVER-1000 units operating at the Kozloduj sites. Bulgaria is grappling with the dependence on Russian institutions both for fuel diversification and the Kozloduj annual overhaul.

Bulgaria started preparing for the switch from TVEL fuel before February 2022. In early 2021 a contract was signed between the Bulgarian government and Westinghouse for a safety assessment of Westinghouse nuclear fuel as a supplement to Russian-sourced fuel for the 1,000-MW Kozloduy-5.41 For the fuel deliveries a decision was taken in December 2022. According to this decision, the 6th unit of the only Bulgarian nuclear power plant, Framatome will start supplying the nuclear fuel. For the 5th unit's fresh fuel however, Westinghouse signed a contract in late December 2022.
According to experts in Bulgaria, the new supply by Westinghouse will come through, but the necessary tests took 2-3 years, and the new fuel has not yet been granted permit for loading by the Bulgarian Nuclear Regulator (BNRA). Westinghouse produces Robust Westinghouse Fuel Assemblies (in its factory in Sweden) that could be used at Kozloduy. However, TVEL is contracted to supply Kozloduy-5 and -6 until 2025.[8]

The Bulgarian government had to accept the fact that a full ban of Russian nuclear services is impossible and issued derogations from the ban on trade with Russia.

The fuel diversification will require a certain level of cooperation with the Russian Kurchatov Institute, based on an existing bilateral contract.[42] Some services for the Kozloduj reactors can only be obtained from Russia: "The derogation will allow the continuation of contracts with "Rusatom Service AD - Bulgaria branch", which is the only participant in the procedure for measuring the actual geometry of the active zone limiter of VVER-1000 reactors. The same company is also the contractor for the modernisation of the neutron flow control equipment, the repair and operation of the turbogenerators, which will also be continued".43 Also the core-reactor-management-system is of Russian design, scientific support by Kurchatov institute, therefore for Westinghouse there will be a need to cooperate with the Kurchatov Institute. The Annex to the September 24, 2022, government decision on Kozloduj contains many items, which will be ordered from Russian companies, e.g., OKB Gidropress, Elsib.

[41] Nuclear Fuels February 8, 2021.

[42] Nucleonics Week, Nov. 1, 2022.

[43] Email from Todor Todorov, Zazemiata, Bulgaria, dated September 26, 2022.

2.4 VVER-440 fuel

There is currently no alternative fuel supplier on the market. Although a well-known fact, the respective countries have chosen to ignore this problem, even claiming that nuclear energy is a domestic energy source ensuring a reliable energy supply. 44 The EC, namely the ESA even financed a project: “EURATOM has allocated funding to support diversification of the nuclear fuel supply for the VVER units operating within the EU. Earlier this year, a consortium of Westinghouse and eight European partners was awarded more than €2 million ($2.2 million as of 14 July 2015) by EURATOM for a programme to qualify a second supplier.”45

Westinghouse has already been delivering fuel to the Loviisa NPP 440 units, however, not even Finland intends to resume the Westinghouse fuel supply. Technical issues include not only the fact that Westinghouse does not produce this fuel, but that there is no one type of VVER-440 fuel which could be used to supply all the reactors of this type (all 4 Slovak reactors, all 4 reactors in Hungary), and the Russian Rosatom company TVEL has developed specialised fuel for the individual reactors. The fuel and the core configuration and other key tasks are in the hands of TVEL, Škoda JS and Řež.

Countries operating VVER-440 units in the EU and Ukraine have also announced a growing interest in qualifying a second supplier. Back in 1998, BNFL (British Nuclear Fuel Limited) delivered lead test assemblies to unit 2 at Finland’s Loviisa plant. The assemblies were manufactured in the fuel facility in Springfields, UK, and the purpose of the program was to qualify a second supplier for Loviisa, as well as for Paks in Hungary. After successful completion of the operation of the LTAs, in December 1999 BNFL was awarded a contract to supply reload deliveries to Loviisa and a total of seven reload batches were delivered between 2001 and 2007. Shortly before the contract award, Springfields was incorporated into Westinghouse fuel operations after BNFL was acquired by Westinghouse. Westinghouse decided that the reload fuel would be assembled by ENUSA in Spain instead of at Springfields. Following some unsuccessful fuel tenders in 2006 and 2007, Westinghouse decided to exit the VVER-440 business. Lately, the increased importance of diversified fuel supply has resulted in discussions with different utilities about re-entering the market with an upgraded Westinghouse fuel design, including more advanced materials, as well as improved mechanical features. The EURATOM program has allocated funding to support diversification of the nuclear fuel supply for the VVER units operating within the EU. Earlier this year, a consortium of Westinghouse and eight European partners was awarded more than €2 million ($2.2 million as of 14 July 2015) by EURATOM for a program to qualify a second supplier. The programme will mainly focus on establishing the methods and methodology required to license a VVER-440 fuel design. The consortium includes partners with expertise in different technical disciplines and the countries operating VVER440 within the EU are represented (see

[44] MPO, Ministry of Trade and Industry: Czech State Energy Concept 2015. https://www.mpo.cz/assets/dokumenty/52841/60959/636207/priloha006.pdf. p. 44, where nuclear fuel is categorized as primary domestic source.

[45] Nuclear Engineering International NEI, September 2015.

box). As part of the programme, steps will be taken to update the design previously delivered to Loviisa, and to create a state-of-the-art design.46

Both Paks and Loviisa are being supplied by TVEL with a newly modified second-generation VVER-440 fuel, although these fuels are not identical. The fuel for Paks enables an increase in the coolant volume inside the reactor core and optimization of the hydro-uranium ratio. TVEL also decreased the amount of fuel bundles loaded in the reactor core. Loviisa has the same number of fuel assemblies, but a lower uranium enrichment level was developed.47 In late 2020, TVEL loaded 18 fuel bundles of a modified design of VVER-440 fuel into the 500-MW Paks-3 in Hungary during last month's recent refuelling outage at the unit.48

TVEL confirmed this being the company's strategy in December 2020: "We are actively engaged in the development of new models and modifications of VVER-440 fuel for power plants in Europe. The projects of the new fuels for the Loviisa plant in Finland, Dukovany plant in the Czech Republic, [and] Mochovce and Bohunice plants in Slovakia are currently at various stages of implementation. Despite the same reactor model, these projects are quite different technically and conceptually."49 Two more VVER-440 units are also depending on TVEL supply, Metsamor in Armenia.

2.5 Hungary

Hungary made clear several times that there is no intention to diversify from TVEL/Rosatom and find an alternative nuclear supplier for the four VVER-440/213 units operating at the Paks site. Rather the contrary: Even the future fuel supply contracts for the Paks 2 units have already been signed with TVEL; only due to pressure from the European Commission the contract was shortened to 10 years from the intended 20 years.

