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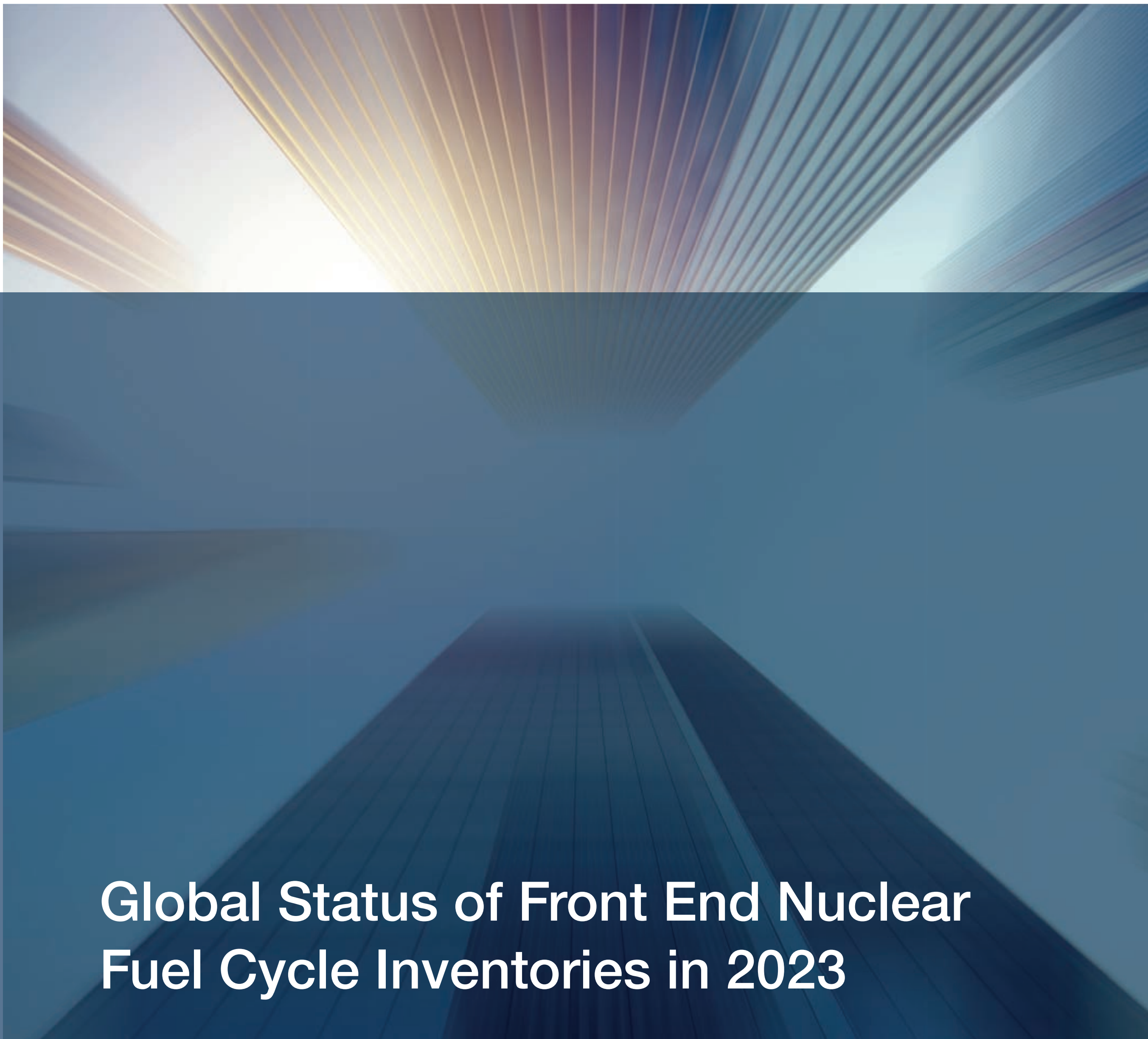

Global Status of Front End Nuclear Fuel Cycle Inventories in 2023

GLOBAL STATUS OF FRONT END NUCLEAR FUEL CYCLE INVENTORIES IN 2023

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The Agency’s Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is “to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world’’.

GLOBAL STATUS OF FRONT END NUCLEAR FUEL CYCLE INVENTORIES IN 2023

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2025

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Printed by the IAEA in Austria
July 2025
https://doi.org/10.61092/iaea.v7z2-qnw7

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Global status of front end nuclear fuel cycle inventories in 2023 / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2025. | Includes bibliographical references.
Identifiers: IAEAL 25-01769 | ISBN 978-92-0-114525-3 (paperback : alk. paper) | ISBN 978-92-0-114625-0 (pdf)
Subjects: LCSH: Nuclear fuels — Inventory control. | Nuclear fuels — International cooperation. | Nuclear fuel elements. | Uranium as fuel.
Classification: UDC 621.039.54 | CRCP/FUI/005

FOREWORD

The security of nuclear fuel supply is essential when considering the sustainability of nuclear energy. This publication provides an assessment of the global front end nuclear fuel cycle inventories, which are an important part of the total supply of uranium for nuclear power plants. This assessment qualifies and quantifies the uranic inventories that are available across the world in the front end of the nuclear fuel cycle. It explains some of the key drivers of inventory policy related to nuclear fuel supply management and addresses the current ability of surplus or strategic uranium supplies to supplement the primary uranium supply chain for front end components of the nuclear fuel cycle. It also provides insights regarding the appropriate level of inventories sufficient to ensure the ongoing supply of nuclear fuel for end users.

This publication is a revision of IAEA-TECDOC-2030, Global Inventories of Secondary Uranium Supplies, and is intended for IAEA Member States with existing nuclear power programmes and Member States considering adding nuclear power to their energy mix.

This publication includes a supplementary file, available on-line, containing tables of uranic inventories by country and region.

The IAEA acknowledges the contributions of the experts who participated in the consultancy meetings for the planning and preparation of this publication, in particular, S. Harding (United Kingdom) for extensive reviews and contributions at the various stages of the manuscript preparation. The IAEA officer responsible for this publication was A. Hanly of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Ensuring the reliable, safe, secure and sustainable supply of uranium for use as nuclear fuel is crucial to demonstrating the long term viability and sustainability of nuclear power. Primary (freshly mined and processed[1]) uranium supplies represent the mainstay of resources for this purpose, but secondary uranium supplies have also periodically been an important component of nuclear fuel supply. It is therefore essential to have an understanding and assessment of these secondary supplies of uranium in support of current and future nuclear plant operations.

Market participants in the front end of the nuclear fuel cycle have traditionally held uranic[2] inventories as a dependable secondary resource that can be used to flexibly fill potential shortfalls in primary uranium production. This approach is facilitated by cyclical oversupply against nominal demand. These uranium supply overhangs (i.e. excess supply) have been held off-market for periods of time due to regulatory, commercial or political factors, but have eventually been made available to end users through individual disposition programmes. Often a release has been coincident with market downturns and so also represents a conservation of primary production that could not otherwise be economically deployed. Those periods of primary uranium production conservation have eventually restored a market equilibrium and gradually drawn down the inventories of secondary uranium supply, particularly in component markets or regional sectors.

Historically, primary uranium supply has often exceeded civil uranium needs. In the period 1945–1990, military procurement of uranium was a significant and even a dominant part of world demand. Since 1990, the partial reduction of nuclear arsenals has been an important element of ongoing uranium supply for commercial and non-weapons purposes. Defined programmes by the United States of America (USA) and the Russian Federation reduced significant portions of their surplus highly enriched uranium (HEU) and stockpiles of other forms of uranics during this period. Thereby, the oversupply created by ex-weapons uranium stocks was gradually reduced between the 1990s and the early 2010s, in civil nuclear power programmes, research reactors and by naval propulsion demand.

As implied by Fig. 1 [1], between 1990 and 2013 a gap between primary uranium supply and civil reactor related uranium requirements was filled by secondary uranium supply stockpiles, a supply gap that sometimes represented close to 50% of total annual civil uranium requirements. The demand for nuclear propulsion (not shown) also served to shorten the periods of oversupply by a meaningful amount [2]. Since 2015, secondary uranium supplies have again become an increasingly important factor in achieving a balance between uranium supply and demand.

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1 Natural uranium oxide, uranium hexafluoride as feed material and enriched uranium product or powdered uranium dioxide for fabrication into fuel pellets. Commonly referred to as NatU.

2 Products relating to or containing uranium.

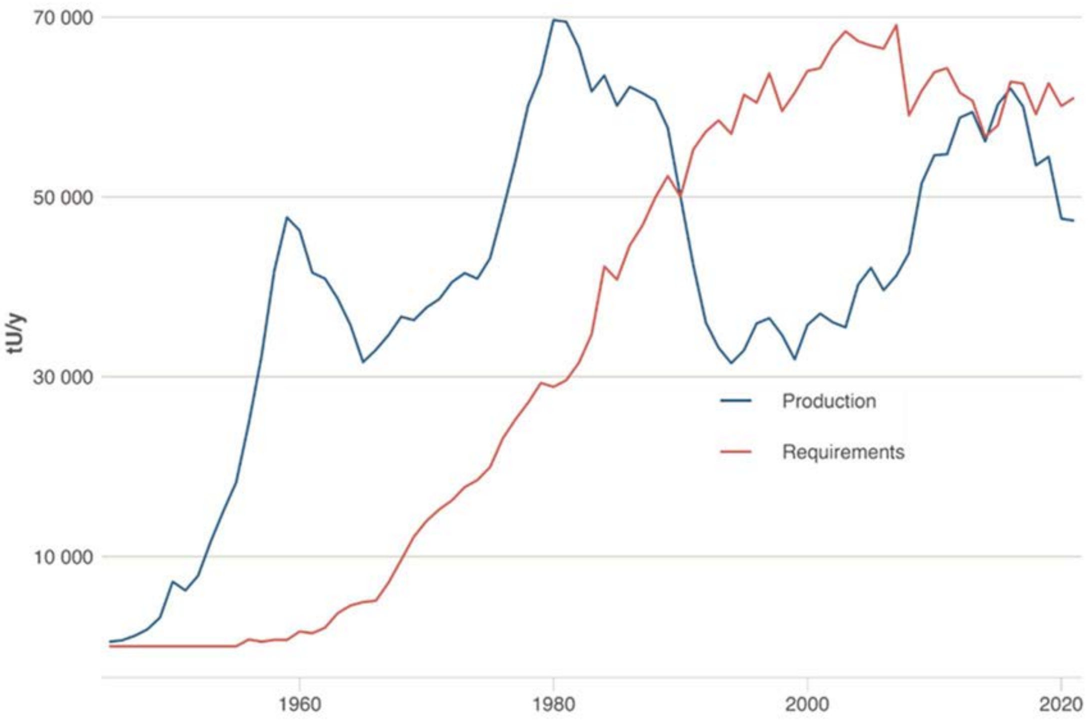

FIG. 1. World Annual Uranium Production and Civil Nuclear Requirements (1949-2023), reproduced from Ref. [1] with permission and courtesy of the OECD.

During the last 25 years there have been notable trends in inventory management, influenced by prominent events. For instance, by 2010 new fuel cycle capacity expansion programmes were at a peak. Governments were discussing the creation of strategic stockpiles of uranics (such as in China, Japan, the Russian Federation and the USA), as was the IAEA. Action was taken in the USA to set up the 'Reliable Fuel Supply' (latterly renamed the 'American Assured Fuel Supply') and 'MOX Backup' inventories, as well as additional down-blending and tails upgrading to create a low enriched uranium (LEU) tritium production stockpile for the Tennessee Valley Authority (TVA). In the Russian Federation, the 'LEU Reserve' at the International Uranium Enrichment Centre in Angarsk was created in 2011. Meanwhile, China began a programme in 2007 of acquiring the natural resources needed for the fulfilment of its nuclear power ambitions. The IAEA proposed an 'LEU Fuel Bank', which subsequently became operational at Ulba in 2019 as a global assurance mechanism. During this period, fuel cycle market price indicators were suggesting a supply shortfall in some sectors (especially for uranium and enrichment services), with price levels driven by the investment costs necessary for new primary capacity to be deployed.

