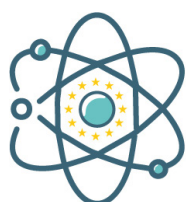


Analyzing Open-Source Data on Uranium and Nuclear Fuel Imports

OBSERVATORY OF NUCLEAR FUEL
GEOPOLITICS

DATA PAPER N°1

2025



GeoNuFE

Critical Geopolitics of Nuclear Fuel Supply in Europe



European Research Council
Established by the European Commission

Foreword

This report was prepared by the research team of the GeoNuFE project (Critical Geopolitics of Nuclear Fuel Supply in Europe), hosted by the Université de Haute-Alsace (France). It is part of the work conducted by the Observatory of the Geopolitics of Nuclear Fuel.

This program is led by Prof. Teva Meyer and is fully funded by the European Research Council through the ERC Starting Grant No. 101162722.

GeoNuFE Data Papers are a series of reports aimed at journalists, elected officials, policymakers and civil servants, as well as the general public. Their objective is to explain where to find and how to interpret data related to nuclear fuel supply chains.

All inquiries can be directed to Prof. Teva Meyer (teva.meyer@uha.fr)

GeoNuFE research project

GeoNuFE, short for « **critical Geopolitics of Nuclear Fuel supply in Europe** », is a research project funded by a European Research Council (ERC) Starting Grant.

Its core objective is to understand how nuclear-powered countries secure their fuel supply. To achieve this, it focuses on two key research questions :

- Where does power reside within the nuclear fuel supply chain ?
- Second: How do perceptions of these geopolitical risks influence the decisions of those responsible for shaping supply policies ?

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Introduction

The invasion of Ukraine in February 2022 and the coup in Niger in July 2023 have brought the supply of nuclear fuel to power plants back to the center of media and political debates. The main question has been to quantitatively assess the dependence of European and North American countries on imports and to clarify the potential risks this poses to the operation of power plants.

Data on global trade in materials used to produce nuclear fuels are available in open sources, online. While access to this data is simple, interpreting it requires understanding certain keys to reading and contextualizing. These difficulties

have led to several media controversies, particularly about the continuity of trade between Europe and Russia.

The objective of this report is to enable journalists, elected officials, and more broadly civil society to :

- Know where to find these data ;
- Understand the material flows they cover ;
- Learn how to read and interpret these data.

The analysis of the data will be the subject of a forthcoming report.

This report does not address by-products of the nuclear fuel chain, such as depleted uranium, or materials derived from the reprocessing of spent fuel. These issues will be covered in a separate report.

1. Fundamentals of the Nuclear Fuel Supply Chain

1.1. How is Nuclear Fuel Produced?

Uranium is and will remain, for at least the next half-century, the primary material used in nuclear fuels. Of the 416 reactors in operation worldwide as of summer 2025, all use uranium. All the 62 units under construction at the same time are based on uranium technology, even if the type of fuel varies (natural uranium, enriched uranium, or uranium-plutonium mixed oxide fuel [MOX]).

Uranium enrichment remains a central step in the nuclear fuel supply chain. Nuclear reactors can be roughly divided between those operating on natural uranium (PHWR) and those using enriched uranium (PWR and BWR). There are only 46 PHWRs in operation worldwide and only one was under construction in June 2025. Finally, of the 122 reactor models under development listed by the IAEA, about 10% plan not to use enriched uranium.

The fuel manufacturing chain is often summarized in four steps, carried out at different sites :

1. **The extraction of uranium.**
2. **Its conversion**, i.e., its transformation into uranium hexafluoride (UF₆). The goal is to obtain a product whose physicochemical characteristics simplify the passage into the gaseous form necessary for the subsequent enrichment of uranium.
3. **Enrichment**¹, to achieve the proportion of ²³⁵U required by the buyer.
4. **The assembly of enriched uranium**, i.e., its

transformation into pellets, stacked and strung into cladding, which are then called a fuel rod. A typical assembly consists of between 179 and 264 rods.