Currently Hungary is operation four VVER-440/213 with 500 MWe each at the Paks site. Paks 1-4 is supplied by TVEL with a newly modified second-generation VVER-440 fuel. The fuel for Paks enables an increase in the coolant volume inside the reactor core and optimization of the hydro-uranium ratio. TVEL also decreased the amount of fuel bundles loaded in the reactor core. Loviisa has the same number of fuel assemblies, but a lower uranium enrichment level was developed.50 In late 2020, TVEL loaded 18 fuel bundles of a modified design of VVER-440 fuel into the 500-MW Paks-3 in Hungary during last month's recent refuelling outage at the unit.51

At the end of 2023 Hungary gave in to the European Commission's pressure towards fuel diversification, when during a session on 23 November 2023 lawmakers approved the amendment, which had been proposed by the government, Russian news agency *Tass* reported. The amendment says that "the NPP may use a

[46] Ibid.

[47] World-nuclear-news.org, May 24, 2021.

[48] Nuclear Fuels December 28, 2020.

[49] Ibid.

[50] World-nuclear-news.org, May 24, 2021.

[51] Nuclear Fuels December 28, 2020.

different, alternative fuel from another company, including during the extended period of its operation."52 This will have no practical consequences in the near future.

2.6 Czech Republic with VVER 440 and VVER 1000

Since the beginning of the war in Ukraine, for the third time Czech Republic a nuclear fuel delivery has been flown into the Czech Republic. This was so urgent that, in the midst of the war in Ukraine, an exemption to the ban on flights for Russian aircraft into the airspace of the European Union had to be granted. ČEZ, the operator of both Temelín and Dukovany NPP explained that this was the last of the planned deliveries.53 ČEZ also informed the public that Temelín currently has sufficient fuel stored for two years and Dukovany for three.

The nuclear fuel supplier for both NPPs is TVEL which belongs to the Russian state holding Rosatom. For Temelín, this contract expires in two years' time and ČEZ announced it will try to avoid renewing the contract with TVEL. For the construction of the new reactor, Rosatom has already been excluded for security reasons.54

As early as June 28, 2022, the CEZ Group reported that they "are strengthening the energy security of the Czech Republic: we have signed contracts for the supply of fuel assemblies with Westinghouse and Framatome." Furthermore, they claimed to have „concluded contracts with Westinghouse and Framatome for the supply of fuel assemblies for the Temelín Nuclear Power Plant (...) Both suppliers, American and French, were selected in a tender in April this year. Deliveries of assemblies for more than 10 years will begin in 2024. The value of the contract is in the order of billions of crowns."55

Also, for Dukovany NPP, announcements were made: In March *2023* ČEZ signed an agreement with Westinghouse for the supply of VVER-440 fuel assemblies to Dukovany from 2024. What actually happened: ČEZ will have TVEL testing its 3rd generation fuel intended for VVER-440 reactors. The new TVEL fuel PK3+ was loaded in Dukovany unit 4 in October 202356. Goal is to have the reactor operate with increased thermal capacity and to extend the fuel cycle at the plant, leading to better economic efficiency.57 Nuclear Fuels reported in more detail: "The modification includes a higher uranium load and will enhance the efficiency of fuel usage (…). Increasing the mass of uranium in one fuel rod will allow a lower uranium

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[52] https://www.world-nuclear-news.org/Articles/Hungary-to-consider-alternative-sources-for-nuclea (Accessed January 18, 2024).

[53] https://www.idnes.cz/ekonomika/domaci/rusko-jaderne-palivo-temelin-dukovany-dodavka-letadlo-zasoby-jaderne-elektrarny-cez.A220401_192525_ekonomika_hend.

[54] https://www.idnes.cz/ekonomika/domaci/rusko-jaderne-palivo-temelin-dukovany-dodavka-letadlo-zasoby-jaderne-elektrarny-cez.A220401_192525_ekonomika_hend.

[55]https://www.cez.cz/en/media/press-releases/we-are-strengthening-the-energy-security-of-the-czech-republic-we-have-signed-contracts-for-the-supply-of-fuel-assemblies-with-westinghouse-and-framatome-160156 (Accessed January 19,2024).

[56] oenergetice.cz. Elektrárna Dukovany odstaví čtvrtý blok, poprvé použije palivo nové generace (Accessed January 19, 2024).

[57] IAEA/NEA: Uranium 2020, Resources, Production and Demand, p. 9. https://oecd-nea.org/upload/docs/application/pdf/2020-12/7555_uranium_-_resources_production_and_demand_2020__web.pdf, p. 59.

enrichment level without reduction of thermal power generation in the reactor," the company said. It did not say how much uranium is contained in a rod of either the new or current design. Lower enrichment will also reduce the cost of the nuclear fuel production chain and facilitate handling of irradiated fuel, Rosatom said. (…) the company had developed different VVER-440 fuel cycle strategies for its customers in Hungary and Finland."58

When looking at facts, the switch to Westinghouse or Framatome are announcements only: In September 2023, unit 2 Temelín started transitioning from a 12-month to an 18-month fuel cycle, a major change undertaken with TVEL. "During its shutdown, 163 fuel assemblies will be placed in unit 2, including 48 fresh assemblies, which is six more than previously. Extending the fuel cycle to 18 months will increase the efficiency of the plant, allowing it to operate for longer between shutdowns. The fuel enrichment will be the same, but the assemblies will contain more absorbers to dampen their reactivity," was reported by the operator ČEZ.59

This impression, that no non-Russian fuel will be used in Temelín or Dukovany any time soon was confirmed in an email to the author by the Czech Nuclear Regulator SÙJB, which is responsible for permitting the safe use of nuclear fuel: "At present, SÚJB has general information on the planned fuel changes for JEDU and JETE and is aware of the suppliers of this fuel, Westinghouse and Framatome, but until now applications have not been submitted for a change to use the new fuel types. (…) SÚJB has only general information at its disposal, which is we provide below. This situation is due to the fact that between the operator JEDU and JETE and the suppliers, negotiations are still ongoing on the specific design of the fuels. According to the information available SÚJB, the Temelín Nuclear Power Plant, is expected to undergo a gradual transition between 2024 and 2026 to fuel of the

- type TVSA-Tmod.2 from Framatome and
- type RWFA-T from Westinghouse.

Framatome's TVSA-Tmod.2 fuel is supposed to be identical to the fuel from Russian supplier TVEL, which is already in operation at JETE today, based on the granting of a commercial licence to produce the fuel between the suppliers. Westinghouse's RWFA-T fuel is said to be based on the LTA WSE design, a fuel already tested in three campaigns at JETE Unit 1 under the LTA programme between 2019 and 2022."60

In January 2024, this situation, which was prepared long in advance, was commented by ČEZ: „A couple of months delay for Westinghouse fuel." And: "Framatome fuel deliveries expected in 2025."61

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58 Nuclear Fuels May 31, 2021.

59 https://world-nuclear-news.org/Articles/Temelin-switching-to-18-month-fuel-cycle#:~:text=Operator%20%C4%8CEZ%20says%20that%20the,year%20operation%20of%20the%20plant. (Accessed January 13, 2024).