Following the accident at the Fukushima Daiichi nuclear power plant, plans for the development of nuclear power were changed. The cessation of operations at more than 20% of the world civil nuclear fleet by mid-2012 had an immediate and lasting impact on the uranium supply and demand balance. Furthermore, in China, France, Finland, Japan, the United Kingdom and the USA advanced new-build plans were either halted or delayed. Phase outs were imposed (or reimposed) in Belgium, Germany, Republic of Korea (ROK), Spain, Taiwan, China and other countries stepped back from project initiations (e.g. Vietnam). The accelerated closure of nuclear power plants under more stringent regulatory environments were also seen in France, Japan, ROK, Spain, Sweden, Switzerland, and the USA.

At the same time, many fuel cycle expansion commitments were already underway, both creating unwanted secondary uranic inventories and primary uranic supply overcapacity. Through the middle of the last decade, much of this was delivered under existing contracts to utilities in material that was surplus to uranium demand. From the second half of the decade as contractual commitments ended, the surplus capacity was reoptimized or moved into care and maintenance by suppliers. This move had an impact on adjacent segments of the fuel cycle, such as the substitution of primary uranium conversion supplies by uranium enrichment capacity.

For those utilities that were decommissioning plants, their unused nuclear fuel has remained stranded for long periods. This is particularly true for German, Japanese, Swedish, and Taiwanese utilities who have had to construct a reuse supply chain for fresh nuclear fuel defabrication. In 2020, material finally began to flow under these new arrangements. Furthermore, the reuse of partly burned fuel in Germany and Japan has depressed uranium demand in those specific markets.

The above events serve to provide a contextual backdrop to the snapshot of uranic inventories being analysed in this publication. However, there are also more recent changes specific to inventory management. Until 2021, inventory policy was driven by the trends in nuclear power programmes – declining markets became more reliant on just-in-time (JIT) supply and enacted drawdown policies (e.g. in the European Union (EU), Japan, Republic of Korea and Taiwan, China and the USA), while growth markets took a more strategic view (e.g. in China, India and the Russian-aligned markets). The conflict in Ukraine that began in February 2022 and subsequent sanctioning and logistical disruptions has meant that security of supply has become foremost in any nuclear fuel procurement policy. The nuclear industry's credentials for energy security and zero emissions are once again being promoted and recognized internationally. This security of supply edict and a reversal of globalization are both impacting risk-based decisions in the nuclear fuel cycle. The response has been to again consider the strategic value of uranic inventories, irrespective of the growth status of nuclear energy within individual countries.

To identify the part being played by uranic inventories in the market, the methodology of this study has focused on expert analysis of the available public information to identify the extent of secondary supply. The study was conducted by an Expert Group comprised of industry consultants, nuclear fuel cycle primary suppliers, utility fuel buyers and supra-national monitoring bodies. Information was gathered from resources that include regulatory and financial filings, industry body reports, press statements, trade statistics and (where publicly available) safeguards data. This information has been assessed alongside modelled front end component uranium demand [3] and aggregated market price information, in order to estimate volumes. By specifically tracking the ownership of material, rather than attempting to simply determine its location, this approach also provides an ability to assign a confidence level to the results for each country under review.

This publication is an updated and expanded view of the IAEA TECDOC, *Global Inventories of Secondary Uranium Supplies* [4]. The current update allows the reader to track developments over the intervening two years since the first publication. The Expert Group has also identified improvements and made corrections to the first publication, in order to ensure the validity and accuracy of the analysis. These updates are noted in this publication and a restatement of the

2021 data has been provided in the Annex spreadsheets which contain the tables of uranic inventories by country and region accompanying the publication.

1.2. OBJECTIVE

The role played by the various stakeholders in building or depleting secondary uranium supply inventories needs to be continuously assessed, as they have an important role amongst established market indicators. The outputs from this publication go well beyond a largely generic and face-value analysis of reported secondary uranic stockpiles, by providing a more robust quantitative analysis based largely on financial and trade statistics. Wherever possible, the Expert Group has used multiple sources to disaggregate raw data to facilitate a greater level of insight into material forms and quantities. It has also enabled the development of targeted regional insights into the purpose, liquidity and mobility of the identified nuclear fuel inventories, which are critical factors in judging the availability of secondary uranium supply.

This publication can inform private industry, government entities and policy makers in all countries, in support of assuring a dependable supply of nuclear fuel to support civil nuclear power programmes – both existing and under development. An overview of uranium supply fundamentals and the types of secondary uranium inventories guides the reader in understanding the role of the secondary uranium supply in sustainably fulfilling the demand for uranium. Security of supply is evaluated through an analysis of publicly reported or statistically implied holdings of front end uranic material (referred to as ‘uranic inventories’), before discounting the volumes therein that are needed for continued reactor operation (often described as supply chain work in progress (WIP) and if appropriate in-core partly burned nuclear fuel). It can also inform the debate for a more detailed look at back end inventories (including depleted uranium, reprocessed uranium and plutonium) that will be important for the potential closed cycle and circular economy credentials of nuclear power and the opportunities for next generation reactor technologies.

1.3. SCOPE

This publication is focused on a comprehensive evaluation of front end nuclear fuel inventories in the public domain, while considering the approach of end users towards the reliability of their once-through supply chain. It presents and analyses data from a variety of complementary sources and qualifies, where appropriate, the reported information in order to align definitions and metrics to avoid misinterpretation.

The publication considers global nuclear power markets, with research covering 33 countries including a review of national or commercial policies in relation to front end uranic inventory management. The research covers secondary uranic materials owned by most utility operators, primary suppliers, brokers and traders, financial investors and national or international agencies.

It provides a snapshot of uranic materials as of 31 December 2023, which represents the end of the most recent reporting cycle for most entities at the time of drafting of this publication. Where appropriate, comparisons have been made to 2021 data sets to test for consistency and also contextualise year-on-year changes.

1.4. STRUCTURE

The publication comprises a high-level overview of uranium supply fundamentals with a focus on concepts and definitions of secondary uranium supplies. This is followed by an introduction to the background and methodology of the main part of this publication, which is a study of uranic inventories grouped by six regionalized blocks of countries (i.e. Africa and Middle East, Eurasia, Europe, North America, South America, and South and East Asia). Supporting material is tabulated and referenced in the Annex supplementary files which contain tables of uranic inventories by country and region.

2. GENERAL OVERVIEW OF THE NUCLEAR FUEL CYCLE

The nuclear fuel cycle starts with the exploration and mining of uranium and ends with the disposal of nuclear waste (Fig. 2 [5]). Mined uranium has to undergo several steps before it is suitable for use in a nuclear reactor. Depending upon the type of reactor (shown in circles in Fig. 2 [5]), additional steps can include processing, refining, conversion, enrichment, deconversion and fuel fabrication. The combination of each of these steps prior to the fuel being loaded into the reactor make up the front end of the nuclear fuel cycle and can take two to three years to accomplish. As such, it is typical in a normal fuel supply chain for an end user to have a years' worth of demand in each form appropriate to its needs (e.g. for light water reactors this would result in one year's demand as U_3O_8, one year's demand as UF_6 and one year's demand as UO_2).

Uranium fuel can spend up to six years in a reactor core to produce electricity, during which time its value is typically depreciated based on energy production. Once the irradiated fuel has been discharged, it may undergo a further series of steps including temporary storage, reprocessing and recycling. Residual nuclear waste is targeted for storage or disposal depending on its form. These steps performed after the spent fuel has been removed from the reactor are known as the 'back end' of the fuel cycle. A closed cycle is achieved when reprocessing of spent fuel is utilized as an alternative to a 'once-through' cycle. The scale of secondary uranium supply from reprocessed uranium is determined by a few existing spent nuclear fuel reprocessing plants. As of 31 December 2023, such plants were available in France, the Russian Federation and the United Kingdom. China, India and the USA have small-sized research or test reprocessing facilities. One major difference between the front and back end of the nuclear fuel cycle is that global commercial markets exist for most front end components, whilst the back end is largely a localized/internal market based on national policies and economic considerations.

3. URANIUM SUPPLY FUNDAMENTALS

This research is focused upon determining the availability and reliability of secondary sources of uranium supply to satisfy any imbalance between demand and primary supply. The greatest demand for uranium is to supply the components of nuclear fuel for civil nuclear power, which is almost entirely dedicated to the generation of electricity. Military uranium demand, which during the period 1945–1990 was a significant and even dominant part of demand, is beyond the scope of this publication, as is nuclear propulsion and research reactor demand.

Civil uranium demand can be characterized as a predictable function of the number of operating nuclear power plants, their capacity factors and fuel burnup levels. Fuel cycle component demand is essentially an economic relationship governed mainly by the price of uranium and the cost of each beneficiating service step in the process of turning the ore into nuclear fuel.

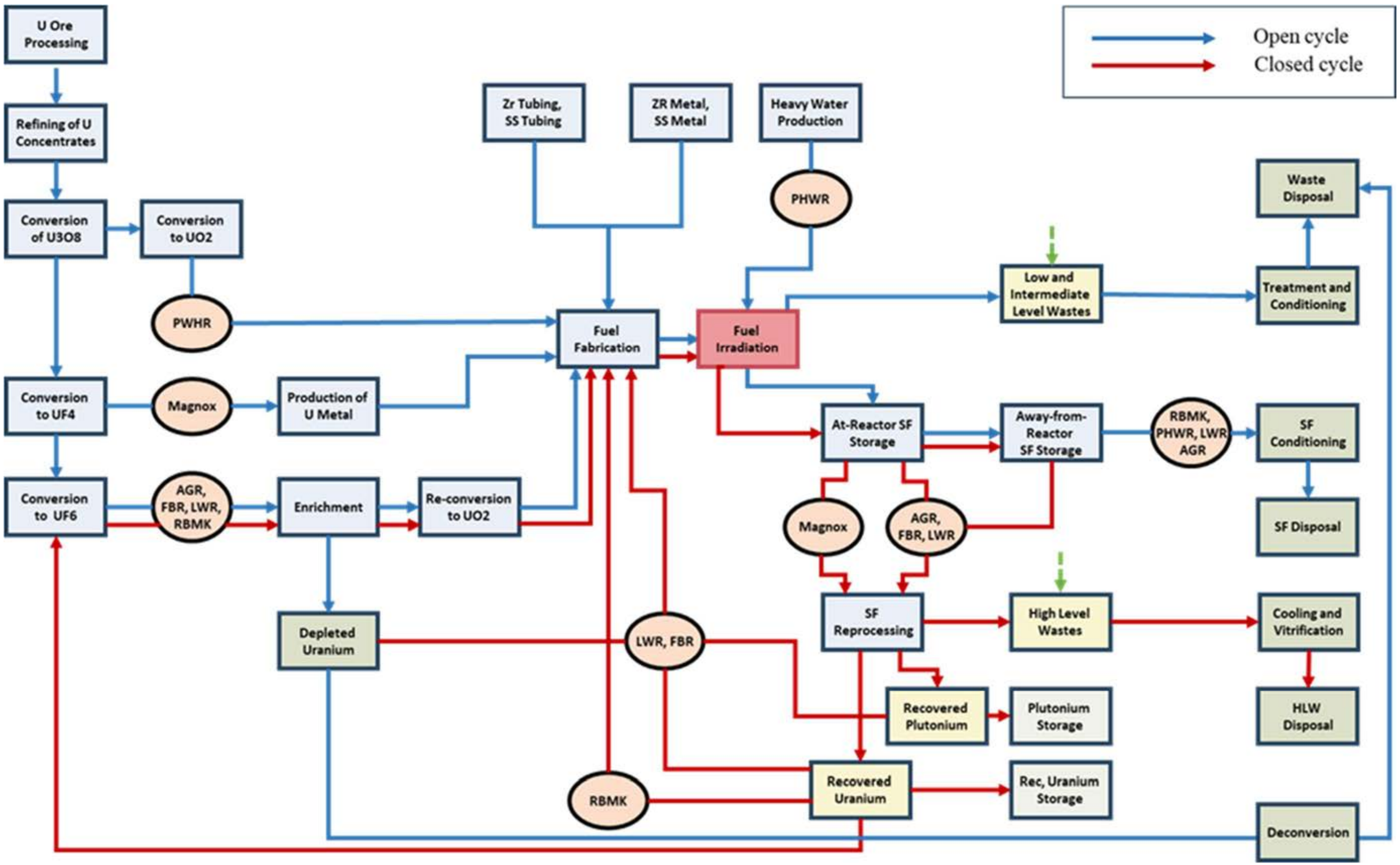

FIG. 2. Flowsheet of processes in the typical nuclear fuel cycle (modified from Ref. [5]).