However, the actual chain is more complex, involving multiple sites:

- The transition from extraction to conversion may require an intermediate step if the mines do not have all the necessary infrastructure for purification of uranium. This is particularly the case in Kazakhstan.
- Conversion can take place at two sites. This is the case for the company Cameco in Canada, where uranium is first refined into uranium trioxide (UO₃) at Blind River before being transformed into UF₆ at Port Hope. The same is true for Orano in France, where uranium is changed into uranium tetrafluoride (UF₄) at Malvési and then into UF₆ at Tricastin.
- Before being manufactured into pellets, UF₆ must be deconverted to return to an oxide form (UO₂), essential for the subsequent operations. Not all assembly sites have the infrastructure to do this, as is the case with the Enesa plant in Spain, which requires transit through another company.

These steps lead to the import and export of materials, accounted for in open sources:

- **Natural uranium:** generically called Uranium Concentrate (UoC), but which can take different chemical forms (U₃O₈, Uraninite, UO₃, UO₄, UO₂), with colors ranging from orange-yellow to anthracite green.
- **Uranium tetrafluoride (UF₄) and uranium hexafluoride (UF₆):** the transformation of uranium into a material whose physico-chemical properties facilitate enrichment.
- **Enriched UF₆,** more often called Enriched Uranium Product (EUP) or Low Enriched Uranium (LEU). It can be in the form of UF₆ or dioxide (enriched UO₂) if it has been deconverted.
- Assembled fuel bundles

¹ Natural uranium primarily consists of three isotopes: ²³⁴U, ²³⁵U, and ²³⁸U. While ²³⁸U accounts for approximately 99% of natural uranium, it typically contains only about 0.72% of ²³⁵U. However, it is this isotope, ²³⁵U, that is fissile and therefore usable in nuclear reactors. To be suitable for use as fuel, the proportion of ²³⁵U must be increased through an enrichment process, generally reaching a concentration between 4% and 5%, depending on the reactor operator's specific requirements.

1.2. How Do Supply Contracts Work?

When a nuclear power plant operator wants to procure fuel, they can roughly choose between two strategies.

- Purchasing the fully assembled fuel from a producer without worrying about the intermediate steps, leaving the responsibility to the supplier.
- Purchasing natural uranium (from a mining company or an intermediary) and then contracting separately others suppliers

for conversion, enrichment, and assembly services.

