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Logistics of international uranium supplies

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Abstract. The article discusses the organization of uranium supplies from the Republic of Kazakhstan to France with an emphasis on logical, technological and regulatory aspects. Kazakhstan, being the largest producer of uranium in the world, provides about 40% of global supplies, while it does not have operating nuclear power plants, exporting all the extracted uranium. Special attention is paid to the existing routes for the supply of uranium to France, including the classic route through the port of St. Petersburg and the alternative through the Trans-Caspian International Transport Route (Middle Corridor). The stages of the logistics supply chain are analyzed: from the extraction and primary processing of uranium to its transportation, customs clearance and transfer to French processing enterprises. The main challenges associated with multimodal transportation of radioactive materials, including compliance with international safety standards, are presented. The article substantiates the need to introduce modern digital solutions such as ERP and SCM systems, as well as to create a unified logistics information space (ELIP) to increase transparency, synchronize processes and minimize logistical risks.

Keywords: *uranium, logistics, supply chain, multimodal transportation, Kazakhstan, France, unified logistics information space.*

1. Introduction

Currently, thirty-one countries in the world receive energy through 192 nuclear power plants. There are 438 power units in operation at these stations. The top ten leaders in terms of the amount of electricity generated at nuclear power plants include the United States, France, Japan, Russia, South Korea, China, Canada, Ukraine, Germany and the United Kingdom [1].

Kazakhstan is currently the largest producer of uranium in the world, providing about 40% of global supplies. The most important mineral resource base in Kazakhstan is the Shuisuy uranium deposit (69.7%), which is operated by JSC National Atomic Company Kazatomprom together with subsidiaries, affiliates and joint ventures and is developing 26 sites in the Republic of Kazakhstan, combined into 14 mining assets. In 2024, the volume of uranium production amounted to 23,270 tons per year, which is 9.2% more than in 2023, and 8.5% more than in 2022 [2]. The dynamics of uranium production by JSC NAC Kazatomprom for 2020-2024 is shown in Figure 1. Kazakhstan has also launched a major program to increase the volume of uranium production and enrichment with the start of implementation in 2025. According to the design decision, the additional production capacity will amount to 6,000 tons per year. The successful implementation of this project will be an important step in increasing exports of enriched uranium.

Thus, Kazakhstan has established itself as the undisputed market leader in recent years, Kazakhstan has established itself as the undisputed market leader in recent years. However, despite the impressive uranium reserves of uranium, there are no operating nuclear power plants in the country, so all the extracted uranium is exported. Most of Kazakhstan's uranium is exported to countries such as China, India, and the European Union [3].

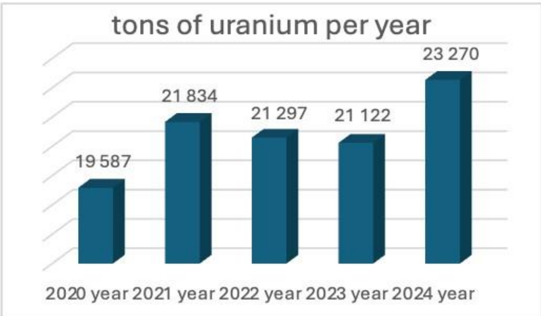

Figure 1. Dynamics of uranium production by JSC NAC Kazatomprom

In particular. China has significantly increased the import of uranium from Kazakhstan in recent years to supply a growing number of nuclear power plants. Among the countries of the European Union, France is the leader in importing Kazakhstani uranium, where in 2023 the share of nuclear energy in total electricity production was 70%. At the end of 2015, Kazatomprom and Electricité de France (EDF) signed a long-term agreement on the supply of 4,500 tons of uranium concentrate each from 2021 to 2025. Considering the course of development of nuclear energy in France and the inevitable growth in demand for raw materials for nuclear power plants, it makes sense for Kazakhstan to step up the development of the uranium industry, expand export capacities, and strengthen strategic cooperation with France [4]. The contract for the supply of uranium to France expires this year, and there is reason to assume that the contract will be extended. Because the issue of ensuring stable supplies of uranium for France's nuclear energy sector is strategically important issue. Kazakhstan and France have established a trusting partnership, which will undoubtedly contribute to the extension or conclusion of a new contract.