3.1. PRIMARY URANIUM SUPPLY

Uranium supply is divided into primary and secondary supply, with primary supply defined as fresh fuel in the form of newly mined U_3O_8, upon which conversion, enrichment and fabrication are applied. It is either sold directly by primary producers, or traded through a series of intermediaries. The production of freshly mined uranium is relatively highly concentrated, both geographically and commercially, as shown in Fig. 3.

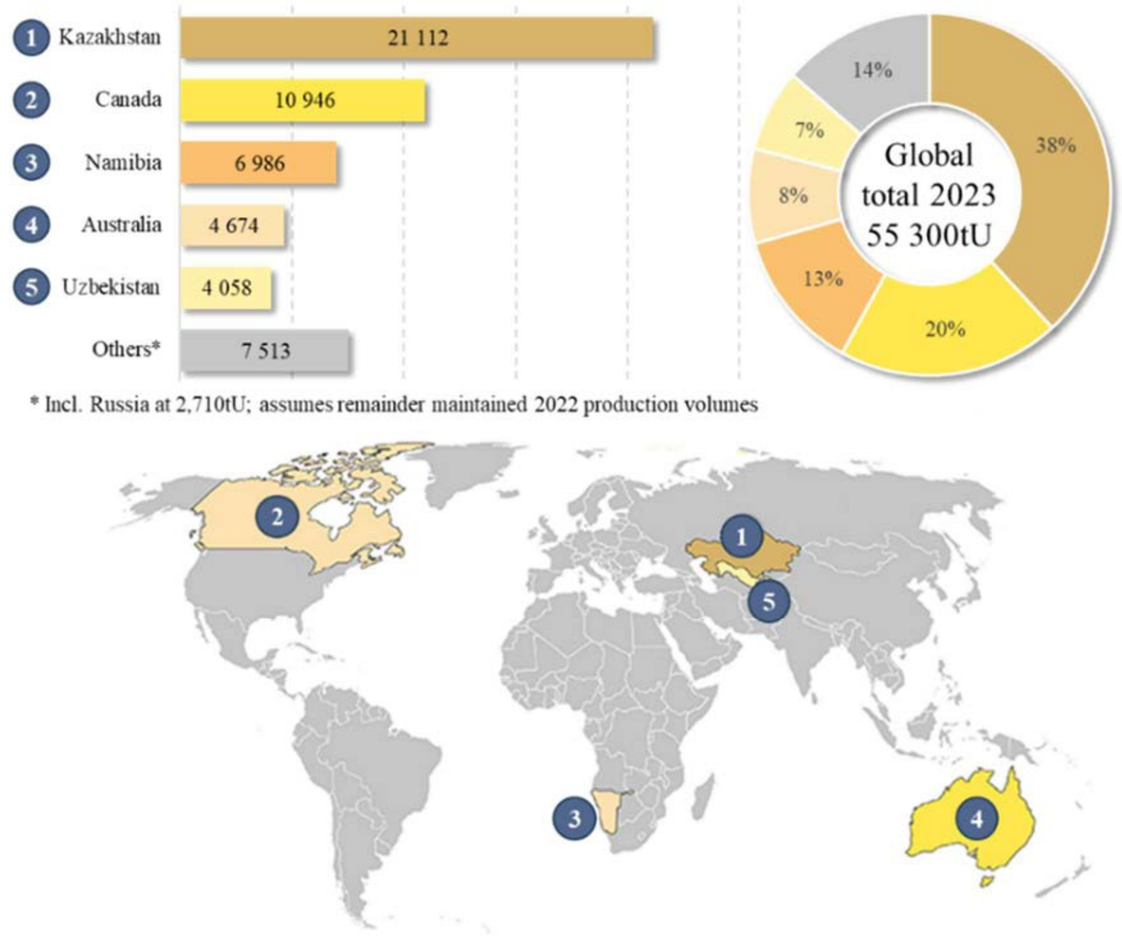

FIG. 3. Major uranium producing countries in 2023 (data from Refs. [3, 6, 7, 8, 9, 10, 11, 12])

In 2023, more than 85% of mined uranium came from five countries (Australia, Canada, Kazakhstan, Namibia, and Uzbekistan) and approx. 87% was controlled by the nine largest mining companies [13]. The production and strategic deployment of these resources has a direct impact upon the accumulation of and need for secondary uranic stockpiles. Operational, economic and political factors will influence the availability of supply from each resource. These supply risks are compounded by the relative distribution of the downstream processing steps, with China, Canada, France, the Russian Federation, the United Kingdom, European Union and the USA providing the majority of global capacity for the conversion, enrichment and deconversion stages of the front end industry.

3.2. SECONDARY URANIUM SUPPLY

The categorization and definition of secondary supply stockpiles or 'inventories' is not straightforward. Differences in how they are described by practitioners and analysts in the industry can be confusing to non-experts and experts alike. Therefore, a brief introduction to the types of secondary uranium supply will be provided in this section. A useful starting point for describing and understanding secondary uranium supplies is a scheme developed by the World Nuclear Association (WNA) [3]. Secondary supplies can be exhaustively categorized on the basis of the following characteristics (as shown in Table 1):

- Originating stage in the nuclear fuel cycle;
- Type of initial source;
- Owner;
- Marketable forms of secondary material and its mobility.

This research is intended to qualify a distinct subset of the material defined by the WNA Nuclear Fuel Report [3]. The resulting focus is on the following forms of uranic material, listed in the order of the relevant nuclear fuel cycle processing stages:

- Natural uranium concentrates (usually held as U_3O_8);
- Natural or reprocessed uranium as UF_6 or UO_2;
- LEU or enriched uranium product (EUP) as UF_6 or UO_2;
- High assay LEU or HEU, often in metal forms;
- LEU and EUP as UO_2 in fabricated fuel (including viable part-burned fuel);
- Reprocessed uranium as U_3O_8 or UO_3 and separated plutonium as oxides.

The analysis is specifically concerned with uranic inventories that are physically held in marketable forms by national operators, suppliers, governments or institutions in countries with existing commercial nuclear power industries. To that extent, this approach excludes underfeeding as a source of secondary uranium supply (being an economic optimization of separative work production capacity, rather than a physical stockpile).

The more beneficiated products tend to have increased regulatory controls placed upon them. Furthermore, the physical location of the inventory and ownership of the material are additional factors that can result in jurisdictional controls. These elements can restrict both the material's mobility and liquidity, so this publication will also seek to clarify the physical mobility status of various inventories at a country level by also considering its liquidity (i.e. the ability to commercially trade or monetize material). In many circumstances, mobility and liquidity are often significantly influenced by the need to further process any residual or recycled materials, thereby permitting this publication to narrow the focus of its analysis on the materials that are most accessible for global secondary supply.

TABLE 1. DESCRIPTIONS OF SECONDARY URANIUM SUPPLIES (*modified and adapted from Ref.* [3])

Originating stage in the nuclear fuel cycle	Type of initial secondary source	Owners	Marketable forms of secondary material
Front end (Pre-loading/irradiation in nuclear reactors)	Commercial inventories	Commercial entities (producers, traders, funds, utilities, converters, enrichers, fuel fabricators)	Natural Uranium Ore Concentrate [a] or UF_6 EUP [b] as UF_6, EUP as Uranium Oxides, fabricated fuel and its feed/SWU components
	Military-related materials and depleted uranium	Governments and their contractors	Downblended EUP from surplus weapons-grade HEU Natural uranium equivalent as UF_6
	Other government-owned uranic material	Governments and their contractors	Natural UF_6 Off-spec. EUP as UF6 and other forms (potential future source)
	Comparable to commercial inventories in terms of specifications	International fuel banks	EUP as UF_6 stocks
	Unused fuel assemblies	Commercial entities (utilities)	Unused fuel assemblies or defabricated UO_2
	Legacy tails	Commercial entities (enrichers) or governments and their contractors	Natural uranium equivalent or EUP as UF_6 from upgraded tails
Back end (Post-irradiation in nuclear reactors)	Recycled material	Commercial entities or governments and their contractors	Reprocessed uranium (RepU) Enriched reprocessed uranium (ERU) mostly as UO_2 MOX fuel containing plutonium from spent fuel or defence Unprocessed spent fuel (potential source)
		Commercial entities (enrichers, fabricators or governments)	EUP from depleted slightly irradiated uranium Depleted RepU as UF_6 or UO_2

[a] Natural uranium ore concentrate, U_3O_8 or other forms of uranium produced by mines and mills
[b] EUP = Enriched uranium product, includes all enriched uranium with ^{235}U <20 % enrichment levels, i.e. includes HALEU

3.2.1. Secondary uranium supplies existing within the front end

As a result of narrowing the focus of research, there are three main categories of inventories or secondary supplies to be considered:

— Commercial inventories that are owned by producers, traders, funds (tradeable and non-tradeable), utilities, converters, enrichers, and fuel fabricators. Several marketable forms of these inventories exist, including: natural uranium ore concentrate (mainly as U_3O_8).

natural UF_6, enriched uranium product as UF_6 and uranium oxides, fabricated fresh fuel[3] and its feed and separative work unit (SWU) components.
- Government-owned uranic materials potentially including surplus High Assay LEU (HALEU) and HEU stockpiles - often managed by designated contractors and having uses beyond power generation (e.g. military propulsion or research reactor fuel).
- International fuel banks represent a third class of holding, governed by supra-national bodies, such as the IAEA.

3.2.2. Secondary uranium supplies derived from recycling

The definition above specifically discounts the recycling of uranic material, which many industry observers class within the definition of inventories or secondary supplies. Within this wider category resides:

- Depleted uranium (tails) for upgrading (held as U_3O_8 or UF_6);
- Fuel cycle scrap recovery (oxides);
- Partly burned fuel;
- Spent fuel reprocessing (generating separated plutonium for mixed oxide (MOX) fabrication and reprocessed uranium as U_3O_8 or UO_3).

Recycled material can displace primary front end uranium supply through a number of channels, the most prominent examples of which are tails upgrading and reprocessed fuel. However, these are considered as inaccessible to the wider nuclear fuel market.

Tails upgrading is often cited as a secondary uranium supply resource for countries with enrichment capacity, in particular within France, the Russian Federation, and the USA. Significant stockpiles of depleted uranium as U_3O_8 or UF_6 exist, and large proportions contain viable ^{235}U assays (> 0.1 wt% ^{235}U). Those in UF_6 form are more readily accessible and (subject to surplus enrichment capacity being available) can be upgraded to levels equivalent to natural uranium. Tails in U_3O_8 form are far less accessible and would require surplus conversion and enrichment capacity to enable reuse. As such, U_3O_8 represents a form normally intended for long term storage and/or disposal.