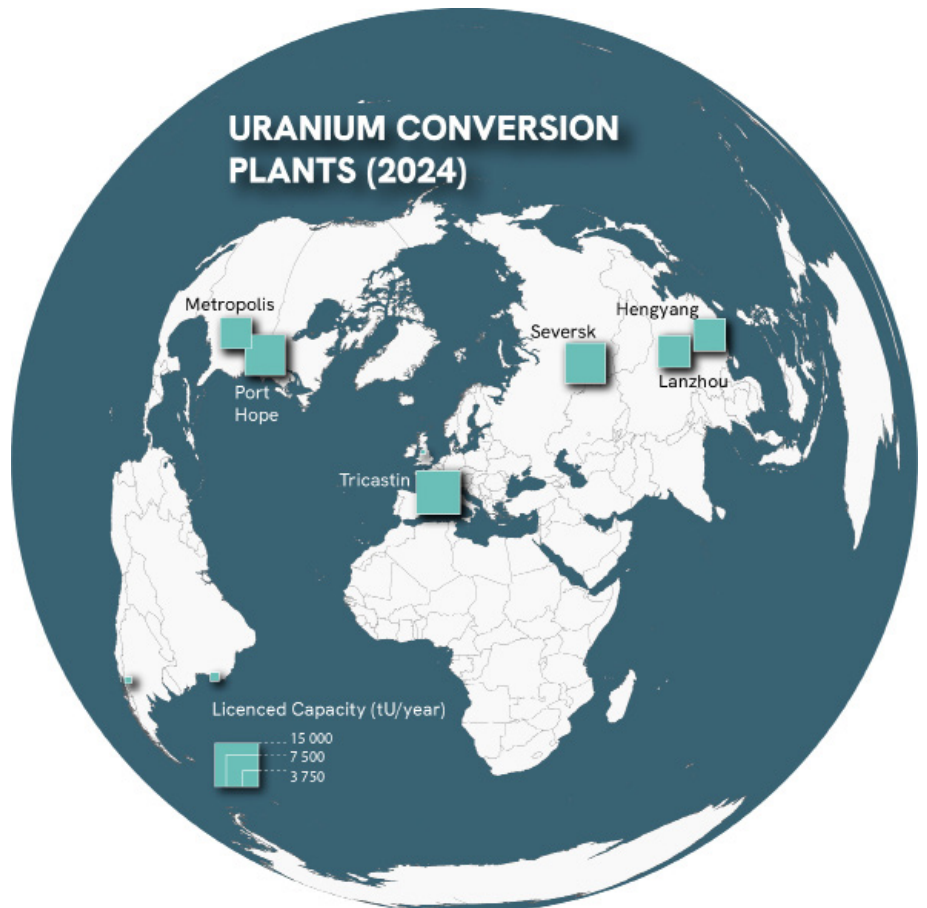
This last approach allows for cost control but, more importantly, for diversifying supply sources by multiplying suppliers and thus increasing resilience in the face of disruption. This option is largely preferred today, except for companies operating a small number of reactors.

The physical structure of supply contracts can be shaped by national regulations. For example, purchases of enriched uranium from Russia by U.S. reactor operators are regulated by the Russian Suspension Agreement (RSA). A U.S. operator seeking enriched uranium on the global market has two options: buy the EUP or contract only the enrichment service (SWU-Only contract). In practice, even in SWU-Only contracts, natural uranium and UF₆ are supplied by Russia to minimize transportation. Officially, the operator purchases natural uranium, conversion, and enrichment services separately, even if all are provided by a single Russian entity, Rosatom. To discourage Russian sourcing, the RSA requires that operators physically return to Russia the volume of natural uranium equivalent to what was enriched ("returned feed").