60 SÚJB email to the author, dated November 16, 2023.

61 Nucleonics Week, January 17, 2024.

2.7 Finland

In March 2022, Fortum announced that although there are potential alternative suppliers of fuel for the NPP Loviisa they intend to continue with TVEL fuel for the two units as foreseen in the current contract until 2027 and 2030 respectively. According to TVEL, modified VVER-440 fuel for the Loviisa plant served to enhance the efficiency of fuel usage. It consisted of a higher uranium load in each fuel road, and a reduced level of uranium enrichment without a reduction of thermal power generation in the reactor.62

The company noted the project has involved the participation of a number of Russian nuclear industry enterprises, such as OKB Gidropress (part of Rosatom's machine-building division Atomenergomash), Bochvar Institute (TVEL's material science research facility), the Elemash Machine-building plant and the Kurchatov Institute national research centre. The new fuel passed a range of hydraulic, longevity and vibration tests at the site of OKB Gidropress research and experiment facility.

Finnish utility Fortum signed a contract with TVEL in March 2018 for the supply of the modified fuel for use at its twin VVER-440 Loviisa plant. It followed the signing in November 2017 of a similar contract between TVEL and MVM Paks for development of the new VVER-440 fuel for use in the Paks plant in Hungary.

At the beginning of 2024, a supposed switch was reported in Finnish media, claiming that the Finnish majority-state-owned energy utility Fortum plans to use up its existing Russian stock and then to switching to a western supplier. The minister commented this by saying that “the Loviisa nuclear power plant is no longer dependent on new shipments of Russian nuclear fuel.”63 However, clearly there is no contract in place.

The only real development consists of the fact that the Finnish government now re-formulated its position and acknowledged the need to look for a new supplier; only after 2030 that is, when a tendering process would be arranged for fuel supply for the next operating license period until 2050.

More reliable industry reports said: “Fortum had announced in November 2022 that it had signed an agreement with Westinghouse Electric Company to deliver a new fuel type for Loviisa. However, the introduction of new fuel is a multi-year project that requires regulatory approvals. (…) According to its report to the Ministry, Fortum will tender for fuel production after 2027/2030. Meanwhile the agreement with Westinghouse and the fresh TVEL fuel in stock will ensure Loviisa’s fuel supply. In addition, Fortum announced that it is investigating the possibilities of another Western fuel supplier developing VVER-440 fuel in order to improve the security of fuel supply and strengthen competition. Most likely this could be France’s Framatome, which recently signed a fuel supply agreement with Hungary, which also

62 World-nuclear-news.org, May 24, 2021.

63 Fyi.fi (Accessed January 13, 2024).

operates VVER-440s. The Ministry said it will continue to monitor the availability of fuels.[64]

2.8 Slovakia

Slovakia is a good example of total dependence. Currently, Slovakia's utility Slovenské elektrárne is the operator of four units of VVER-440 reactors, delivering over 50 % of Slovak power. This reactor type is operated with fuel which only the Russian company TVEL can deliver. Slovakia ignored the warning from EU institutions which kept enforcing alternative fuel suppliers. Instead, Slovakia continued with the construction of two additional VVER-440 units (Mochovce 3 & 4).

Therefore, three flights operated by the Volga Dnepr airlines, with special exceptions from the ban of Russian airspace, delivered fuel to Bratislava in the first days of the war on Ukraine. However, these batches may last only for another year. Compared to other countries, Slovakia is very silent when it comes to efforts to find other suppliers of nuclear fuel. The reasons might be that no alternative suppliers exist for those VVER 440 units, and the existing infrastructure for licensing new fuel – Nuclear Regulator and TSO – is not very capable. Consequently, it might prolong the time needed in order to use new fuel up to ten years. It is fair to assume that Slovakia is most likely lobbying the other member states and the EU Commission hard to keep fuel from Russia coming in, despite the ongoing war, war crimes and the crimes against humanity committed by the Russian army in Ukraine. This could turn Russia into a pariah state for years to come and lead to charges in the Hague – and result in a very difficult political situation for Slovakia.

Over the course of 2022, Slovakia received five deliveries of fresh fuel from Russia. 65 At least but accepted the need to diversify or rather replace Russian fuel and intends to contract Westinghouse fuel. In an interview on September 9, 2022, Branislav Strýček, the Slovak utility SE CEO mentioned that one month earlier a tender for a new fuel supplier had been announced. He commented on the situation which has improved compared to 6-7 months ago, also due to intensive cooperation with the group of other countries with VVER-440 reactors (Czech Republic, Hungary, Finland) and said that he believed in Framatome's and Westinghouse's ability to deliver this type of fuel.66 However, one year later the situation has not changed, not even the wording:" I am very pleased that we have teamed up with Framatome on this project in cooperation with other European operators of VVER-440 reactors," said Branislav Strýček, CEO of Slovenské elektrárne."67

As of early 2024, the status remains the same, the switch to another supplier is not seen as urgent, the newly elected government's minister of economy raised the topic

[64] https://www.neimagazine.com/news/newsfortum-plans-tender-for-loviisa-fuel-supplier-11409055 (Accessed January 17, 2024)

[65] https://www.energie-portal.sk/Dokument/jadrove-palivo-2022-javys-108687.aspx (Accessed January 17, 2024).

[66] https://www.youtube.com/watch?v=UgyNe9JhMjI.

[67] https://www.framatome.com/medias/framatome-signs-memorandum-of-understanding-with-slovenske-elektrarne-to-extend-long-term-partnership/ (Accessed November 15, 2023).

and confirmed that “the switch to non-Russian fuel”68 will continue. However, only very general comments were made on how this should take place.

Meanwhile the state-controlled Slovak utility SE concluded a TVEL delivery contract for the years 2022 - 2026.69 According to the SE website (only in the section in Slovak language), this contract with TVEL has the option of extending it until 2030.70. Another fuel contract was also signed with Westinghouse (WEC) in August 2023.71 The timeline may be considered very flexible, but also realistic, because the “first WEC fuel will be delivered one year after approval” by the Slovak Nuclear Regulator (UJD).71 Again, no hastiness: The approval procedure takes a few years. In an email to the author, the regulator UJD confirmed that “until today no application for new fuel was filed.”72

TVEL is developing accident-tolerant fuel (ATF)

TVEL invested into developing accident-tolerant fuel (ATF). This type of fuel is a response to the Fukushima catastrophe, and it should, among other factors, lower the impact of accidents by modifying certain fuel compositions. The goal is to produce nuclear fuel without zirconium content because this leads to hydrogen development under accident conditions. It was this that led to explosions at the Fukushima unit 1 when the hydrogen that was being created rose to the ceiling of Unit 1, leading to a spark that led to the reactor exploding. In 2019, TVEL was reported as testing fuel with up to 7% U-235. TVEL also tried to enter the US market with TVS-Kvadrat for Western PWRs.73

This ATF is required in order to allow include nuclear generated power under the currently prepared EU taxonomy (draft CDA).74

High-assay low-enriched uranium (HALEU) for SMR

Currently some politicians and lobbyists claim that the answer to the energy crisis will be to deploy so-called next-generation or advanced nuclear reactors, many of them Small modular reactors. Many of these reactors need HALEU – which is higher enriched than the approx. 5% enriched fuel for Light Water Reactors (LWR) currently used, as the following overview shows:

- Small modular reactors, LWR-based → mostly use UO2 with enrichment < 5%

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[68] https://e.dennikn.sk/3663904/od-ruskeho-paliva-sa-odstrihneme-potvrdila-sakova-aj-navzdory-dankovym-a-ficovym-vyhlaseniam/ (Accessed on January 16, 2024).