Another potential source of secondary supply is reprocessed fuel. After it has been burned in a reactor, uranium oxide fuel still contains most of the fissile matter that was present in the original 'fresh' uranium fuel and therefore in principle could be used again to create more nuclear fuel. The plutonium created during fission can be separated, as well as unused uranium oxide to form the components of MOX, RepU or depleted slightly irradiated uranium fuels. The commercial processes currently used enable 25–30% more energy to be utilized from the original fuel and also reduce by about a fifth the amount of spent fuel that needs to be stored. China, France, India, Japan and the Russian Federation, currently follow active recycling policies and thus have laid the foundations for sustainable use of fuel, in contrast to a once-through fuel cycle. However, the supply of these fuels is limited by the reprocessing capacity

[3] Unused fuel assemblies. For example, in Japan there have been delayed reactor restarts and premature closures and this has resulted in stranded, unused (i.e. non-irradiated) fuel assemblies that are no longer suited for direct use in reactors. However, practical utilization of this material has several challenges including potential (defabrication) capacity constraints and commercial considerations.

and output is exclusively directed to the small number of recycling countries that have licensed their reactors to accommodate the alternative fuel characteristics.

These wider secondary supply categories cover elements in both the front and back end of the supply chain, as they are subject to the application of additional processing steps that consume primary production resources (i.e. reconversion, upgrading, enriching, blending or chemical separation). This reliance on primary capacity and more complicated processes to deal with radiological hazards means that the lead time for reuse of recycled material is beyond what could be readily considered as tradeable (i.e. liquid) and/or physically mobile. Therefore, channels to re-introduce legacy material into a market (either locally or internationally) have significant constraints.

As with down-blended HEU (to HALEU or LEU), the above recycled material is more likely to play a part in guaranteeing the future fuel cycle availability for Generation IV or small modular reactors, research reactors and advanced reactors than existing nuclear power fleets. Therefore, this publication focuses on secondary uranium supplies originating in the front end of the fuel cycle, which can be directly substituted for freshly mined resources (i.e. without additional processing to reach American Society of Testing and Materials' standards for their chemical form). Irrespective, reference has been made in specific circumstances to the availability of recycled material (U_3O_8, UO_3 or P_u) at a country level, in order to recognize where supply gaps are currently being filled, or to inform the reader to this additional (less liquid) resource – most notably in Russia and France.

4. COMMERCIAL INVENTORY DEFINITIONS AND DRIVERS

4.1. INVENTORY MATERIAL CHARACTERISATION

Distinct from the physical form of uranics material, the term nuclear fuel 'inventory' or 'stocks' has a number of important subdivisions that characterise its status, as described below.

4.1.1. Work-in-progress (WIP)

Also known as 'pipeline' or 'in-process' inventories: These are uranic materials in all forms, based on normal commercial lead times for processing/beneficiation and shipment and are effectively servicing the ongoing periodic refuelling needs of a nuclear power plant. As such, their absence would result in an immediate or imminent shutdown of a reactor or otherwise significantly limit its availability to produce electricity at rated capacity. This research assumes a three year supply chain that puts WIP at one year's demand each for natural uranium, enriched uranium and fabrication (from mine to core). This results in a global WIP that includes three years' worth of uranium, two years' worth of enriched uranium and one years' worth of fabricated fuel.

4.1.2. Surplus inventories related to short term needs

These may include temporary excesses of uranic material beyond WIP that are due to: advanced purchasing (buy-and-hold policies); a temporary mismatch between supply and demand; or a buyer otherwise implementing longer-than-usual lead times for material supplies. However, the material will have been purchased in the expectation of internal consumption in a relatively short timeframe (i.e. less than 12 months, being similar to material designated as 'current assets' for financial purposes). One example is a utility that purchases a fixed amount of uranium (uranic material) each year, regardless of its nuclear fuel requirements varying from year-to-year. This results in surpluses in some contract years, followed by a drawdown in subsequent periods.

4.1.3. Surplus inventories compared to long term needs

There are circumstances in which quantities of nuclear fuel components are purchased but result in a surplus that will likely become permanent (or at least semi-permanent). The reasons for such an accumulation are often unforeseen, for instance due to the early or temporary shutdowns of a reactor or delays in startups or cancellation of new units. When an entity is unable to consume these quantities itself, the expectation is that the material will eventually be liquidated to recover its purchase costs. The timing of the liquidation is usually dependent upon a number of financial determinants, as well as more practical regulatory constraints.

4.1.4. Strategic inventories

These occur where an entity determines the need for security of supply beyond diversified sourcing of nuclear fuel components, or alternatively if uranic material is considered as a financial asset to hedge against future developments in price or availability. As a result, risk-based policies may be enacted to secure and maintain a certain volume of material as a fixed stockpile. Such strategic stockpiles may physically revolve material through them in a first-in-first-out (FIFO) manner, but the basic level of inventories is maintained. This type of inventory can take a number of forms:

- Extended lead time purchasing of components, so that an entity always has a significant quantity of material readily available at one or more stages in the fuel cycle to mitigate against short or medium term supply interruptions;
- An immobile but accessible physical stockpile held at one or more locations across the fuel cycle, to compensate for a deficiency in deliveries under supply contracts;
- An inventory of finished fuel in dry or wet storage at a reactor to cope with fuel failures or a disconnect in the upstream fuel supply chain.

This research consolidates and identifies three main types of inventories: WIP, surplus and strategic, in order to emphasise that only the latter two categories can be considered to represent a buffer against supply shortfalls from primary production of uranic material.

4.2. REASONS FOR HOLDING INVENTORIES OF URANIC MATERIAL

Normal nuclear fuel operational practices and the length of supply chains determine a minimum requirement for inventory hold-up as WIP. As already noted, from mine to core an indicative processing time for light water reactor (LWR) fuel can be up to three years, subject to the location of each of the processing steps. For pressurized heavy water reactors (PHWRs) where fuel chain steps are often localized and UF_6 and enrichment services are not necessary, the lead times are somewhat reduced. Diversified markets where uranium mining, milling, conversion, enrichment, deconversion and fabrication can all happen in different countries tend to accommodate longer lead times under component contracts. In contrast, centralized/localized production industries — such as in Canada, China, India and the Russian Federation — can operate with shorter lead times and thus tolerate somewhat lower total working inventories. Irrespective, both examples will require a working stock to be held by suppliers in order to smooth production peaks or troughs and to buffer against supply chain risks.

Reserves held by commercial entities are a hedge against price fluctuations and supply shortfalls from factors such as contractual performance or operational issues. The level of such inventories is largely dictated by the risk profile of each individual entity, be it end user, primary supplier, trader or broker. For utilities and primary suppliers, there is often a national perspective in terms of security of energy supply that is dictated by government policy.

Additionally, at a national level, strategic reserves and stockpiles are often established to cover supply interruptions and the potential for geopolitical disturbances. Some of these stockpiles are specifically dedicated and managed, but otherwise such uranium inventories are simply a nominal allocation from surpluses that are held across a number of material forms that are not readily substitutable for fresh nuclear fuel components (e.g. HEU, tails material, reprocessed/separated spent fuel or scraps and residues).

Lastly, there is a growing impact of financial institutions who see investment opportunities from holding homogeneous commodities, but less so for more bespoke products in the nuclear fuel cycle. The material can be considered tradeable or non-tradeable, dependent upon the funds stated aims. As such they contribute to the level of liquidity in the upstream front end markets (U_3O_8 and to a more limited extent UF_6 and EUP). However, they can equally represent a repository that holds material off-market, thereby changing an otherwise predictable market equilibrium state. Their fundamental driver is therefore reward-related, rather than a response to operational risk.

4.3. WHERE URANIC INVENTORIES RESIDE

As noted, utility inventories are located across the fuel cycle. Depending on the reason for their creation, they are either held strategically to ensure uninterrupted supply or are stockpiled after processing. The latter state is often the result of a temporary or persistent oversupply, where additional spend on further downstream processing does not represent added value to the owner. Meanwhile, strategic stocks are best held after whichever stage of the fuel cycle that presents the most risk, or at the stage where a delay in availability could impact rapidly escalating consequential damages. The ultimate (but most costly) form of inventory is fabricated fuel. If held on a rolling stock basis, fabricated fuel can assure an operator of future power generation capability. However, it carries with it the risk of redundancy due to being a highly bespoke product, tied to a specific design of core and reactor.

For primary suppliers, inventories will be held at their respective production facilities. Licences for individual installations may prescribe the need for on-site processing, so husbanding of third-party stockpiles may be deprioritized if space is limited.

Government holdings are often intermingled with primary supplier holdings, particularly where a supplier is a state-owned enterprise. Otherwise, nuclear material reserves are held at national facilities under state ministry control or supra-national body supervision. Legacy nuclear sites in the process of being decommissioned or remediated have also been designated as appropriate locations, albeit largely due to the pre-existence of stocks on site.

Financial institutions or brokers and traders arrange for holding accounts at primary supply locations or dedicated storage facilities. The ability of the site owner to conduct location swaps is often of prime interest, as it enhances the liquidity and mobility of their asset.

4.4. HOW DIFFERENT ACTORS VALUE THEIR URANIC HOLDINGS

Utilities generally value inventories on a FIFO or average cost basis. This is particularly the case for a once-through fuel cycle, where the spent fuel has zero value once it is discharged from a reactor core. However, for utilities in countries using a closed fuel cycle (such as France, Japan and the Russian Federation), a residual value can be extracted from back end recycling and is therefore included in the value of spent nuclear fuel undergoing reprocessing.

Traders, intermediaries and financials dealing with (almost exclusively) front end components will assign net realizable values to their stocks. This imbues their holdings with more liquidity and mobility.

Governments consider all aspects, but are generally too slow to act on market index valuations for anything but long term policy decisions. As such they are mindful of impacts on the market from disposition programmes and tie the release of supra-national stockpiles to achieving market neutrality (e.g. requiring secretarial determinations for US Department of Energy (DOE) inventory disposals, or IAEA-sanctioned call-off from fuel banks).

Often the desire to build inventories is a reaction to market dynamics, for example when high prices are taken to indicate material shortages for a particular component. These price signals can encourage utilities and suppliers to re-optimize their contractual commitments, which has the effect of widening the impact of price movements or perpetuating a trend. Also, utilities who had once deemed material to be economically surplus are considering either how best to monetize their holdings in a (currently) rising market, or whether there is now a need to consume or stockpile material internally. One further aspect is the increasing interest in the market from financial entities, for whom market volatility generally pays dividends.

5. RESEARCH METHODOLOGY FOR THE STUDY OF FRONT END URANIC INVENTORIES

5.1. TRIANGULATION METHOD

To accurately identify front end uranic inventories, three distinct but complementary methodologies have been employed:

1) A ‘top-down’ analysis using periodic regional or country reporting by national or international bodies. There are a number organisations that report on inventories for particular regions or countries. These include: the Euratom Supply Agency for the European Union, the Energy Information Administration (EIA) for the USA, the Nuclear Regulatory Authority (NRA) for Japan, the National Agency for Radioactive Waste Management (ANDRA) for France, the Finnish Radiation and Nuclear Safety Authority (STUK) for Finland, the Federal Energy Office (FEO) for Switzerland and the Nuclear Decommissioning Authority (NDA) for the United Kingdom[4].

2) An evaluation of fuel cycle supplier and nuclear utility financial reports since 2010 (where available) and interpretation of policy statements by governments. Almost all holders of nuclear materials make audited financial reports of their nuclear fuel inventory status. However, many combine the categories referenced above (e.g. including WIP stocks and

[4] The UK data is for April 2022.

even partly burned fuel) such that a clear indication of quantities and forms is not available. Also, many governments mandate an inventory policy as part of a strategic approach to national energy security. As such, both financial and policy statements can provide guidance for further analysis and extrapolation. Where necessary, reporting in local currency values has been converted to US dollars using an average foreign exchange rate for 2023 (unless stated).