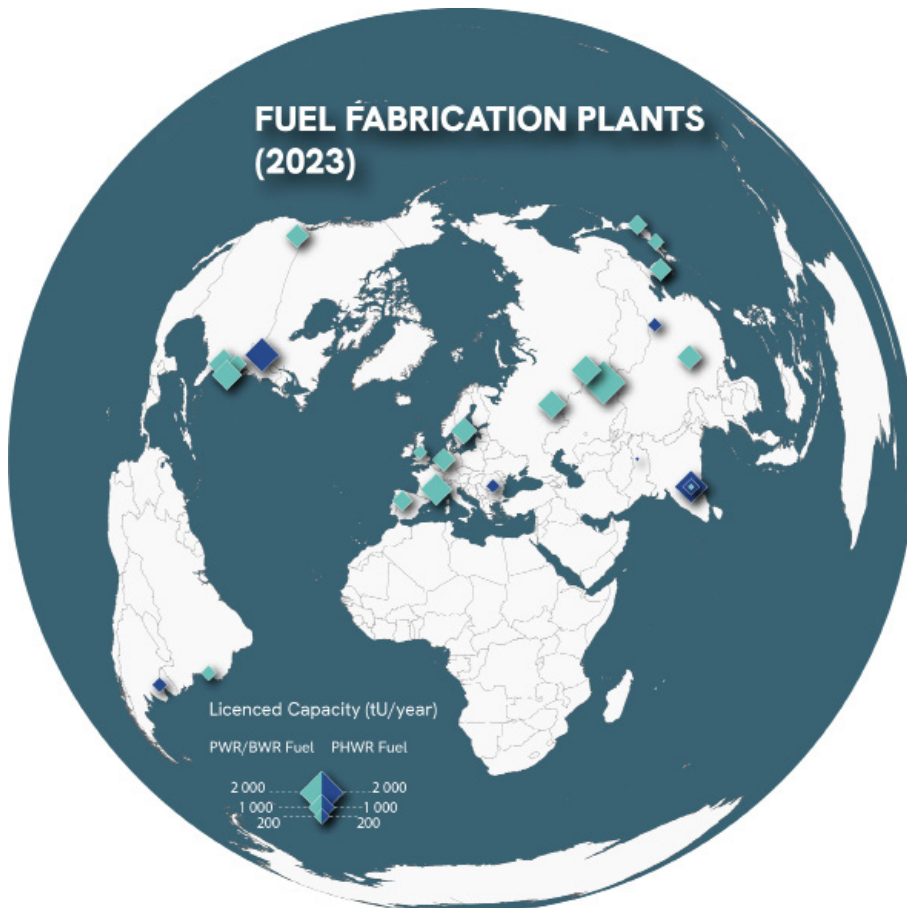
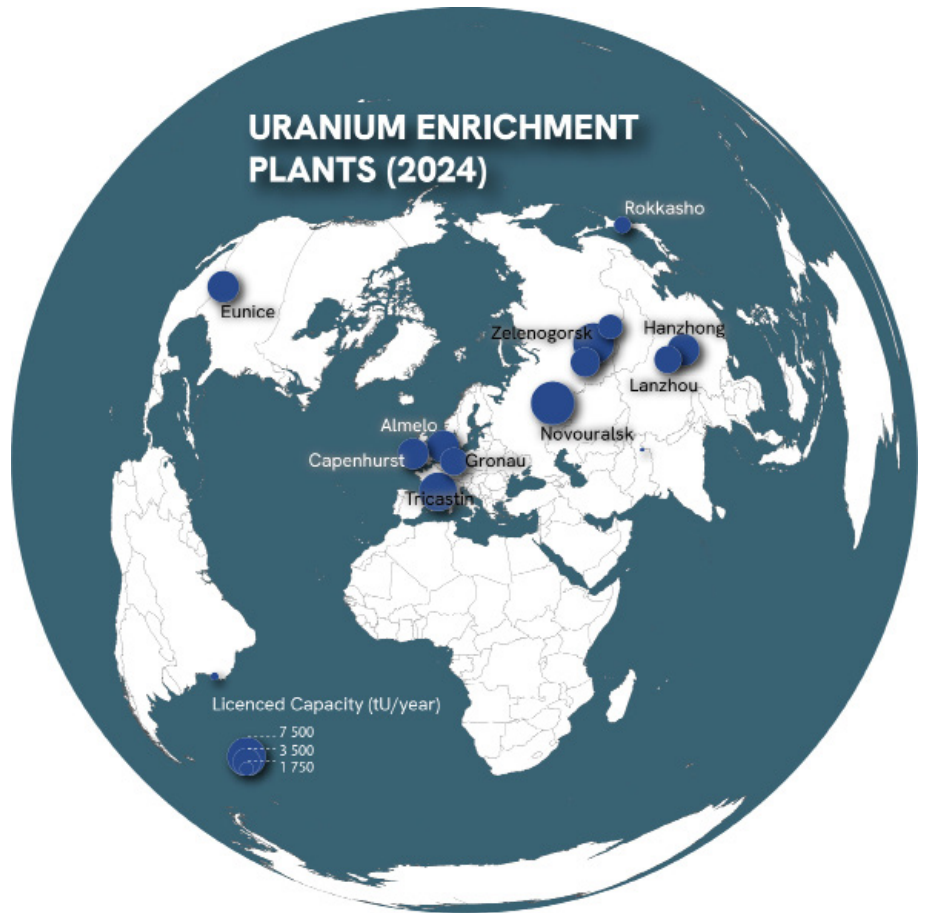


1. Natural uranium production

2. Conversion of natural uranium to UF₆



3. UF₆ enrichment



3. Production of the nuclear fuel assemblies

1.3. Do Not Confuse Material Imports/Exports with Material Purchases

Materials are therefore constantly circulating between the different sites in the fuel chain. These flows are recorded in global trade databases. **However, it should not be confused :**

- **An import situation**, i.e., a physical flow of material between two countries. These movements are recorded by customs.
- **A purchase situation**, i.e., the acquisition of this material by a reactor operator from an industry supplier.