[69] https://www.energie-portal.sk/Dokument/jadrove-palivo-westinghouse-slovenske-elektrarne-110238.aspx (Accessed January 17, 2024).

[70] https://www.seas.sk/tlacove-spravy/palivo-pre-jadrove-elektrarne-na-slovensku-doda-spolocnost-tvel/#pll_switcher (Accessed January 18, 2024).

[71] https://openiazoch.zoznam.sk/energetika/vymenia-rusov-americania-slovenske-elektrarne-podpisali-novu-zmluvu-o-dodavke-jadroveho-paliva-pre-nase-atomky/ (Accessed January 18, 2024).

[72] UJD email to Patricia Lorenz, November 10,2024.

[73] NIW July 5, 2019.

[74] https://www.euractiv.com/wp-content/uploads/sites/2/2022/01/draft-CDA-31-12-2021.pdf.

- Small modular reactors, HTR-based → mostly use HALEU
- Small modular reactors, MSR-based → mostly use HALEU
- Small modular reactors, sodium- or lead-cooled → mostly use HALEU or mixed oxides (MOX)
- Advanced reactors > 300 Mwe.75

These are mostly fast reactors, sodium or lead-cooled, and use MOX fuel or, in some cases, HALEU.

So-called next-generation nuclear reactors generally require fuel enriched with up to 20 percent U-235, called HALEU. Higher enrichment allows nuclear power plants to operate longer before refueling. The more energy-dense fuel also allows for smaller reactor designs. But the only major supplier of HALEU is in Russia. With the Russian invasion of Ukraine, this type of fuel will also be out of reach. The US Administration which is supporting SMR development has acknowledged this problem. Two Department of Energy-funded demonstration projects for advanced reactors will need HALEU by the end of 2024. Until then, a production facility must be established in the US; this will take at least 4-5 years. President Biden's budget proposal for 2023 includes a funding boost for the DOE that includes money to help "secure the availability" of HALEU.76

After having banned the import of oil, gas and coal from Russia, US uranium imports from Russia remain an open issue. The obvious alternative to uranium imports from Russia would be to re-open US mines. The obvious problem would also be re-opened: environmental pollution on a vast scale, and often close to sacred Native American sites.77

[75] ESA 2019, Securing the European Supply of 19.75% enriched Uranium Fuel.

[76] https://www.theverge.com/2022/3/31/23003494/war-ukraine-nuclear-energy-uranium-russia-supply-chain (Accessed April 2, 2022).

[77] https://www.theguardian.com/us-news/2022/mar/28/native-americans-ban-russian-uranium (Accessed April 5, 2022).

3. From Uranium Mines to Nuclear Fuel Assemblies

Several steps outlined in the following chapter are needed to produce nuclear fuel assemblies which are then used in NPP. They are very specialized and only available in some countries for several reasons. To understand why Russia's nuclear fuel deliveries to European countries cannot be simply replaced by importing Australian uranium, for example, it is necessary to understand that fuel is specific for reactor types and the different production phases are available only on a limited scale in certain countries, and there can be bottlenecks. In addition, some data are not available, e.g., for decades Germany managed to keep the origin of the uranium it used a secret, and until today the uranium deployed in French reactors is mostly labeled "French", in spite of being imported from Niger, because the initial processing is undertaken in France.

Mining of uranium

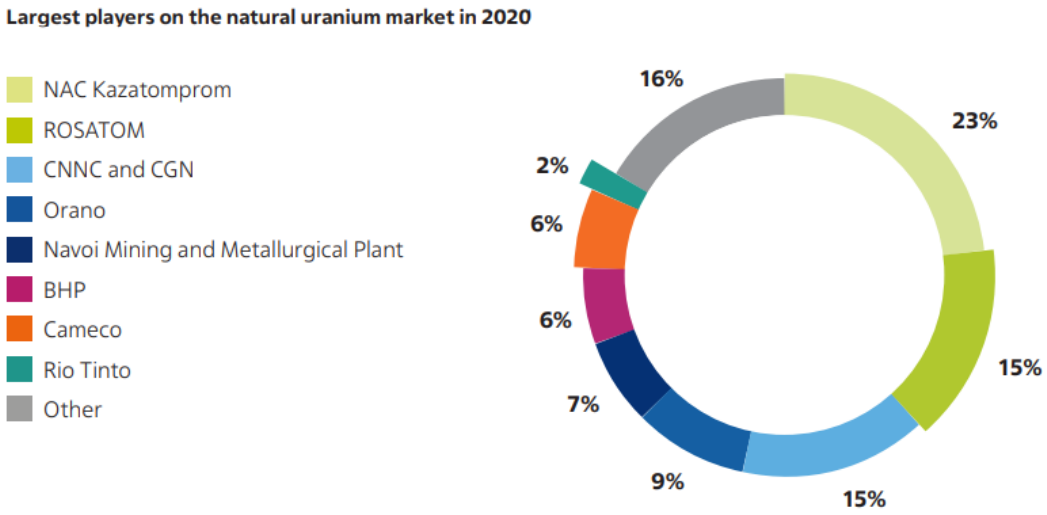
Uranium mining is a very hazardous and environmentally damaging activity. The next step is milling and processing the uranium ore, where the goal is to isolate uranium oxide (U3O8), the so-called yellowcake which, after conversion, is then sold to companies for further enrichment. Enrichment of uranium is seen as a safeguarding risk and therefore the IAEA non-proliferation policy bans this technology from being exported to countries which do not yet have enrichment capacities. Increasing the share of uranium's most fissile isotope, U-235 is called enrichment. Low-enriched uranium, which typically has a 3-6% concentration of U-235, is used for fueling NPP. The fuel loaded into EU reactors has an average enrichment assay of 3.94%, with 85% falling between 3.43% and 4.52%.78 Highly enriched uranium, or HALEU, is 20% enriched or more, while weapons-grade uranium for nuclear bombs is 90% enriched or more. The very same plant can be used to enrich all the way through to bomb-grade material, making it a safeguarding risk.