3) A 'bottom up' research approach using trade statistics and demand modelling to estimate supply and consumption, particularly for markets with no domestic fuel processing or where material is dedicated directly to the in-country end user. Where neither of the above-mentioned sources (points 1 and 2) of intelligence were available or the resources are considered unreliable or lack transparency, then this third approach can provide meaningful insights. It involves collating publicly available trade statistics (e.g. UN Comtrade or locally reported customs data) to track net imports over a reasonable period of time. For this study, data since 2010 was considered which in the expert group's opinion) was the last time the nuclear fuel market was in a reasonable equilibrium state. The resulting information was used to establish whether a surplus of material has been accumulated after modelled consumption was deducted. The material forms were identified and reported under the harmonized system of tariff codes [14] as follows: 261210/284410 – natural uranium ore/oxide/UF_6; 284420 – enriched uranium as UF_6 and UO_2; and 840130 – unirradiated fabricated nuclear fuel[5]. An evaluation of the reported material forms was then made in order to translate gross weights into metric tonnes of uranium (tU). Demand actuals, or more usually estimates modelled by the WNA [3], are deducted from net imports (i.e. after any exports of processed or returned material) to estimate the physical inventories remaining in-country. These quantities are used as a proxy for holdings, whilst accept that inventories may also be held internationally and cannot be captured by this methodology. As such, the results require a degree of reconciliation with the available intelligence on supply chain characteristics and flows for each market.

5.2. PRICING ASSUMPTIONS

To align the volumes and values of the results from all three approaches, prices are needed for uranium in different chemical forms. Where possible, trade data has been analysed to inform these price levels for individual countries. In some cases, it is valid to replace those indicators with locally reported prices. However, for most markets this information was not available (or was not considered robust), so alternative best estimates were taken, based upon the period average market indices between 2012 and 2023[6] or (in the case of downstream sectors) extrapolations from published accounts. These values are approximately:

- US \$95/kgU as U_3O_8;
- US \$110/kgU as UF_6;
- US \$250/kgU as UO_2 in fabricated PHWR fuel;
- US \$1 505/kgU as EUP[7];
- US \$1 655/kgU as UO_2;

[5] HS 840130 can include fuel components as well as fully fabricated fuel. Where possible these volumes/values are removed, allowing for trade statistic comparisons based on uranium-baring volumes alone.

[6] As published by UxC, TradeTech and Energy Intelligence.

[7] Based on an optimal price for 4.5wt% U235 EUP.

— US $1 830/kgU as fabricated LWR fuel[8].

These estimates are intended to reflect market levels over the past decade, accepting that individual commercial agreements will vary within an acceptable range around these representative benchmarks. The fact that most fuel is purchased under long term contracts means that using average legacy indicators can provide a reliable approximation of inventory values, where such inventories have been accumulated and costed over extended periods.

5.3. CONFIDENCE LEVELS

In most cases this research has sought to combine the available intelligence from at least two different methodologies to triangulate and benchmark its results. This multi-faceted approach provides a more robust outcome and a higher degree of confidence on the resulting predictions of material forms and volumes. However, despite such methodological rigour the above approaches cannot provide 100% clarity on national inventories, due to a lack of fully transparent data. As such, in Table 2 a level of confidence is indicated on a country-by-country or regional basis.

TABLE 2. METHODOLOGIES USED TO ASSESS URANIC INVENTORIES BY LOCATION

Region/Country	Method 1: Public Reports	Method 2: Financials (Utility/ Supplier)	Method 3: Trade analysis	Confidence level (%)	Comments and caveats
Africa/Middle East:					
Islamic Republic of Iran	Yes	No	Partial	60%	Trade stats limited. Commercial agreements and IAEA reporting
Pakistan	No	No	Yes	80%	Trade stats align with commercial agreements
South Africa	No	Yes	Yes	90%	Comprehensive trade and financial data
Türkiye	Yes	No	Yes	100%	First core quantities and values confirmed
United Arab Emirates	No	No	Yes	50%	Supply chain inventories not clearly identified
Eurasia:					
Armenia	Yes	Yes	Yes	90%	Trade statistics align with policy and financial statements
Belarus	Yes	No	Partial/Yes	75%	No trade statistics since 2022
Kazakhstan	Yes	Yes	Yes	90%	Supplier financial information, trade data and IAEA press
Russia	Partial	Yes/Yes	Yes	80%	Ambiguity on supply chain forms from single sources
Uzbekistan	No	Yes	No	70%	Only supplier financial data available
Europe:					
European Union [a]	Yes	Yes	Yes	80%	ESA does not report supplier data; improved access to financial data
Switzerland	Yes	Yes	Yes	95%	Assumptions made on utility financial data (i.e. locations)
Ukraine	Yes	Yes/No	Yes	60%	Inconsistencies between trade and financial data
United Kingdom	Yes	Yes/No	No	70%	2022 NDA data only records aggregated material forms

[8] Part-burned fuel is evaluated at 50% of the fresh fuel cost.

TABLE 2. METHODOLOGIES USED TO ASSESS URANIC INVENTORIES BY LOCATION (cont.)

Region/Country	Method 1: Public Reports	Method 2: Financials (Utility/ Supplier)	Method 3: Trade analysis	Confidence level (%)	Comments and caveats
North America:					
Canada	No	Partial	Yes	75%	Utility and supplier data is incomplete
Mexico	No	Yes	Yes	85%	Utility data ambiguous in terms of material in use
USA	Yes	Yes/Partial	Yes	90%	EIA data exhaustive; some supplier financial data is withheld
South America:					
Argentina	No	Yes/Yes	Yes	80%	Potential for overlap between utility and supplier data
Brazil	No	Yes/Yes	Yes	80%	Potential for overlap between utility and supplier data
East Asia:					
Bangladesh	Yes	No	Yes	100%	First core quantities and values confirmed
China	No	Yes/No	Yes	60%	Over-reliance of trade statistics and modelling
India	Yes	Yes/Yes	Yes	80%	Over-reliance of trade data and public statements
Japan	Yes	Yes/No	Yes	80%	Increasing clarity on foreign-located inventories and resales
Republic of Korea	Partial	Yes/Yes	Yes	85%	Improved alignment of anecdotal, trade and financial data sources
China [b]	Yes	Yes	Yes	95%	Good alignment between trade stats and public statements

[a] Nuclear countries in the EU comprise Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain and Sweden.

[b] Taiwan

6. REGIONAL REPORT: AFRICA AND THE MIDDLE EAST

6.1. OVERVIEW OF AFRICA AND THE MIDDLE EAST

- Africa and the Middle East is a geographically diverse region that has a relatively low installed nuclear power capacity base.
- Domestic capabilities to produce nuclear fuel are either limited or non-existent.
- A heavy reliance on the international nuclear fuel cycle for JIT supply of finished fuel is further complicated by non-proliferation treaty, Nuclear Suppliers Group controls or restrictions regarding bilateral arrangements.
- In most cases, the result is an underdeveloped strategic stock policy towards inventories, exacerbated by long commercial lead times due to the geographical dispersal of fuel suppliers (i.e. in Europe, Republic of Korea, the Russia Federation and China).
- Türkiye joins this region as a new nuclear country in 2023.

As of 31 December 2023, the total value of inventories in the region is estimated to be US $530 million. Table 3 summarizes the analysis of inventories in the region, by country and form. In relation to restated 2021 data for Africa and Middle East (see Annex – Global 2021 tab), the most significant changes are seen from additional inventories in Pakistan (up 15% and 30% by value and volume, respectively) and the United Arab Emirates (down 63% and 57% by value and volume, respectively).

TABLE 3. SUMMARY OF AFRICA AND MIDDLE EASTERN INVENTORY STATISTICS

Country	Nuclear entities reviewed	Value of inventories (US $ millions)	Value of inventories Reported (R) or estimated (E)	Estimated volumes (tU)	Assessed material form [a]
Islamic Republic of Iran	1 utility/supplier [b]	7	E	4	EUP
		35	E	19	Fabricated fuel
Pakistan	1 utility [b]	183	E	116	Fabricated fuel
Türkiye	1 utility [b]	117	R	79	Fabricated fuel
Republic of South Africa	1 utility [c]	55	R	37	EUP
		27		15	Fabricated fuel
United Arab Emirates	1 utility [b]	106	E	68	Fabricated fuel
Africa/Middle Eastern totals	All	530		0	tU Natural uranium
				41	tU as EUP/enriched UO_2
				297	tU as UO_2 (Fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated
[b] Utility had no publicly available statistics on inventories
[c] Financial data for year ending 31 March 2024

6.2. BACKGROUND FOR AFRICA AND THE MIDDLE EAST

Africa and Middle East includes five commercial nuclear power countries: Islamic Republic of Iran, Pakistan, South Africa, Türkiye (a new member) and the United Arab Emirates. As of 31 December 2023, the region's operators had approx. 10 GWe (net) of nuclear power in service as shown in Table 4.

TABLE 4. NUCLEAR POWER CAPACITY AND NUCLEAR FUEL CYCLE DEMAND IN AFRICA AND THE MIDDLE EAST

Country	NPPs (operating or in temporary shutdown + under construction) and generating capacity[a]	Estimated annual demand in 2023 [b] (tU)	Fuel cycle component (tU as)
Islamic Republic of Iran	1+1 VVER-1000;	153	U_3O_8/UF_6
	915MWe (net)	18	EUP/fabricated fuel
Pakistan	6 PWRs;	558	U_3O_8/UF_6
	3 262MWe (net)	72	EUP/fabricated fuel
South Africa	2 PWRs;	277	U_3O_8/UF_6
	1 854MWe (net)	33	EUP/fabricated fuel
Türkiye	+4 VVER-1200	441	U_3O_8/UF_6
	n/a	0	EUP/fabricated fuel
United Arab Emirates	3+1 PWRs;	853	U_3O_8/UF_6
	4 011MWe (net)	104	EUP/fabricated fuel

[a] IAEA PRIS database[9].

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

9 https://pris.iaea.org/PRIS/home.aspx

6.3. LOCAL INVENTORY POLICIES AND STATUS

The nuclear power industries in the Africa and Middle East region are specific to the operations of (mostly) their respective state-owned nuclear utility. Nuclear fuel inventory polices are therefore an extension of government policies on nuclear power, but are also reflective of continuing strong links to the reactor vendor as the original equipment manufacturer (OEM).

6.3.1. Islamic Republic of Iran

Nuclear fuel for the Atomic Energy Organization of Iran (AEOI) Bushehr 1 VVER-1000 reactor is supplied by Russia's TVEL. The reactor core consists of 76tU in 163 fuel assemblies, for which the long term fuel contract was signed in 2006. Also, AEOI/TVEL signed a new contract in June 2017 for the delivery of reserve fuel. As of 31 December 2021, TVEL had supplied a total of approx. 620 assemblies to the Bushehr 1 reactor site, including reserve fuel in 2017. Historical deliveries are shown in Fig. 4. Deliveries since that date have not been reported.

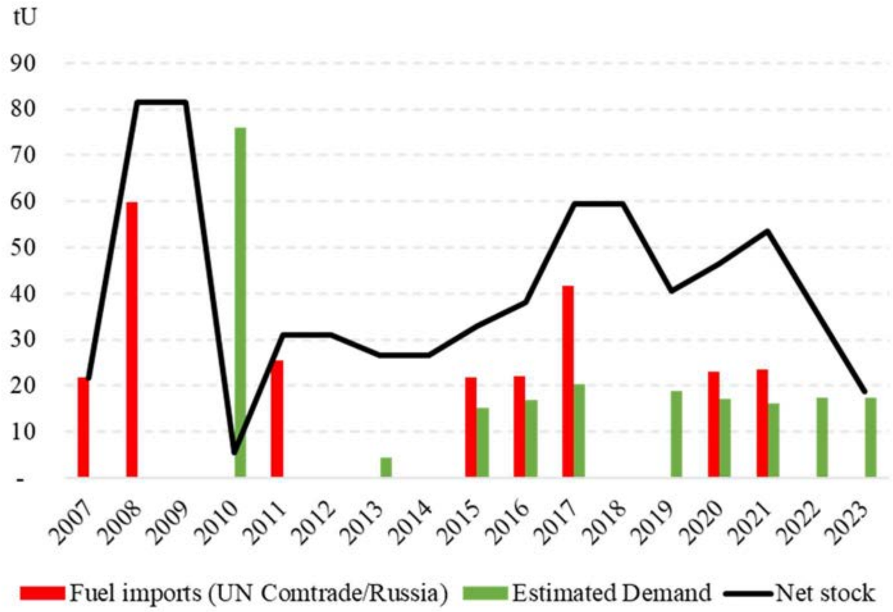

FIG. 4. AEOI imports and fuel demand.