Due to the geographical dispersion of fuel manufacturing steps, a material is frequently imported into a country where a plant in the chain is located to be transformed, before being re-exported to another country.

Concretely, a database may show the export of

Australian uranium to France. This information does not necessarily mean that the uranium will be used in French power plants. A Swedish nuclear reactor operator may have purchased this uranium and then contracted the French company Orano to convert and enrich this material, before having it assembled in Germany and using it in their power plant.

Similarly, the import into France of enriched uranium from Russia does not mean that it will be used by French reactors. Thus, a Spanish company may have contracted the Framatome group, based in Isère (France), to assemble fuels from this material for its power plants.

1.4. The Uranium Used in a Plant Is Rarely the One Initially Purchased

During the fuel manufacturing steps, materials are frequently mixed or exchanged. Consequently, if a reactor operator purchases uranium from a mine operator, it is highly likely that this material will not be physically present in the power plant at the end of the chain.

Several mechanisms lead to this separation between the contractual origin (the company from which the material is purchased) and the physical origin (the actual provenance of the material used).

From the conversion plants, the flows of natural uranium arriving in drums are mixed, regardless of their origin. This strategy limits waiting times due to the transport of the material and allows contracts to be honored more quickly. Conversion companies keep accounts of suppliers and buyers.

The fuel market operates through immaterial exchanges called swaps, to limit transport needs. Imagine a situation where reactor operator A has uranium delivered to a converter in Europe and has an enrichment

contract in North America. Simultaneously, reactor operator B has a conversion contract in the United States and enrichment in Europe. To avoid transatlantic transport, the two companies can agree to exchange, or swap, their stocks from an accounting perspective.

To limit waiting times, enrichment and assembly plants also use the inventories they

have on site to honor their contracts, without systematically waiting for the arrival of the material purchased by the reactor operator.

Thus, if a Swedish nuclear reactor operator purchases its uranium from a Kazakh mining company, there is no guarantee that the uranium actually used in the power plant physically comes from Kazakhstan.

2. Open-Source Data for Analyzing Fuel Chain Imports

As previously explained, it is fundamental to distinguish between data on the purchases of materials by reactor operators (contractual data that reflect supply sources) and data on imports (customs data that reflect physical flows).

2.1. Who Supplies Whom? Gaps in Data on Material and Service Purchases

There is little open-source data on the contractual origin of materials used in reactors. No global database exists. The availability of this information depends on the legal framework of each country, which may or may not require power plant operators to disclose the origin of their purchases, or on the transparency policies of these companies. So, where can these data be found ?

For Europe:

At the European Union level, the European Supply Agency of the European Atomic Energy Community (Euratom) annually publishes a report describing the origin of purchases of natural uranium, conversion services, and enrichment services made by European reactor operators.

- **Geographical Coverage** : All EU countries are compiled together. Data by country is not available.
- **Temporality** : Data is available for the previous year, up to 1995.
- **Attention** : Data on the origin of enrichment is divided between Europe, USA, Russia, and other non-European countries, without further precision on the exact country for

For North America:

The U.S. Energy Information Administration (EIA) annually publishes complete data on the origin of natural uranium and enrichment services purchased by U.S. reactor operators.