2. Materials and methods

The study used an analytical method in studying the global nuclear energy industry, Kazakhstan's position on the uranium market, as well as in considering logistical routes and transportation conditions. A comparative analysis was used to evaluate the uranium supply routes. Statistical data on uranium mining, data on the volume of supplies, the number of containers, the speed of delivery, and other logistical parameters were also used. A content analysis of regulatory documents has been applied to the analysis of international standards and agreements governing the transportation of radioactive materials.

3. Results and discussion

The current uranium supply chain from Kazakhstan to France is a multi-stage process that includes uranium extraction and primary processing, multimodal transportation, customs clearance, and compliance with international and European standards upon import into France, as well as the transfer of raw materials to French enrichment facilities.

The beginning of the current supply chain will be directly from the French side, namely, the Electricité de France (EDF) company, whose requirements and demand for uranium act as the primary stimulator for launching all subsequent stages of the logistics chain. Requests from the French market determine the volume, timing, and specifics of supplies, which, in turn, set the direction and framework for mining enterprises and processing structures in Kazakhstan.

After receiving the application from France, uranium ore mining began in Kazakhstan. The extraction and primary processing of uranium to France is carried out by the joint French-Kazakh enterprise KATCO.

To fulfill the annual supply of 4,500 tons of uranium concentrate from Kazakhstan to France. It takes about 225 containers. Uranium is transported to France by in accordance with a long-term uranium supply agreement between Kazatomprom and the French energy company EDF. However, uranium ore is enriched at Orano conversion plants. Thus, Kazakhstan is engaged in transportation to licensed conversion plants, and not directly to the French energy company EDF.

The organization of logistics is entrusted to the subsidiary of Kazatomprom JSC – KAP Logistics. This company provides efficient delivery of uranium concentrate and necessary reagents from mining fields and processing plants to export terminals by rail and road transportation.

Uranium is mainly transported in the form of a «yellow cake», since in this form its transportation is less expensive than the transportation of crude uranium ore. «Yellow cake» is a concentrated product of primary processing of uranium ore, the main component of which is uranium oxide (U_3O_8). This product is characterized by a high concentration of uranium, usually in the range of 70-90%, which ensures its effectiveness in further stages of enrichment and conversion into nuclear fuel. The material has a stable chemical structure, low humidity, and high density, which facilitates its transportation and storage, as well as reduces the likelihood of adverse reactions during operation [5].

The transportation process itself is strictly regulated by a whole range of international and national standards aimed at ensuring radiation and physical safety. A key role in this process is played by the set of rules of the International Atomic Energy Agency (IAEA), set out in the «Regulations for the Safe Transportation of Radioactive Materials» (SSR-6) [6-7], as well as regulatory documents such as the International Maritime Dangerous Goods Code (IMDG Code), The European Agreement on the International Carriage of Dangerous Goods by Road (ADR), the Agreement on International Freight Transport by Rail (SMGS) and the rules included in the COTIF Convention (based on the provisions of the CIM).

Special attention is paid to the development of optimal transportation routes that minimize transit through densely populated areas and reduce the number of shipments. The principle of minimizing time and distance also applies, according to which uranium materials are transported on the shortest route with the least amount of congestion, and delays at hub stations are minimized.

The choice of vehicles and packaging is determined not only by the level of cargo activity, but also by critical safety parameters such as the possibility of heat release and the likelihood of nuclear criticality. In this regard, containers certified according to strict standards (for example, types IP-2, IP-3 or B(U)) are used, and the concept of «Transport Index» (TI) is also applied, which determines the radiation level at a distance of one meter from the surface of the package and It serves as a guideline for taking additional protective measures when exceeding established standards. If the TI exceeds the permissible limits, additional protection measures or a revision of the route are required.