Assuming no deliveries from TVEL in 2022 or 2023, AEOI has been drawing down on its strategic stock in order to reload Bushehr 1. That being the case, as of 31 December 2023, AEOI was estimated to have the following stocks [15]:

— Approx. 19 tU or 39 assemblies of fabricated fuel for Bushehr 1;
— HALEU <20wt%U^{235}, 712.2 kg;
— LEU UF_6 (LEU as EUP), <5wt%): 4.3 t.

The HALEU and EUP quantities relate to production from AEOI's domestic enrichment plants. These are monitored by the IAEA and held for Iran's internal needs. AEOI, has stated that it wishes to integrate domestic EUP production into the TVEL fabrication contract, but there are no indications that this is actually happening.

6.3.2. Pakistan

Pakistan's Atomic Energy Commission (PAEC) relies on Chinese imports to fuel the Chasma (CHASNUPP) and Karachi (KANUPP) nuclear power plants that were built by China National Nuclear Corporation (CNNC). The nuclear fuel is supplied under a bilateral civil nuclear agreement signed in 2010 (albeit that Pakistan is not a signatory to the Non-Proliferation of Nuclear Weapons treaty, nor a member of the Nuclear Suppliers Group). Despite having domestic fuel cycle technology, PAEC does not independently produce or procure the front end components for its fuel, so is entirely reliant on imports from China Nuclear Energy Industry Corporation (CNEIC) for the bundled package of enriched uranium and fabrication services. Figure 5 shows PAEC imports and fuel demand from 2009 to 2023.

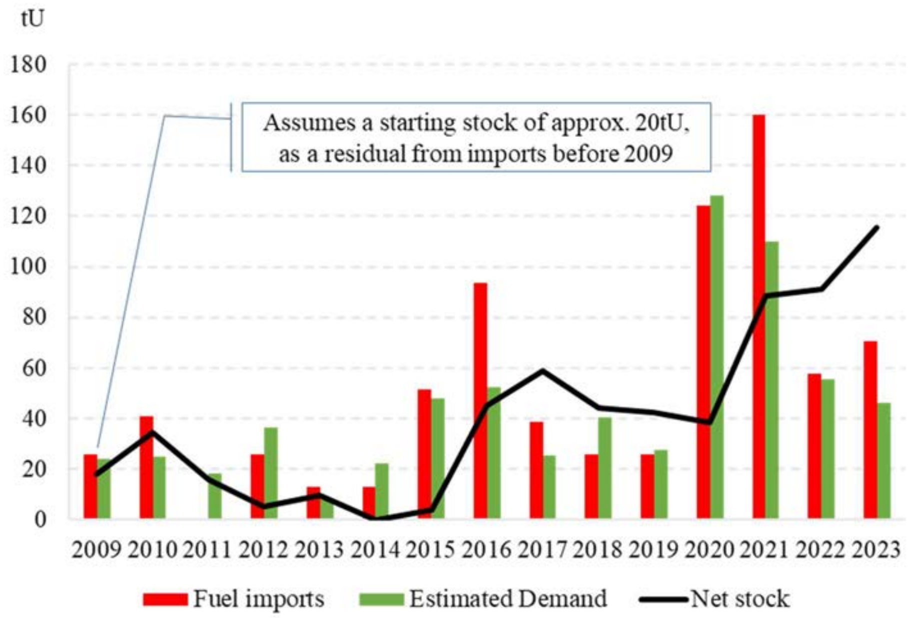

FIG 5: PAEC imports and fuel demand

Based on trade statistics[10] and calibrated to spent fuel reports, as of 31 December 2023, PAEC's net fabricated stocks (Chinese imports less reactor demand) is approx. 116 tU. As such, PAEC is assessed to have accumulated approximately 1–2 years' worth of additional fresh fuel at its two stations since 2015 as a buffer stockpile.

6.3.3. South Africa

The national utility Eskom operates two pressurized water reactors (PWRs) at the Koeberg site near Cape Town. These units each have a core with 72 tU and 157 assemblies. A normal reload on a 16–18 month cycle is 56 assemblies (approx. 26 tU, or 52 tU for both units). Fuel procurement is enacted through periodic public tenders; Westinghouse and Framatome are the incumbent fuel manufacturers from European production facilities[11]. As of 31 March 2024, Eskom declared the following commercial stocks in its financial accounts:

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[10] UN Comtrade export statistics and reactor demand modelling has been used for this analysis, as PAEC doesn't produce any financial or operating statements.

[11] In addition, NECSA operates the Safari-1 test reactor at Pelindaba. It has used stockpiles of domestic HEU to fuel this research reactor, before switching to importing HALEU from the US, fabricated by Compagnie pour l'Etude et la Realisation de Combustibles Atomiques, France.

— Rand 2.6 billion (approx. US $141 million) as ‘Nuclear Fuel Inventories’;
— Rand 1 billion (approx. US $55 million) in ‘Future Fuel’, which is effectively pipeline/WIP material (i.e. Uranium and/or EUP).

Eskom reports ‘Nuclear Fuel Inventories’ that include in-core material and finished fuel. Therefore, to avoid counting partly burned fuel, an estimate of fresh fuel inventories is established from reported ‘Finished Fuel Transfer’ values (relating to fabricated fuel imports for reloads), net of spent nuclear fuel depreciation (based on FIFO accounting) plus ‘Future Fuel’ derived from Eskom accounts as shown in Fig. 6.

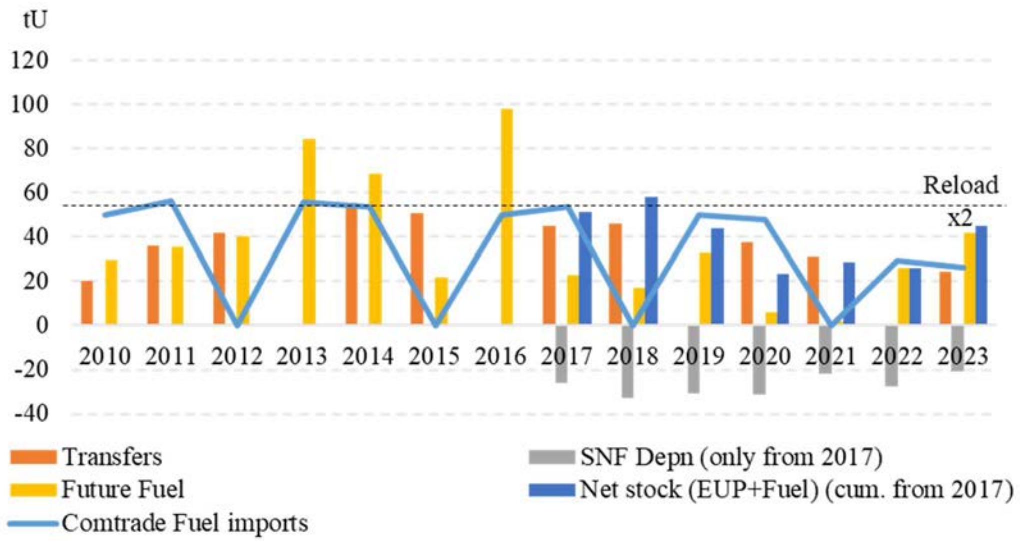

FIG.6. Eskom nuclear fuel volumes (financially derived values[12] shown in bars; cum=cumulative).

‘Future Fuel’ values peaked in 2016 but have since declined to an estimated 37 tU as EUP. Some finished fuel stocks appear to have accumulated in 2017/18, resulting from large amounts of pipeline material and subsequent reactor availability and performance issues. By March 2024, ‘Future Fuel’ and finished fuel stocks are believed to have decreased to close to operational minimums, net of WIP.

6.3.4. Türkiye

Construction of the first of four VVER-1200 units in Türkiye by Akkuyu Nükleer Anonim Şirketi is nearing completion. Under the related fuel contract signed in 2017 [16], the first core for Akkuyu Unit 1 was delivered by TVEL in April and May 2023, comprising 169 assemblies and 79 tU. The value of the first core is reported to be US $117 million. As of 31 December 2023, the material was in storage on site awaiting the start of commissioning work in late 2024 or early 2025. Similar advanced deliveries of first core fuel will accompany the commissioning of the remaining three units at Akkuyu, a process which is targeted for completion by 2028.

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[12] Fiscal Years (April to March); volumes estimated using average imported values for the relevant form.

6.3.5. United Arab Emirates

As a new nuclear power country, the United Arab Emirates (UAE) has developed its fuel cycle policy from scratch since 2010. The implementation by Emirates Nuclear Energy Corporation (ENEC) aimed to ensure material availability for the predicted online dates for the four Barakah APR1400 reactors. A diversified fuel management policy was implemented, including multiple independent contracts for the front end components. First core and initial reload fabrication was left to the reactor vendor (Korea Electric Power Corporation (KEPCO)/KEPCO Nuclear Fuel (KNF)) and strategic inventory management was largely handled between ENEC and KNF), including advanced fabrication campaigns and modest buffer stocks.

According to the Republic of Korea export data, as of 31 December 2023, ENEC had received a total of approx. 587 tU in fabricated fuel and approx. 1 289 fuel assemblies. This equates to:

— Four first cores (241 assemblies each for units 1-4);
— The first reloads for Units 1-3 (typically 100 assemblies each);
— A small number of spare assemblies.

Excluding the first cores and two consumed reloads, ENEC is believed to hold approx. 68 tU in fabricated fuel. Due to delays in reactor commissioning, there was also a potential for ENEC to accumulate an oversupply of upstream front end components. This may have led to temporary surpluses throughout the upstream supply chain. However, this cannot be independently verified neither ENEC, Nawah or the operator Barakah One produce public financial statements.

6.4. REGIONAL SUMMARY

Figure 7 shows estimates for the five Africa and Middle Eastern nations' uranic inventories.

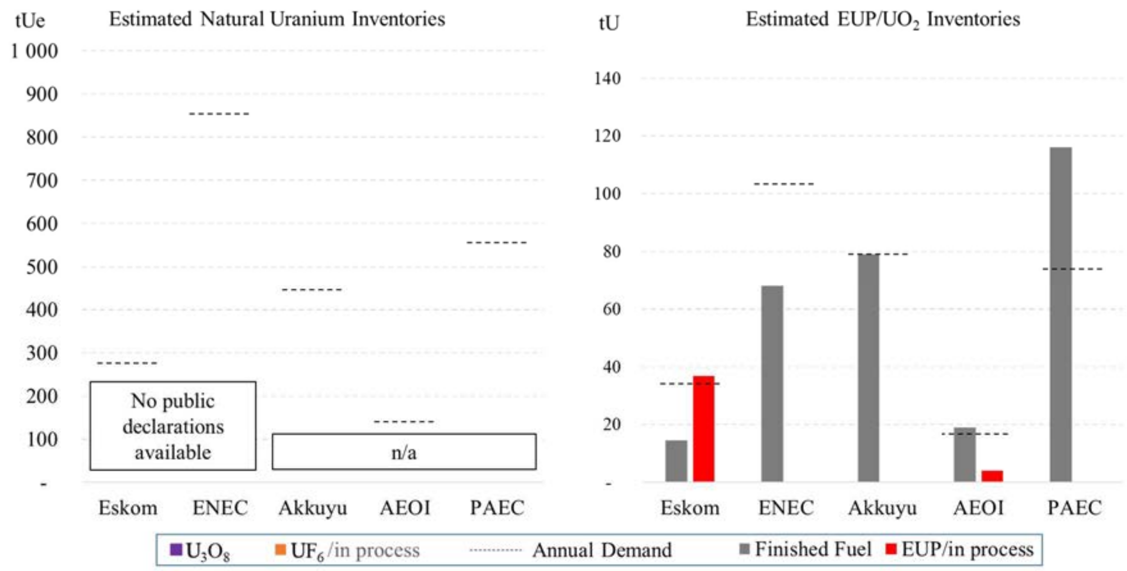

FIG. 7. African and Middle Eastern utility uranics inventories by form (n/a=not available).