- **Geographical Coverage**: All U.S. reactor operators, compiled.
- **Temporality**: Data is available for the previous year, up to 1992.
- **Attention**: Data is not available for conversion and assembly services.
- **Find the Data**: <https://www.eia.gov/uranium/marketing/>

The Canadian government does not provide official statistics on the nuclear fuel supply for its power plants. The same applies to

the latter. By deduction, it could be China or Japan. Data on the origin of assembly services is also missing.

- **Find the Data** : https://euratom-supply.ec.europa.eu/publications/esa-annual-reports_en

None of the Euratom member states provide an open database compiling the source of their supplies. While some mention supply countries, no company operating reactors in Europe provides precise or quantified data on a regular basis. This also applies to Great Britain and Switzerland.

the three reactor operators in the country: Ontario Power Generation, Bruce Power, and New Brunswick Power.

For Latin America:

In Mexico, Brazil, and Argentina, no official data from governments or companies operating the reactors are produced for the public

For Asia:

In **Japan**, the Agency for Natural Resources and Energy (ANRE) of the Ministry of Economy, Trade, and Industry provides data on the volumes of natural uranium and its derivatives purchased but does not provide the countries of origin. The companies in charge of operating the reactors do not provide public data.

- **Find the Data:** https://www.enecho.meti.go.jp/statistics/total_energy/

In **South Korea**, the supply of power plants is entirely carried out by KEPCO. Neither the company nor the government provides a database. However, this data is partially available on the U.S. Securities and Exchange Commission (SEC) website. Since KEPCO is listed on the stock exchange in the United

States, the group is subject to transparency obligations under investment security. KEPCO must fill out a document called 20-F each year, which contains information on supply sources.

- **Find the Data:** The 20-F forms are available on the SEC search engine (<https://www.sec.gov/edgar/search/>). A search using KEPCO's identifier (0000887225) allows downloading the documents.

For China and India, no official database exists on the origin of natural uranium and fuel manufacturing services.

For Africa:

No official data is available regarding the continent's only operating nuclear power plant, in Koeberg, South Africa.

How to Track Supply Contracts Without Official Data?

Press releases regarding the signing of contracts: World Nuclear News, the press service of the World Nuclear Association, relays the main commercial events in the industry. While it does not provide all the information, it is the main source that makes these contracts visible, and its articles are freely accessible. Other tools for monitoring the commercial news of the nuclear industry exist (NucNet - <https://www.nucnet.org/> or Nuclear Engineering International - <https://www.neimagazine.com/>), but they are either paid or less complete than WWN.

Annual, financial, and environmental reports of nuclear power plant operators : The content of these documents varies from country to country depending on national legal obligations that constrain the dissemination of certain information. Most often, they do not provide the volumes of materials purchased but mention the countries of origin.

2.2. Customs Data on the Circulation of Materials in the Nuclear Fuel Chain

Available Sources

Imports and exports of materials or objects are reflected in customs data. There are four types of online accessible sources :

- **National customs agencies**, such as those of France, Germany, the United States, China, or Great Britain.
- **Eurostat**, the Directorate-General of the European Commission responsible for EU statistics : <https://ec.europa.eu/eurostat/comext/newxtweb/>.
- **UN Comtrade**, the United Nations database compiling global trade statistics from the declarations of national customs agencies: <https://comtradeplus.un.org/>.
- **Third-party databases** that reuse the above sources, focusing on certain products (such as agriculture, oil, or gas), reworking the data to clean it of certain methodological errors (such as the CEPII database), or making it more easily accessible through graphical visualization tools (such as the Chatham House database or the Atlas of Economic Complexity).

There are no third-party databases dedicated to the nuclear fuel chain. Since this chain largely exceeds national borders or those of the European Union, **UN Comtrade constitutes the main source for studying these flows.**

Searching for Nuclear Fuel Data in Comtrade

HS Code

The Comtrade database operates using a system of harmonized codes called "HS" for Harmonized System on its search engine (<https://comtradeplus.un.org/>). The codes to use to track materials in the nuclear fuel chain are:

- **HS 261210** : Uranium ores and concentrates.
- **HS 284410** : Natural uranium and its compounds.
- **HS 284420** : Uranium enriched in U-235 and its compounds.
- **HS 84013000** : Non-irradiated fuel elements.