In addition, in some countries, including Kazakhstan and France, enhanced security protocols are in place, providing for the escort of cargo by armed units or specialized security services, as well as mandatory notification to regulators when crossing the state border. All participants in the logistics chain, from the sender to the carrier and the recipient, must be informed in advance about the timetable, cargo characteristics, and contingency plans. This makes it possible to form a closed control system that reduces the risk of unauthorized access and prevents emergencies.

In addition to technical and organizational measures, the transportation of uranium is accompanied by strict compliance with the requirements for the choice of vehicles. Railway wagons, shipping containers, and tank cars used for the transportation of radioactive materials must have official approval from regulatory authorities, which confirms their suitability for the transportation of dangerous goods. Special protocols also regulate the procedure for loading, securing and fixing cargo to prevent its displacement or damage during transportation.

All participants in the logistics chain, starting from loading at the mining site to unloading at the final enterprise, are required to act in accordance with approved radiation safety protocols, which minimizes the risk of leaks, accidents and unauthorized access to the material [8].

According to the first route, uranium is transported by rail from Kazakhstan (Turkestan station) to the Russian port of St. Petersburg, which takes 17 days. From the port of Saint Petersburg, the cargo is loaded onto a specialized vessel and transported by sea to a European port, most often to the port of Le Havre in France, which takes about 9 days. Upon arrival in Le Havre, the cargo passes through customs clearance, followed by further land transportation to the final recipient. The total duration of this route is approximately 26 days (Table 1).

Table 1. Transportation time on the first route

Stage 1	
Departure point – destination	Turkestan Station - Port of Saint Petersburg
Key points	Turkestan – Bessaryk – Belkol – Toretam – Mailybas – Shokisu – Kaidaul – Sagarchin – Iletsk I (exp.) – Kanisai (rzd) (exp.) – Syrt – Platovka – Gamaleyevka – Zalivnaya – Zhiguli Sea – Polivanovo – Nazarovka – Divovo – Panki – Perovo – Kuskovo – Sunflower – Bryantsevo – Likhoslavl – Akademicheskaya – Torfyanoe – Kolpino – Pargolovo – Saint Petersburg
Distance/ average speed of movement	3721 km / 300 km/day.
Transportation time	13 days
Loading/unloading time	4 days
Stage 1 time	**17 days**
Stage 2	
Departure point – destination	Port of Saint Petersburg - Port of Le Havre
Distance/ average speed of movement	2835 km / 10-15 knots per hour (26 km/hour)
Transportation time	5 days
Loading/unloading time	4 days
Stage 2 time	**9 days**
The total transportation time is 26 days.	

However, due to geopolitical risks, a significant part of the uranium supplies is currently being carried out via an alternative route. By the end of 2023, 64% of all shipments of uranium from Kazakhstan to Western countries were successfully implemented through the Trans-Caspian International Transport Route (TMTM, also known as the Middle Corridor). According to this scheme, uranium is first delivered by rail to the ports of Aktau or Kuryk, which takes about 12 days. Then the cargo crosses the Caspian Sea by sea and arrives at the Azerbaijani port of Alat. On average, ships travel 10-15 knots per hour, and thus transportation by sea to the port of Alat takes 5 days.

The transportation of uranium from the port of Aktau to the port of Alat is carried out by the national shipping company Kazmort-Ransflot, having specially obtained a license for the transportation of dangerous goods in 2023, Kazmortransflot transported 228 containers of natural uranium concentrate across the Caspian Sea, while full container ships with uranium run every two to three months.

After transshipment, the cargo again follows the railway to the Georgian port of Batumi, the journey takes 8 days, from where it is transported by sea across the Black Sea to the ports of Romania (Constanta) or Bulgaria (Burgas), which takes another 6 days. The final stage is rail transportation from Romanian or Bulgarian ports to France, which takes 13 days. Thus, the total delivery time along the TMTM route is 44 days, depending on weather conditions, the schedule of carriers, as well as customs and border procedures at each stage (Table 2).