While it is believed that Eskom and AEOI have some modest U_3O_8/UF_6 holdings due to legacy/domestic production, the lack of publicly available evidence means that these categories are left blank. Similarly, ENEC is known to contract directly with uranium and conversion suppliers, so will likely own material within the supply chain at these stages. However, no financial statements are available to identify the respective quantities (and regardless they may simply be work-in-progress). Meanwhile PAEC and Akkuyu Nükleer S.A. are known not to buy front end components, so are deemed to have zero holdings.

With regard to enrichment and fabrication, three utilities are believed to have established strategic stockpiles: ENEC has quantities of buffer stock to facilitate the core loadings at Barakah and PAEC has added supplies from CNEIC. Similarly, AEOI has worked with TVEL to establish a strategic stock of approximately two years' worth of fabricated fuel (although these may have been progressively depleted since 2021). AEOI also holds domestically produced quantities of EUP (LEU and HALEU), which have the potential to be integrated into its supply chain for Bushehr or other domestic nuclear programmes. In contrast, Eskom has almost no appreciable buffer stocks available, despite their international supply chains having long transport and processing lead times.

6.5. INVENTORY LIQUIDITY AND MOBILITY

From available evidence the Africa and Middle Eastern region has very limited quantities of inventory material. Those that do exist are specifically intended to ensure domestic security of supply and on the whole do not displace ongoing requirements from primary suppliers.

6.5.1. Islamic Republic of Iran

Any remaining reserves of fuel at Bushehr is intended to provide for ongoing operation in the event of a supply interruption. As such, it is not considered to be either liquid or mobile, particularly given the current geopolitical constraints on both the supplier and end user. AEOI stocks of enriched uranium (including HEU) are also exclusively for domestic use. While Iranian EUP may be drawn down to supplement Russian supplies, it is unlikely to cover more than a fraction of the needs of Bushehr, particularly if Unit 2 comes online later this decade.

6.5.2. Pakistan

Chinese-produced fuel for PAEC is specific to the China–Pakistan bilateral nuclear cooperation and the Chinese-designed reactors for which it is intended. Fuel imported by PAEC will be used in-country and therefore buffer stocks are considered both immobile and illiquid.

6.5.3. South Africa

Any finished fuel inventories in South Africa are immobile, as they are held as bundles dedicated to the Koeberg PWRs. As such, they are not considered liquid and (aside from the next reload in hand), may only amount to a small supply of backup assemblies to mitigate fuel failures. Modest reported 'Future fuel' values (effectively front end WIP) means that surplus pipeline material is also limited to operational needs.

6.5.4. Türkiye

The initial core for Akkuyu unit 1 will be destined for in-country use in 2025. Further imports from TVEL are assumed to be equally intended for consumption at the Akkuyu NPP.

6.5.5. United Arab Emirates

It is assumed that ENEC's in-country inventories of fabricated fuel will be consumed during reactor commissioning and the first operating cycles. Thereafter, any supply chain surpluses will decrease as operations continue, so none of the suspected WIP inventories are likely to become commercially liquid.

7. REGIONAL REPORT: EURASIA

7.1. OVERVIEW OF EURASIA

- Russia and Kazakhstan represent significant shares in all of the front end sectors for the Eurasia region supply chain. As such localized primary production adds significantly to supply guarantees.
- Atomenergoprom has a fully integrated domestic fuel cycle, plus HALEU, DUF_6, reprocessed uranium (RepU) and slightly irradiated uranium (SIU) inventories to backstop supply interruptions to Rosenergoatom.
- Russia's capabilities in spent fuel management have allowed it to follow a strategy to use a closed nuclear fuel cycle, which supports security of supply.
- All countries within this region (with the exception of Russia) have built medium to long term inventories to ensure reactor operations.
- Regional membership of the International Uranium Enrichment Centre (IUEC) provides certain additional supply guarantees.
- As of 31 December 2023, total regional inventories (including pipeline material) were valued at approx. US $4.2 billion, more than doubling since 2021.
- Fabricated fuel is estimated to make up around US $0.5 billion of this figure, specifically for Russian-designed reactors.
- Various upstream front end materials are held by Atomenergoprom in the Russian Federation. Primary uranium reserves are reported by Kazatomprom and Navoiyuran.
- There are also strategic reserves readily available to the commercial sector (e.g. the IUEC Fuel Reserve and IAEA Fuel Bank), as well as the Russian national reserves of DUF_6, RepU and SIU that support Atomenergoprom's domestic and international orderbook. However, these latter categories are not included in the above table, as they require further primary processing capacity to restore their material form to a natural-equivalent level.

Table 5 summarizes the analysis of inventories in the region, by country and form. Since 2021, access to data on the Eurasian nuclear power industry has been progressively restricted. Reporting on trade flows has been curtailed, on top of already limited financial statistics. That said, the general picture painted by increased inventories (mostly WIP) held by primary producers in the region corroborates a wider perspective that the regional nuclear power sector has a high degree of self-sufficiency. The same producers have also responded to geopolitical tensions since Q1 2022 by increasing production to facilitate global stockpiling as the nuclear fuel cycle becomes increasingly bifurcated between the BRICS and OECD economic blocks. As a consequence, inventories by value have increased 54% since 2021 and while local fabricated fuel inventory volumes have declined 42%, uranium and enriched uranium volumes have increased 5% and 53% respectively. Given that the regional utilities outside of Russia (i.e. in Armenia and Belarus) had already built reasonable strategic inventories by 2021/22, a redirection of TVEL's fabrication capacity towards VVER customers outside of Eurasia is not considered to have compromised local security of supply.

TABLE 5. SUMMARY OF EURASIAN INVENTORY STATISTICS

Country	Nuclear entities reviewed	Value of inventories (US $ millions)	Value of inventories: Reported (R) or estimated (E)	Estimated volumes (tU)	Assessed material form [a]
Armenia	1 utility	22	R	12	Fabricated fuel
Belarus	1 utility	360	E	281	Fabricated fuel
Kazakhstan	1 supplier	713	R	7 242	U_3O_8
		78	R	47	UO_2
		150	R	90	EUP
Russian Federation	1 utility	0	R	0	Fabricated fuel
	1 supplier	397	R	3 968	U_3O_8/UO_3
		2 335		1 303	EUP
		84		42	Fabricated fuel
Uzbekistan	1 supplier	71	R	758	U_3O_8
Totals	All	4 211		11 969	tU natural uranium
				1 441	tU as EUP/enriched UO_2
				335	tU as UO_2 (fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

7.2. BACKGROUND FOR EURASIA

The Eurasian region consists of only three commercial nuclear power countries: Armenia, Belarus and the Russian Federation. As of 31 December 2023, the region operators had approx. 30 GWe (net) of nuclear power in service. Total demand for nuclear fuel products in 2023 was estimated to total 6 676 tU as U_3O_8 or UF_6 and 813 tU as EUP or UO_2 in fabricated fuel as shown in Table 6.

TABLE 6. EURASIAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

Country	NPPs (operating or in temporary shutdown + under construction) and generating capacity [a]	Estimated annual demand in 2023 [b] (tU)	Fuel cycle component (tU as)
Armenia	1 VVER-440;	50	U_3O_8/UF_6
	448MWe (net)	8	EUP/fabricated fuel
Belarus	2 VVER-1200;	357	U_3O_8/UF_6
	2 220MWe (net)	40	EUP/fabricated fuel
Russian Federation	2 KLT-40S/2+1 FBR/3 EGP/6 VVER-440/12 VVER-1000/4+3 VVER-1200/8 LWGR1000;	6 264	U_3O_8/UF_6
	27 727MWe (net)	765	EUP/fabricated fuel

[a] IAEA PRIS database

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

As key nuclear fuel cycle producer countries, Kazakhstan and Uzbekistan are added for completeness, where they have a material impact on nuclear fuel inventories and stockpiling.

7.3. LOCAL INVENTORY POLICY AND STATUS

The nuclear power industries in the countries of the Eurasian region all fall under a single State-owned national entity. Their respective inventory polices are therefore considered as being an extension of government policies on nuclear power.

7.3.1. Armenia

Haykakan Atomayin Electrakayan CJSC (Armenia NPP, HAE) operates a single VVER-440 at Metzamor (Unit 2). Life extension work will see the unit operate until 2026 and further renovations will extend this to 2036. Nuclear fuel is supplied under lifetime arrangements with TVEL, with periodic renegotiation of terms. Armenia's 10% shareholding in the IUEC at Angarsk also provides certain assurances with regard to accessing supplies of front end components [17].

Financial reports indicate that total inventory values have increased by about 17% since 2021, from AMD 21.2 billion to AMD 24.8 billion. Within that figure nuclear fuel represents AMD16.7 billion (US $42 million). Although no 2021 comparison data is available, the fresh fuel inventories have increased by 17.5% since 2022 [18]. Statements made in 2019 asserted that "Based on the documents that were signed in 2017, a nuclear reserve stock has been formed at the power plant ... to replenish its reserve on the platform of the station" [19]. According to the 2023 report, the on-site inventory includes AMD 8.8 billion of stored fuel, with the remaining AMD 7.9 billion being in-core inventory. With annual fuel costs of approx. AMD 7–8 billion, it appears that HAE has maintained a 1–2 reload strategic inventory at the site in 2023 (equivalent to approx. 12 tU as EUP).

7.3.2. Belarus

Commissioning of the Ostrovets station is now complete, with the first VVER-1200 unit having achieved commercial operation in June 2021 and the second in May 2023. The fuel supply contract between TVEL and Belarus covers the next 14–15 years [20]. In addition to supplying two full cores of 163 fuel assemblies, two more spare core loads will be delivered to each Ostrovets unit. Additionally, the operator stated that "[as] we are launching the station, and we already have a supply of fuel for 10–12 years without any economic and economic perturbations" [21].

On that basis, the target for advanced reload fuel stockpiling was approx. 650 assemblies (330 tU as UO_2), giving two first cores and eight spare reloads each (assuming 25% of the core is ejected after an annual cycle) [22].

According to Russian and UN Comtrade export/import statistics and press statements [23], TVEL has now delivered approx. 975 assemblies (i.e. 2 full cores in 2019 with 17 spare assemblies [24], plus approx. 640 reload fuel assemblies in 2020, 2021 and 2022), or 491 tU. This establishes the required inventories on site at Ostrovets. Ongoing consumption means that inventories at the end of 2023 are estimated to have been depleted to 281 tU as UO_2. A bilateral dispute over reactor commissioning and performance led to a new nuclear fuel deal being concluded, whereby future fuel deliveries will be supplied at lower prices [25]. This implies further near-term procurement, whereby a drop in costs may facilitate the rebuilding of the inventory over time.