TO TRACK...	...USE THE FOLLOWING CODE :
URANIUM ORE CONCENTRATES (UOC)	284410 AND 261210
URANIUM TETRAFLUORIDE (UF4) AND URANIUM HEXAFLUORIDE (UF6)	284410
ENRICHED URANIUM AS UF6 OR UO2	284420
ASSEMBLED FUEL BUDLES	84013000

Why Two Codes for Uranium Concentrate?

The difference between code 284410 and 261210 lies in the concentration of uranium in the material. Imports/exports recorded under code 261210 refer to exchanges of ores with low uranium content, while those under code 284410 correspond to uranium processed to a standard concentration level for conversion.

At the global level, the preferred code is 284410. The market value of trade recorded under this code accounts for 90% of the total for both combined codes. Code 261210 is

predominantly used for Namibia's exports, potentially reflecting the low uranium content of its ore.

There is no HS code for UF6

UF6 produced by uranium conversion does not have a specific HS code. These imports/exports are compiled under HS 284410. This situation requires data cleaning work to identify UF6 flows (see protocol below).

Import or Export?

The Comtrade search engine allows users to select the "time period", "transport mode", "trade flow" (import/export), and "reporting country" (ie: the origin of the customs agency reporting the data to the UN).

It is advisable to prioritize data on imports. Russia and Great Britain do not disclose their data on the export of enriched uranium. By choosing imports, this embargo is circumvented by accessing data reported by the importing country.

What Information Does Comtrade Provide?

Once I have indicated the HS Code of the material I want to track, chosen the reporter (i.e., the country that provided the data), the years I am interested in, and selected the imports, I access a spreadsheet file with 47 different columns, each corresponding to a piece of information. Most of these columns are not useful. The important columns are :

- **refYear** : the period of the data.
- **reporterDesc** : the country reporting the data. Concretely, if "import" is correctly selected, the reporting country is the importer of the material. In Comtrade data and in the case of imports, the reporter is the country of final destination where the goods are to be delivered.
- **partnerDesc** : in the case of "imports," the partner is the country of origin of the good where it was produced.
- **partner2Desc** : randomly filled in by the reporters, the second partner corresponds to the country of dispatch of the goods, if different from the partner.
- **cmdCode** : le code HS
- **qty** : the quantity of material as declared by the reporter.

- **altQty** : the quantity of material, given in another unit, as declared by the reporter.
- **netWgt** : the quantity of material (in kg) retained by Comtrade.
- **cifvalue** : the value of the exchange, in dollars, including the price of transport and transport insurance.
- **fobvalue** : the value of the exchange without transport.

Cleaning Comtrade Data for Nuclear Fuel Analysis

Comtrade data must be cleaned before use. These databases rely on the reporting of information by national customs agencies and may contain errors, duplicates, and inconsistencies that require preprocessing. This work is specific to each HS code and can only be done with knowledge of the concrete context of the materials being studied.

Step 1: Removing geographical inconsistencies

After downloading the files from Comtrade, the first step is to identify geographical inconsistencies in the database, i.e., flows between, on the one hand, a country that is not a producer of the material being studied and, on the other, a consumer. These errors mainly reflect errors in the choice of HS code by the reporters at the time of data reporting.

For example, a line in the database showing a flow of natural uranium between a country without mines and another without a conversion plant can be considered an inconsistency and removed. The possibility that this data reflects illegal and undeclared uranium exploitation is minimal. In such a situation, it is more than likely that this flow would not be reported to the UN by the customs authorities of the importing and/or exporting country. Similarly, this line could not represent a flow between a producing country and a country where the material is only stored. In the commercial chain of nuclear fuel, natural uranium concentrate is only stored in conversion plants, except for a storage site in Kazakhstan, at Alashankou, on the Chinese border. The same data cleaning approach can be applied to enriched uranium (HS284420) by removing data concerning flows between countries without enrichment plants and countries without assembly plants. It can also be extended to assembled fuels (HS 84013000) removing flows between countries without assembly plants and those without nuclear power plants.