Uranium mining capacities

About 40% of uranium imported in the EU stem from Rosatom's mine or from Kazakhstan, which is politically considered an ally of Russia. Some of the mines in Kazakhstan are owned or co-owned by Russian companies.

[78] ESA European Supply Agency— ANNUAL REPORT 2020, p. 21.

Figure 3: Largest players on the natural uranium market in 202079



Europe has no uranium production

Europe's last uranium mine in Rožná in the Czech Republic closed in 2017. However, the government reserved the option of reopening other mines, such as Brzkov open. Brzkov is said to contain 3000-4000 tU around 300 m deep; state company Diamo said it would take six to seven years to commission the mine; local resistance it high. In Spain, the Salamanca project was under preparation and could produce 4.4 million pounds (Mlbs) of uranium concentrate annually for 14 years. But this was also recently cancelled. Similarly, the Kvanefjeld mining project didn't start after the Greenland Parliament approved a bill prohibiting uranium exploration and mining in 2021.

Uranium prices and increasing production

Uranium does not trade on an open market like other commodities. Buyers and sellers negotiate contracts privately. Uranium spot prices have surged more than 30% since Russia's invasion of Ukraine to trade at about $58/lb, the highest level since before the 2011 Fukushima-Daiichi disaster. The Wall Street Journal reported fears of disruption to uranium supplies due to sanctions on Russia. (…).80 In the current situation, uranium producers remain cautious before increasing production, which takes several months, in some cases years, and are waiting for long-term contracts before making risky investments.81

An IAEA/NEA report summarised this in saying that "significant investment and technical expertise will be required to bring these resources to the market. Producers will have to overcome a number of significant and, at times, unpredictable issues in

[79] UxC, Company reports.

[80] NucNet's Weekly News Review, April 1, 2022.

[81] NIW, March 25, 2022.

bringing new production facilities on stream, including geopolitical and local factors, technical challenges and legal and regulatory frameworks. To do so, strong market conditions will be critical for achieving the required industry investment".82

When evaluating the issue of replacing dependency on Russian and/or Kazakh uranium, costs are important. Uranium price plays a minor role for the operator of a nuclear power plant, but it is decisive when opening or enlarging a uranium mine. An example here is the US, where the dramatic decline in uranium production from 2016 to 2018 was due to low market prices. At the same time, US utilities started importing cheaper uranium from Rosatom; by March 2022 the dependency was so high that they lobbied hard to prevent the White House from banning the import; this may well be overturned.

The IAEA/NEA reported on global supplies: "Globally, Australia continues to lead with 28% of the world's identified resources in the category <USD 130/kgU (equivalent to USD 50/lb U3O8), with over 64% of Australia's national total endowment related to a single site, the world class Olympic Dam deposit. In terms of lower cost resources <USD 80/kgU and <USD 40/kgU, equivalent to USD 30/lb U3O8 and USD 15/lb U3O8), Kazakhstan leads with 49% and 36% of the world total, respectively."83 Uranium mine development takes long preparatory times, so no sudden new players can emerge. Also here Kazakhstan is leading. Only six countries announced development drilling in 2020: Canada, Iran, Kazakhstan, Namibia, Russia and Ukraine, with Kazakhstan accounting for half of the total global development drilling.84

On top of industrial considerations, ecological limitations will play a role and might in the end block efforts to increase uranium mining.

An embargo of Russian uranium cannot be excluded and has already started worrying the Kazakh state-owned uranium miner Kazatomprom. However, Kazakhstan is considered an ally of Russia and most likely would be become a target, even though Kazatomprom was responsible for a quarter of the world's primary uranium production in 2021, according to company data.

Conversion and enrichment

Western uranium converters and enrichers are facing an explosion in demand from nuclear fuel buyers preparing for a possible cutoff from Russian nuclear fuel. However, new additional capacities are needed and those are a long-term project. Some observers pointed out at the beginning of April 2022 that for many companies uncertainties remain, because if the war ends suddenly and Russian nuclear fuel never stopped entering the EU or the US, the newly build-up capacities for mining, converting and enriching would have been in vain.

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82 IAEA, NEA: Uranium 2020, Resources, Production and Demand. https://oecd-nea.org/upload/docs/application/pdf/2020-12/7555_uranium__resources_production_and_demand_2020__web.pdf.

83 Ibid., p. 9.

84 Ibid., p. 45.

Today there are five major global suppliers of uranium conversion services, Orano/Comurhex (France), Cameco (Canada), Converdyn (USA), Rosatom/TVEL (Russia) and CNNC (China).

Table 3: Estimated world primary conversion capacity 202085

Conversion plants are operating commercially in Canada, France, Russia and China. China's capacity is expected to grow considerably through to 2025 and beyond to keep pace with domestic requirements.

Estimated world primary conversion capacity 2020

Company	Country	Location	Nameplate capacity (tU)	Capacity utilization (%)	Capacity utilization (tU)
Orano*	France	Pierrelatte & Malvési	15,000	17%	2600
CNNC†	China	Lanzhou & Hengyang	15,000	53%	8000
Cameco	Canada	Port Hope	12,500	72%	9000
Rosatom	Russia	Seversk	12,500	96%	12,000
ConverDyn‡	USA	Metropolis	7000	0%	0
Total			**62,000**	**51%**	**31,600**

World Nuclear Association *Nuclear Fuel Report* (2021 edition)

* Orano's new conversion facility is still in the process of production ramp-up, which is expected to be finalized by 2023.

† Estimated capacity according to the assumption that China will develop its conversion capacity to supply the needs of the domestic reactor fleet.

‡ ConverDyn reduced capacity of its Metropolis plant in 2016 then closed it down pending market improvement in 2017. In January 2021 it announced that it plans to restart the plant after refurbishment in 2023.