Table 2. Transportation time on the second route

Stage 1	
Departure point – destination	Turkestan Station – Aktau Port
Key points	Turkestan-Sekseul-Shalkar-Beineu-Mangystau-Aktau
Distance/ average speed of movement	1,858 km / 250 km/day.
Transportation time	8 days
Loading/unloading time	4 days
Stage 1 time	**12 days**
Stage 2	
Departure point – destination	Aktau Port - Alyat Port
Distance/ average speed of movement	450 km / 10-15 knots per hour (26 km/hour)
Transportation time	1 day
Loading/unloading time	4 days
Stage 2 time	**5 days**
Stage 3	
Departure point – destination	Port of Alat – port of Batumi
Key points	Alat-Hajigabul-Akstafa-Boyuk-Kasik (exp.)-Gardabani (express) – Tbilisi – Uzlovaya – Khashuri-Samtredia-Batumi
Distance/ average speed of movement	815 km/200 km/day.
Transportation time	4 days
Loading/unloading time	4 days
Stage 3 time	**8 days**
Stage 4	
Departure point – destination	Port of Batumi - Port of Constanta
Distance/ average speed of movement	1,093 km / 10-15 knots per hour (26 km/hr)
Transportation time	2 days
Loading/unloading time	4 days
Stage 4 time	**6 days**
Stage 5	
Departure point – destination	Port of Constanta - Pierlatt Station
Distance/ average speed of movement	2,200 km / 250 km/day
Transportation time	9 days
Loading/unloading time	4 days
Stage 5 time	**13 days**
The total transportation time is 44 days.	

Despite the increased transportation time, a promising scheme for the supply of uranium from Kazakhstan to France is the second route through the Middle Corridor, which has many «bottlenecks» that directly affect the timeliness of delivery, transportation safety, and the level of trust between supply chain participants. Among the most critical factors, we can single out the congestion of ports and railway stations, difficulty in documentary support for multimodal transportation, and insufficient coordination between all participants in the logistical process. Taken together, these problems increase the risk of delays, lead to duplication of operations, and negatively affect the level of trust between Kazakhstan and France, especially given the specifics of the transportation of radioactive materials (Class 7 dangerous goods).

To overcome the described difficulties, an integrated approach is required, combining the modernization of infrastructure (expansion of ports, installation of intelligent cargo flow management systems), the introduction of a single-window transportation documentation system, and single window transportation documentation system, as well in-depth international cooperation and harmonization of regulatory standards [9]. This will reduce bureaucratic barriers, simplify customs procedures, and minimize logistical risks.

Given the dynamic uranium market and the French nuclear industry's high dependence on stable supplies from Kazakhstan, high dependence of the French nuclear industry on stable supplies from Kazakhstan, the issue of timely coordination of production and consumption plans is of particular importance. Even minor deviations in graphs can lead to a shortage of raw materials at nuclear fuel cycle plants in France or, conversely, to excess uranium reserves on the Kazakh side.

To synchronize production plans by Kazakhstan and consumption by France, it is advisable to implement integrated enterprise resource management systems (ERP - Enterprise Resource Planning) and supply chain management (SCM - Supply Chain Management), which allow operational management of production processes, raw material stocks, transportation and sale of products [10]. The functional relationship between ERP and SCM in the management of the uranium supply chain from Kazakhstan to France can be identified from Table 3.

Table 3. Functionality of ERP and SCM systems at the stages of the uranium supply chain

ERP systems (internal management)	SCM systems (inter-organizational management)
Planning	
Formation of plans for the extraction and processing of uranium based on contracts and facilities of the enterprise	Forecasting the needs of the French side, synchronizing production and consumption schedules
Production accounting	
Automation of accounting of production volumes, reagents, equipment control	Analysis of the compliance of supplies with the terms of contracts, adjustment of volumes and delivery dates
Logistics and inventory	
Inventory management of uranium concentrate and recycled materials	Optimization of routes, transportation schedules, integration with IoT for container monitoring
Document management	
The formation of export documentation: certificates, permits, invoices	Automation of approvals with customs, ports, regulators through EDI
Monitoring and reporting	
Analysis of internal KPIs and financial indicators	Generation of reports, notifications, and execution control at all stages of the supply chain

4. Conclusions

Optimization of logistical processes in the supply chain of uranium from Kazakhstan to France involves not only the elimination of point problems related to infrastructural constraints or documentary support, but also the creation of a systemic digital environment in which all participants can effectively interact. In an environment where uranium concentrates pass through several geographical zones and multimodal stages (railway, sea transport, road transportation), the introduction of a unified logistics information space (ELIP) becomes a key element of improvement.