Step 2: Differentiating a Natural Uranium Flow from a UF₆ Flow

As previously explained, HS codes do not differentiate between flows of natural uranium concentrate and those of UF₆. Data disaggregation methods cannot be entirely reliable, and the results should therefore be taken with caution. A flow between a country A with uranium mines but no conversion plant, and a country B with a conversion plant can without hesitation be considered as uranium concentrate. Similarly, a flow between a country C with a conversion plant but no mine, and a country D with an enrichment plant can be classified as UF₆.

The decision protocol is more complex for an exchange between a country E with both uranium production and UF₆, and a country F with both conversion and enrichment plants. This is typically the difficulty for Canada, the United States, China, or Russia (corresponding to country E), and France, the United States, Russia, and China (corresponding to the case of country F). In this situation, one solution is to look at the value of the exchange, excluding transport (fobvalue), which can be higher for UF₆ than for uranium concentrate at the same date.

The case of Canada poses another problem. Customs agencies do not consider conversion to be a substantial transformation of the material leading to a change in its customs origin. Concretely, UF₆ produced in Canada with uranium concentrate extracted in Kazakhstan and going to the United States for enrichment would have a Kazakh customs origin, not Canadian. This particularity makes it difficult to analyze the flows of UF₆ exported by Canada.

Step 3: Cleaning Duplicates

The Comtrade database may contain duplicate lines, showing an identical exchange between two countries, not referring to two distinct flows, but to a duplicate. A line can be considered a duplicate if the data on quantity (qty or netWgt) and price (cifvalue or fobvalue) are identical.

The existence of a second partner (partner2Desc) in an exchange, i.e., a country through which the goods transit, also inserts a risk of duplication. Imagine a situation where, in the same year, a flow of natural uranium leaves a country A for a country C via a country B, and another flow leaves country A for country C via D. The Comtrade database will always present three lines: two reflecting each particular case (flows A-B-C and A-D-C) and one aggregating the particular cases, where the second partner will be named world in the database (flow A-world-C). Unless this information is of interest, it is advisable to delete the particular cases to keep only the world line to avoid duplicates.

Conclusion

The origin of nuclear fuel supplies has become the subject of new political debates following the Russian invasion of Ukraine. Legitimate questions about the risks posed by these supply chains invite caution regarding the open-source data available for their analysis. It is necessary to :

- Understand the different materials circulating in the fuel supply chain ;
- Integrate the specific characteristics of nuclear fuel supply contracts ;
- Avoid confusing the physical flows of materials (import/export) with contractual flows (source of supply) ;
- Perform preprocessing of the available open-source databases before any analysis of the flows.

Authors



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Teva Meyer is the Principal Investigator of GeoNuFE. He is an Associate Professor of Geography and Geopolitics at the Université de Haute-Alsace and a non-resident Fellow at the French Institute for International and Strategic Affairs (IRIS). His research examines the political dimensions of the relationship between space and the nuclear industry, both civilian and military.



Mélanie EDELIN / Communication and Project Manager

Passionate about transmitting information and promoting knowledge, Mélanie worked as a librarian for 12 years before moving into scientific communications. Since 2022, she has held the position of Communications Officer for the CRESAT laboratory, where she manages and promotes research activities.



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The background of the slide is a close-up photograph of a nuclear reactor core. It shows several parallel fuel rods, which are cylindrical and have a metallic, slightly greenish-blue patina. These rods are held in place by a complex white metal structure, likely part of a fuel assembly. The lighting is bright, highlighting the textures and metallic surfaces of the components.

Critical Geopolitics of Nuclear Fuel Supply in Europe

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