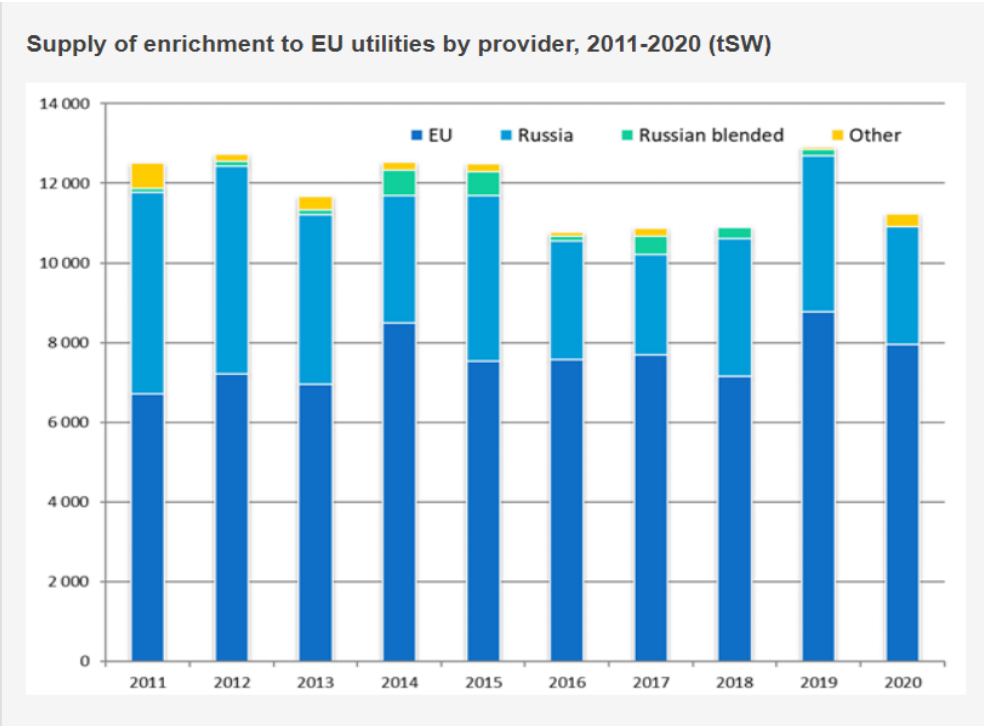
Enrichment capacities

According to European Supply Agency's data86, Europe covers its enrichment demand by 60-70 % itself, the remaining amount needs to be imported from Rosatom's enrichment facilities:

[85] https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/conversion-and-deconversion.aspx (Accessed April 4, 2022).

[86] ESA 2020. https://euratom-supply.ec.europa.eu/activities/market-observatory_en.

Table 4: Supply of enrichment to EU utilities by provider, 2011 - 2020 (tSW)



4. Outlook on Alternatives for New Reactors

A few days after the Russian invasion of Ukraine, discussions started on the fate of ongoing Rosatom projects in EU countries. This chapter explores the current new-build projects and gives an overview of the reactor types and reactor vendors available to replace the Russian supplier Rosatom Holding and its companies. Russia's Rosatom with its many subsidiaries was the market leader in the nuclear industry. Russia was not only constructing nuclear power plants at home, but also successfully completed its NPP projects (Astravets-1/Belarussia) abroad, certainly with fewer delays and cost overruns compared to its competitors. Russia has dominated the nuclear export market since 2009 and was preparing new contracts in many countries. Following its attack on Ukraine and resultant sanctions, many of Russia's contracts, including those in Finland and in Hungary, are likely to be cancelled. Russia's ability to even complete the remaining contracts is also in question.87

EPR/France

The French nuclear industry, usually understood as a powerful branch, is vastly overrated. The issue here is the potential of French nuclear industry to replace the new reactors which were previously, or might have been, delivered by Rosatom in Russia.

The only European reactor on the market is the EPR-1600 MW, which 20 years ago was called the flagship of nuclear renaissance. This Generation III+ reactor, however, is infamously troubled, notorious for its cost overruns and delays: even the domestic project Framatome 3, and Olkiluoto-3 in Finland, are not scheduled to reach full capacity until September 2022 – is a delay of 13 years, following a total construction time of 18 years.

Table 5: EPR reactors – 1600 MWe net

Country and NPP unit	Construction start	Commercial operation
China, Taishan 1	Dec 2009	Dec 2018
China, Taishan 2	April 2010	September 2019
Finland, Olkiluoto 3	Aug 2005	Planned July 2022
France, Flamanville 3	2007	Planned end of 2022
UK Hinkley Point C 1	2018	Planned 2026
UK Hinkley Point C 2	2019	Planned 2027

Two key problems stand in the way of an export offensive: manufacturing capacity and the EPR's design deficiencies which became evident once the first EPR started operating in China. The Taishan NPP unit 1 was taken offline for inspection on July 30, 2021, and it was still shut in April 2022. The immediate cause was fuel rod leakage, however, later it turned out that the problem might be a design failure in the reactor pressure vessel for which EDF is required to present a design solution to the

[87] M.V. Ramana, University of Colorado: https://www.colorado.edu/cas/2022/04/12/even-china-cannot-rescue-nuclear-power-its-woes (Accessed April 17, 2022).

French nuclear regulator ASN. EDF needs to submit a plan for reinforcement of metal grids at the EPR in France. The plan has not yet been submitted and is delayed.[88] This might be a major design failure which affects all EPR reactors.

Czech Republic

The Czech Republic is of particular interest for the discussion for two reasons. It is the only country which has opened a tender procedure, and, after a severe political struggle, decided even before the war in Ukraine to exclude Russia and China from the construction of the fifth unit at the NPP Dukovany site in 2021 after GRU (Russian military intelligence service) involvement in the 2014 explosion of an ammunition depot in Vrbětice was confirmed.

The path chosen by the government and parliament in Prague when it comes to ordering a nuclear reactor can be understood as a path, others also need to take. What remains unclear at this point in time – May 2022 – is the issue of other suppliers such as Škoda JS. One key point applicable to all future NPP financing schemes is the 100% state funding, loan and guarantees provided. The government announced that they will not only keep an eye on the main supplier, but also their sub-suppliers. The following steps must be clear before any contracts are signed.

4.1 Status of Dukovany financing and tendering process

The notification of the project at the European Commission is ongoing. The past cases of state aid notifications for financing packages for new NPP (Hinkley Point C and Paks II) were granted, but the Czech Republic seems to fear problems on some points, namely the relationship between investor (ČEZ) and the state (70% shareholder is the state) and the minority shareholders, and exceptions from public tendering: in a letter to the government Transparency International Czech Republic criticizing the unclear financing structure and unrealistic costs estimates or rather the lack of a limit to the public funding assumed for the NPP and the possible loss of billions of taxpayers' money.[89, 90] The authors of the letter also reminded the Minister of Finance that the Czech Office for the Protection of Competition has informed the government that the NPP tender would not be exempted from public procurement law; moreover, this exemption might also stand in violation of EU law. Currently the utility ČEZ is evaluating the three bids for the fifth reactor in Dukovany and three more optional reactors.

According to the timeline of NPP Dukovany, according to information provided by MPO, the Czech Ministry of Trade and Economy, the March 2022 start of tendering will end with a November 2022 deadline for the offers coming in from vendors, which will then be evaluated for approx. 2 years.[91] The tendering procedure should be

[88] https://www.montelnews.com/news/1313051/crucial-french-epr-report-4-months-late--regulator (Accessed April 18, 2022).

[89] https://www.transparency.cz/wp-content/uploads/2022/03/TI-MPO-JEDU-17.3.22.pdf.

[90] https://english.radio.cz/tender-new-nuclear-unit-dukovany-launched-after-years-delays-8745211 (Accessed April 4, 2022).

[91] https://www.mpo.cz/cz/rozcestnik/pro-media/tiskove-zpravy/stat-dal-souhlas-se-zahajenim-vyberoveho-rizeni-na-dodavatele-noveho-jaderneho-zdroje-v-dukovanech--266463/.

completed by the end of 2023/beginning 2024, followed by 2029 construction start and 2036 start-up of the new reactor.