The implementation of ELIP will provide a single digital space in which all participants in the supply chain will be able to access up-to-date information on cargo status, documentation, routes, and delivery schedules in real time. Such end-to-end information connectivity will increase the transparency of processes and reduce the time for making managerial decisions. By eliminating paper-based document management and switching to automated document coordination, it will be possible to significantly reduce the length of the logistics cycle (by approximately 3-5 days), especially in areas with high administrative burden, such as border crossings or multimodal transfer hubs.

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Уранды халықаралық жеткізу логистикасы

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Аңдатпа. Мақалада логистикалық, технологиялық және реттеуші аспектілерге баса назар аудара отырып, Қазақстан Республикасынан Францияға уран жеткізуді ұйымдастыру мәселелері қарастырылады. Қазақстан әлемдегі ең ірі уран өндіруші бола отырып, әлемдік жеткізілімдердің шамамен 40% -. қамтамасыз етеді, бұл ретте барлық өндірілген уранды экспорттай отырып, жұмыс істеп тұрған атом электр станциялары жоқ. Францияға уран жеткізудің қолданыстағы бағыттарына, оның ішінде Санкт-Петербург порты арқылы өтетін классикалық маршрутқа және Транскаспий халықаралық көлік бағыты (Middle Corridor) арқылы баламалы бағытқа ерекше назар аударылды. Жеткізудің логистикалық тізбегінің кезеңдері талданады: уранды өндіру мен бастапқы өңдеуден бастап оны тасымалдауға, кедендік ресімдеуге және француз өңдеу кәсіпорындарына беруге дейін. Халықаралық қауіпсіздік стандарттарын сақтауды қоса алғанда, радиоактивті материалдарды мультимодальды тасымалдауға байланысты негізгі сын-қатерлер ұсынылған. ERP және SCM-жүйелері сияқты заманауи цифрлық шешімдерді енгізу, сондай-ақ ашықтықты арттыру, процестерді синхрондау және логистикалық тәуекелдерді барынша азайту үшін бірыңғай логистикалық ақпараттық кеңістік (ЕЛИП) құру қажеттілігі негізделеді.

Негізгі сөздер: *уран, логистика, жеткізу тізбегі, мультимодальды тасымалдар, Қазақстан, Франция, бірыңғай логистикалық ақпараттық кеңістік.*

Логистика международных поставок урана

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Аннотация. В статье рассматриваются вопросы организации поставок урана из Республики Казахстан во Францию с акцентом на логистические, технологические и регуляторные аспекты. Казахстан, являясь крупнейшим производителем урана в мире, обеспечивает около 40% мировых поставок, при этом не располагает действующими атомными электростанциями, экспортируя весь добытый уран. Особое внимание уделено действующим маршрутам поставки урана во Францию, в том числе классическому маршруту через порт Санкт-Петербург и альтернативному — через Транскаспийский международный транспортный маршрут (Middle Corridor). Анализируются этапы логистической цепи поставок: от добычи и первичной переработки урана до его транспортировки, таможенного оформления и передачи французским перерабатывающим предприятиям. Представлены основные вызовы, связанные с мультимодальными перевозками радиоактивных материалов, включая соблюдение международных стандартов безопасности. Обосновывается необходимость внедрения современных цифровых решений, таких как ERP и SCM-системы, а также создания единого логистического информационного пространства (ЕЛИП) для повышения прозрачности, синхронизации процессов и минимизации логистических рисков.

Ключевые слова: *уран, логистика, цепь поставок, мультимодальные перевозки, Казахстан, Франция, единое логистическое информационное пространство*.

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