According to the French President, the new plants would be built and operated by state-controlled energy company EDF and tens of billions of euros in public financing would be mobilised to finance the projects and safeguard EDF's finances. The first new reactor, an evolution of the EPR known as the EPR2, would come online by 2035, Mr Macron said. Studies for a further eight reactors in addition to the initial half-dozen new plants would be launched.

EDF has submitted a preliminary, non-binding offer to the Polish government for the construction of four to six EPR nuclear power plants in Poland at two or three different locations. It is also hoping to build six EPRs at the Jaitapur site in Maharashtra state, Western India.

Poland has been planning the construction of four to six EPR for over a decade; India also intends to order six EPR. At the same time, half of the NPP fleet in France (as of May 2, 2022) is out of operation and in need of repairs, thus adding pressure on the existing lack of skilled workforce and other nuclear industry infrastructure. It is safe to doubt the ability of France to go from managing the construction of four EPR in the past 15 years to a significantly larger number. On top of the already envisaged orders of 12 for export and eight for France, and 2 ongoing reactors in UK (HPC), EDF might have a hard time demonstrating its capacities to manage over 22 reactors in the next years.

Rosatom has also been plagued by the inability to deliver new nuclear power plants. NPP Paks II in Hungary was scheduled for start-up in 2025, and Hanhikivi in Finland in 2024.

Concerning the ongoing tender in the Czech Republic for a max. 1200 MW reactor, the experts' opinion on the rumoured intent of EDF to offer a downscaled EPR remains split: some say no problem, other exclude this possibility on technical grounds; the deadline for offers is scheduled for November 2022.

US / AP 1000

Another option is the US company's reactor, the AP 1000. Westinghouse is advertising its new reactor type with passive safety features: The AP1000 features a compact nuclear island per kWe produced (i.e., lower amount of concrete and steel per kWe) with fewer number of nuclear safety grade components relative to other GENIII/III+ reactors including the EPR and APR1400. This is due to AP1000 reliance on passive safety. AP1000's robust station black out scenario response without any need for offsite support already provides effective protection against Fukushima-type events.

This, however, could lead to a time-consuming licensing process, because many regulators lack experience and legal provision for this reactor type with more passive safety features replacing e. g. pumps. Switching from VVER-type reactors to the reactor from the US might need some time for the regulators, including finding staff with sufficient language skills to work with Westinghouse when it comes to

constructing an AP1000 reactor to replace the planned VVER-1200 reactors in Kozloduj or Belene in Bulgaria.

In general, the costs of NPP are always hugely uncertain, consistently turning out to be extremely over budget and the most expensive method of generating power. Lazard projects the capital cost of a nuclear power plant at $6,900 – $12,200/kW, while OECD Nuclear Energy Agency projects the capital cost between $2,157-$6,920/kW.

The newly published MIT study on the AP1000 tries to argue several specific cost-driving factors which have led to the ongoing AP1000 Vogtle project's current cost overruns since its start of construction in 2012. 92 Modular construction is currently promoted as the answer to the well-known delays and subsequent cost overruns. Westinghouse promised to beat this trend because of their expectation that "plant costs and construction schedules benefit directly from the great simplifications provided by the design" and because of the adoption of "modular construction techniques". Based on these, Westinghouse estimated a "cost per kWh of about 3.0 to 3.5¢/kWh for a twin unit plant". Westinghouse projected that the AP1000 reactor would have "an accelerated construction time period of approximately 36 months, from the pouring of first concrete to the loading of fuel". All of these projections have gone spectacularly wrong in both China, with the Sanmen and Haiyang projects, and especially with projects in the United States. The modular construction methods only had the effect of shifting some of the problems from the building site to the factory, found the World Nuclear Report in 2017. Among those technical problems was the unfinished design, pumps which had to be called back, shielding material which expanded in volume – a possibility the company had not considered as it had to admit in its report to the US nuclear regulator, the NRC. China publicly voiced criticism with Westinghouse handling construction of the reactor in China and it was the last order China placed with the US company. The AP1000 disasters in terms of cost overruns and delays with the reactor constructions at V.C. Summer and Vogtle are well-known and ongoing.

On top of technical issues, many observers doubt Westinghouse's abilities as a reactor supplier. Westinghouse filed for bankruptcy reorganisation in 2017, driven by liabilities related to the two US projects, and new owner Brookfield Business Partners has said the company wanted to remain a reactor supplier but not get involved in being the construction contractor on nuclear plant projects.

China as a vendor of nuclear power plants the Europe

Nuclear power features prominently in China's plans for exports of energy technologies under the Belt and Road Initiative. In February 2022, China National Nuclear Corporation signed an agreement to build a nuclear plant in Argentina. This marks China's first export of a nuclear reactor to a country other than Pakistan (with whom China shares a special relationship that also extends to sharing nuclear

[92] MIT-ANP-TR-193 March 2022, Koroush Shirvan: Overnight Capital Cost of the Next AP1000 Advanced Nuclear Power Program.

weapons and related military technology).93 Already earlier, however, countries decided to avoid the risk of Chinese interference and possible threat to infrastructure. In summer 2020, in reaction to doubts which arose in the US, several UK politicians started taking a very critical view on the Chinese involvement in the Hinkley Point C project, as reported by the Telegraph on 26th of July 2020*94*: "Another senior Tory MP has called for an inquiry over Chinese involvement in Britain's nuclear power stations amid rising concerns over the Hinkley Point C mega-project. Neil O'Brien said that urgent questions must be answered following conflicting reports about work by state-owned contractor China General Nuclear (CGN) on the £22.5bn scheme. The firm's role was originally thought to be limited to financial investment (…) Mr O'Brien said that US regulators were already taking aim at CGN and another business, China National Nuclear Corporation, after its department of defence accused them of having ties to Beijing's military forces. He said: "Both CGN and China National Nuclear Corporation have a kind of regulatory sword of Damocles hanging over their heads. Chinese reactors will be built even less, even if the design might be accepted, as the Economist reported in early 2022: "Hualong One…has a more straightforward design than other reactors being built in Europe… Publicly, the government says no decision has been taken. Privately, it is clear that Chinese involvement in British nuclear-power plants is at an end."95

The Czech Republic had already banned Chinese participation in this new reactor project in 2021 with its so-called Lex Dukovany which took effect on January 1, 2022.

Korea Hydro and Nuclear Power (KHNP)

South Korean energy company Korea Hydro and Nuclear Power (KHNP) has confirmed it intends to take part in the Czech Republic's tender process. Its flagship export technology is the 1,345 MW APR-1400 pressurised water reactor design, so far deployed overseas only at the United Arab Emirates' Barakah nuclear power station. Domestically, KHNP operates the APR-1400 at Shin-Kori-3 and 4 and is building more units at Shin-Hanul-1 and 2 and Shin-Kori-5 and 6.96 However, since 2009, when South Korea won this contract thus beating France, South Korea has not won a single reactor export contract.

4.2 Difficult future of Rosatom-Framatome cooperation

VVER reactor producer dependent on Western I&C

Rosatom Holding, the market leader in the past decades, also might run into difficulties because it relied on Framatome's Instrumentation & Control systems in its reactors, as well as receiving support for licensing in Western countries. In many cases it is a Framatome-Siemens consortium providing this service to Rosatom.

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93 M.V. Ramana, University of Colorado: https://www.colorado.edu/cas/2022/04/12/even-china-cannot-rescue-nuclear-power-its-woes (Accessed April 17, 2022).

94 Telegraph on 26th July 2020 at https://www.no2nuclearpower.org.uk/news/hinkley-chinese-involvement-28-7-20/ *(*Accessed April 17, 2022).

95 https://www.economist.com/britain/2022/02/12/british-regulators-have-approved-a-chinese-reactor-design (Accessed 17 April 2022).

96 NucNet Nuclear News Daily/1 April 2022.

The possibly politically or economically forced end to this field of cooperation could pose a serious problem both for Rosatom's new-build and modernisation business, because Framatome has been delivering the I&C systems for VVER reactors. It is almost impossible to replace the supplier of Instrumentation & Control systems which are the brain of a nuclear power plant: only very few companies are able to produce them. It may be that only Framatome can deliver the I&C for Rosatom's VVER reactors, both old and new, as it has many times in the recent past: In 2009, Framatome completed the Dukovany plant (Czech Republic) I&C refurbishment, a nine-year project considered one of the most significant I&C modernisation projects, and was used in 2018 to modernise key parts of the two Loviisa (Finland) VVER plants.97 Framatome also delivered the I&C for Russian and Chinese plants.

Back in 2020, the I&C Business Unit at Framatome announced: "We are delighted to provide our I&C expertise and partner with RASU JSC to support the construction of the Hanhikivi-1 Nuclear Power Plant," and continued by saying that this contract "demonstrates our unique capabilities to support Russian reactor designs in the field of I&C."98 The Rusatom/Framatome/Siemens cooperation for another planned NPP in an EU country was already signed in 2019: Paks-2 in Hungary.99

WNN also reported that in 2018, Framatome and Rosatom subsidiary JSC Rusatom Automated Control Systems (RASU) signed an MoU to enhance their cooperation in the field of I&C, including cooperation in the fields of maintenance and modernisation, training, development of nuclear infrastructure, and support for the certification of Russian equipment to ensure compliance with European and international norms and standards.

In 2021 Framatome and RASU signed a contract to provide technical support in design and integration of the I&C system for Fennovoima's Hanhikivi-1 nuclear power plant project in Finland. Under the terms of the contract, Framatome was to provide consulting support for I&C system integration and design in the plant construction project based on a VVER-1200 reactor. The role of RASU is to review design documentation and to be I&C technical leader and integrator for the Hanhikivi-1 plant.100

Framatome an independent Western company?

Regarding Framatome one needs to raise the question whether it can be seen as a "Western" supplier when seeking to disconnect a sensitive branch from Russia, when the French majority state-owned company continues its dependence and business with several companies of the Rosatom holding.

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97 https://www.framatome.com/solutions-portfolio/docs/default-source/default-document-library/product-sheets/a3038-b-fr-g-en-0422-spinlinefinal.pdf?Status=Master&sfvrsn=c378d37e_2 (Accessed April 25, 2022).

98 https://rosatom.ru/en/press-centre/news/rosatom-and-framatome-sign-instrumentation-and-control-design-support-contract-for-hanhikivi-1-npp-f/?sphrase_id=2953088 (Accessed April 26, 2022).

99 https://emerging-europe.com/business/rusatom-and-framatome-siemens-to-deliver-control-systems-for-hungarys-paks-npp/ (Accessed April 26, 2022).

100 www.world-nuclear-news.org/Articles/Framatome-and-Rosatom-expand-cooperation (Accessed April 26, 2022).

In late 2021, Framatome and Russian state nuclear corporation Rosatom signed a new strategic cooperation agreement further expanding the companies' efforts to develop fuel fabrication and instrumentation and control (I&C) technologies.101

Framatome continues the import of enriched uranium from Russia to its fuel element production facility in Lingen/Germany, which is supplying French nuclear power plants and many other plants in Europe. The French government made clear that the uranium supply will not be allowed to fall under the EU sanctions against Russia. Same position voiced even clearer: “Hungarian officials have consistently resisted the EU pressure to impose sanctions against the Russian nuclear energy sector. Hungary will by no means support sanctions against Russia's nuclear power industry, regardless of what EU package they may be part of.”102

Sanction impacts

Finland has cancelled the NPP construction contract with Rosatom. The NPP Paks II construction was not cancelled by the Hungarian government; instead, the Hungarian government made its worries about deliveries of the necessary Framatome I&C public. While France already cleared the export of the equipment, Germany has not done so.

The reduction of fuel sales in the future is an obvious consequence. Of a more strategic impact could be the fact that the brain of a nuclear power plant, the Instrumentation & Control System (I&C) for VVER-1000 and VVER-1200 are not produced by Rosatom but are a unique product produced and delivered by the French state company Framatome’s subsidiary in Germany. The situation concerning the export permit is unclear. According to media reports, the French already issued the permit, the German government has not said anything. According to the German Nuclear Bill, art.3 on export, a permit is required only for fission material, not technology. One might speculate that the I&C might fall under the EU sanctions for high-tech goods to Russia.

A full ban on the I&C would impact the entire newbuild program, which Russia is trying to keep. On top of keeping some of its nuclear export business, Rosatom is trying to make new acquisitions. Attempts to enter the African markets continue, in particular with Burundi, Zambia, Nigeria and further down the road Ghana, Tanzania and Ethiopia during the International Forum Atomexpo-2022 which was held in Sochi (Russia) on November 21-22.103 Also, Nicaragua, Myanmar, Uzbekistan, Kyrgyzstan confirmed their interest in nuclear cooperation with Russia. An agreement was signed between the Russian government and the Belarusian government on cooperation in the field of used nuclear fuel management.

Existing contracts have not been cancelled e.g., in Egypt, where in October 2022 the first concrete was poured for the El-Dabaa NPP which will comprise four units with

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[101] WNN, Dec 2,2021: Framatome and Rosatom expand cooperation : Corporate - World Nuclear News (world-nuclear-news.org).

[102] Platts Nuclear News Flashes December 12, 2023.

[103] https://www.neimagazine.com/news/newsatomexpo-attracts-65-countries-10381392/.

generation III+ VVER-1200 pressurised water reactors.104 Also, Hungary refuses to even discuss the option of cancelling business with Russian companies and the construction of Paks II is ongoing.

[104] https://www.neimagazine.com/news/newsfirst-concrete-poured-for-unit-2-of-egypts-el-dabaa-npp-10376585/.

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