7.3.3. Russian Federation

Rosenergoatom buys all its nuclear fuel needs directly from TVEL, also a subsidiary of Atomenergoprom, under Rosatom. Most of the fuel for Rosenergoatom is fabricated from irradiated uranium (either reprocessed or slightly irradiated feed) from domestic resources. From annual reports, it appears that Rosenergoatom's inventory including nuclear fuel amounts to approx. ₽ 60 billion (US $700 million) [26]. However, this is assumed to relate to the volume of part-burned in-core fuel and that the finished fresh fuel required for the next reload is accounted for in Atomenegoprom's financial statements. On that basis, the proximity and capacity flexibility within the Russian fuel cycle is deemed to provide a suitably robust front end supply chain for Rosenergoatom. The security of supply assurances from TVEL, as a sister company under Rosatom, are considered in Section 7.5.2.

7.4. REGIONAL SUMMARY

Figure 8 shows the estimates of total uranic inventories across the Eurasian region that are attributable to the reactor operators.

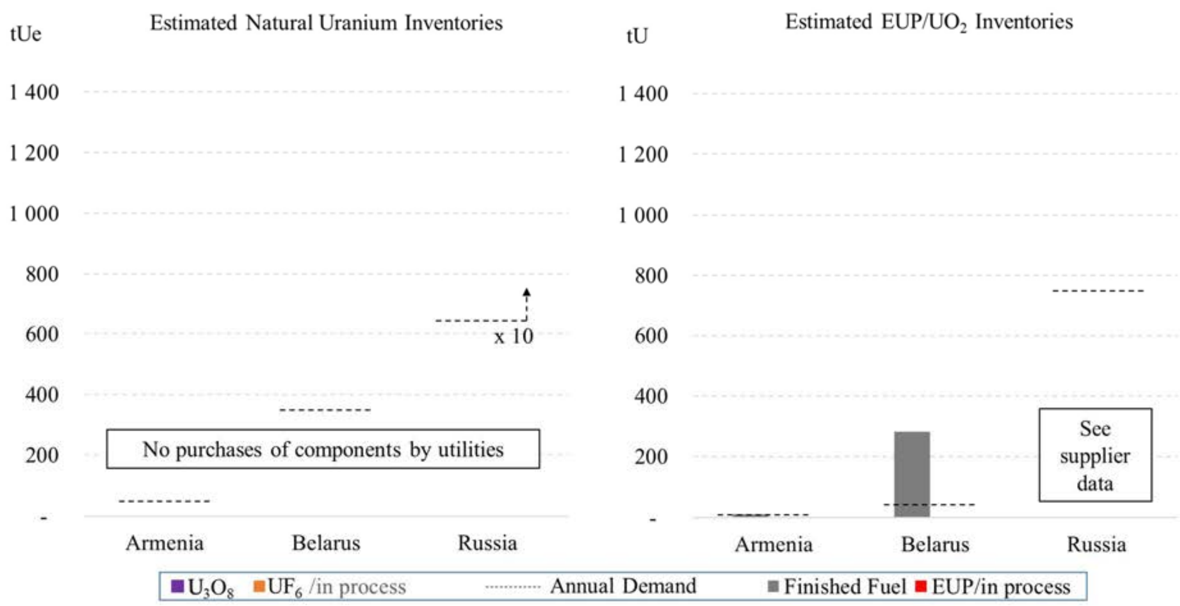

FIG 8. Eurasian utility uranic inventories by form.

Armenia and Belarus follow a strategic approach towards inventories and their Russian supply, whereas Russia ensures its own domestic security of supply through primary capacity and imports.

7.5. MAJOR SUPPLIER INVENTORY POLICIES AND STATUS

7.5.1. Kazakhstan

Kazatomprom (KAP) Group's 2023 year-end U_3O_8 inventories were equal to 7 242 tUe [6]. KAP targets an ongoing inventory level of approximately 6–7 months of annual attributable production, but increased sales have seen some drawdowns on that level since 2021[13]. In total, uranium inventories are valued at ₸ 328 billion (approx. US $710 million).

Kazatomprom also holds certain quantities of EUP/UO_2 necessary for the needs of the CGN fabrication Joint Venture. These are assumed to be recorded within the Ulba factory inventories statement, which amount to ₸ 35.5 billion (approx. US $78 million) and could represent approx. 50 tU as WIP.

Lastly, Kazatomprom also hosts the IAEA fuel bank at Ulba, containing 90 tU as EUP with assays up to 4.95 wt%, paid for by US $150 million in member donations [27].

7.5.2. The Russian Federation

The Russian Federation has historically held a national uranium reserve [28]. This formed a strategic stockpile to ensure a stable supply of uranium for national needs. There is no reliable information on the current size of these reserves, but according to historical information Russia's uranium stockpiles stood at 200 000 tUe in 1991. However, during the 1990s much of this stockpile was sold off, such that by 2010 uranium reserves had dwindled to 47 000 tUe and were expected to run out completely by the mid-2020s. Consequently, Russia stopped selling uranium from its commercial reserves to foreign customers but continued to use approx. 3 000 tU/annum for domestically consumed nuclear fuel derived from RepU and SIU, respectively [29]. As recently as the WNA Symposium in 2018, TVEL asserted that it had no surplus inventories of EUP.

Any depletion of Russia's uranium reserves may have been stemmed or at least slowed by TVEL and Techsnabexport (TENEX) independently accessing significant quantities of Kazakh uranium and foreign depleted uranium respectively. A deal in 2020 to buy 1 150 t of RepU from Orano to bolster national reserves [30] may also be an indicator. The regular drawdown of approx. 3 000 tU/annum noted above would imply residual SIU and RepU inventories of > 20 000 tUe to help cover the domestic fleet requirements until 2030. Articles point to a similar amount of material in reserve, with a 1 500 tU/annum deficit covered by stocks that are assumed to last until 2040–2045 (i.e. 27 000–34 500 tU) [31].

In most countries, DUF_6 tails are not regarded as a true secondary supply source due to the need for primary enrichment production capacity to generate equivalent natural uranium. However, due to the low costs of domestic upgrading, Russia's current requirements for UF_6 and continuing excess uranium enrichment capacities make their stockpile of over 1 million tUF_6 [32] a viable resource. The Angarsk Electrolysis Chemical Complex (AECC) has been dedicated to tails upgrading since at least 2014, producing approx. 2 500 tU annually for immediate consumption. However, this 'tails mining' operation will cease in 2024 in order to increase the production of EUP [33].

In total, Atomenergoprom (AEP) declared ₽ 488 billion of inventories (US $5.4 billion) as of 31 December 2023, but the subset related to fresh nuclear fuel and uranic components only amounted to ₽ 253 billion (US $2.8 billion). This is divided into finished nuclear fuel, WIP, uranium bearing products and shipped materials, which generally demonstrates pipeline volumes of at least 4–8 months of domestic requirements for each stage of the fuel cycle. Evidently, AEP furnishes an international as well as a domestic orderbook. Furthermore, Atomenergoprom supplies fuel to foreign nuclear power plant JVs such as Metzamor (Armenia)

[13] A number of JVs also have their own stock that are not published together with KAP Group figures.

and Akkuyu (Türkiye), values which have been removed from Russian inventories to avoid double-counting. To supply its orderbook, Atomenergoprom has undertaken to significantly expand its inventory holdings since 2021 (up 85%), much of which is assessed as EUP or UO_2 for export. Such increases may be commensurate with increased/advanced customer demand, as OECD utilities that are dependent upon TVEL supplies have been stockpiling themselves (see Section 8 for further commentary).

In addition to the above, in 2010 Rosatom created its own international low enriched uranium Fuel Reserve at the IUEC[14], located at AECC. It contains 132 tU as EUP with assays between 2–4.95 wt% [34] and at least one-third being at 4.95 wt%[15]. This material is accessible upon request from the IAEA and bolsters reserves for that part of the supply chain.

7.5.3. Uzbekistan

Domestic uranium miner Navoiyuran declared U_3O_8 inventories of UZS 835 billion (US $71 million) as of the end of 2023 [7]. This indicates a quantity of approx. 760 tU, so indicate little in the way of strategic reserves beyond WIP to meet planned orders.

Figure 9 shows Eurasian supplier uranic inventories by form for 2023. Russia's direct access to uranium resources is relatively limited, despite domestically generated SIU and RepU from spent fuel. Therefore, Atomenergoprom's ability to cover Rosenergoatom's demand for enriched uranium as well as an export orderbook is to a degree dependent upon a surplus of primary uranium enrichment capacity that can be underfed in order to boost enriched uranium supply.

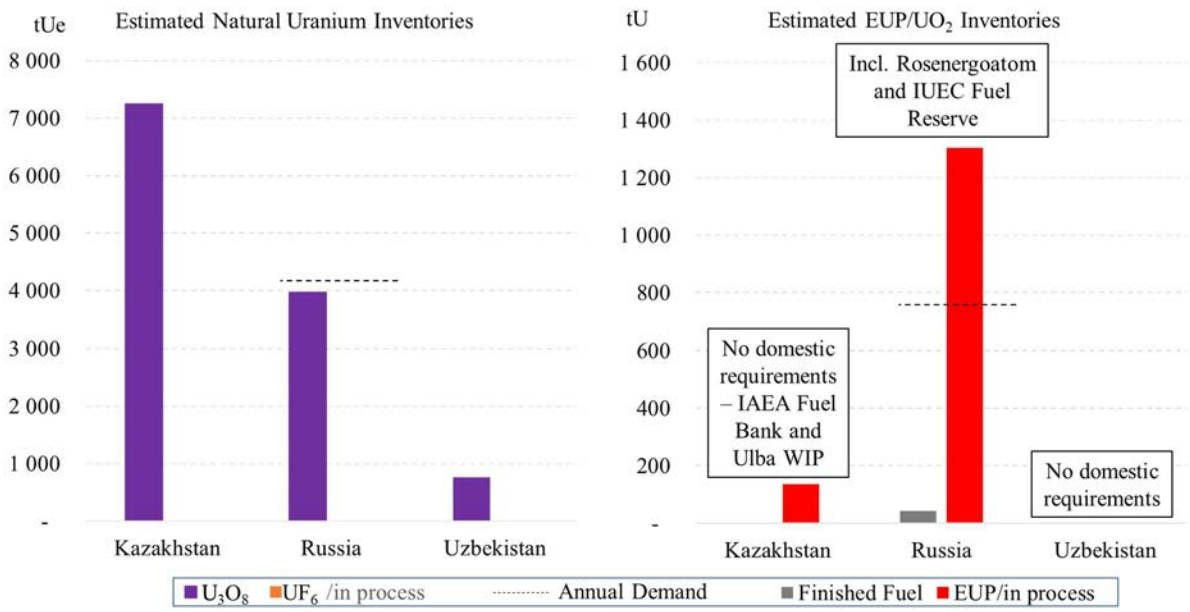

FIG. 9. Eurasian supplier uranic inventories by form.

14 International Uranium Enrichment Centre is a JV, with 70% of shares held by Russia plus 10% each for Kazakhstan, Ukraine and Armenia.

15 https://eng.iuec.ru/activities/fuel_bank/

7.6. EURASIAN INVENTORY LIQUIDITY AND MOBILITY

7.6.1. Armenia

The fabricated fuel at Metzamor is intended to provide a guarantee against supply interruption, so is considered illiquid. The fuel bank at the IUEC also provides similar guarantees against interruption in fuel supplies, but these are not exclusive to Armenia. The latter is therefore considered more flexible and mobile, subject to the procedures for accessing the material.

7.6.2. Belarus

Fabricated fuel stocks are held in dry storage at the Ostrovets site. The imperative of security of supply appears to have committed the station operator to significant expense (> US $620 million by the end of 2023) to ensure fuel supply with large strategic inventories. The material is therefore considered illiquid and solely for domestic use only. However, it is unclear whether Belarus will seek to maintain a stock going forward, or allow the reserve to be drawn down during the next ten years to a more conventional level.

7.6.3. Kazakhstan

KAP holds stock in U_3O_8 form, some of which is for strategic/WIP purposes. Since the remainder of the stock material is planned for sales, it is highly liquid and relatively mobile. However, KAP continues to target an inventory level of approximately 6–7 months of annual attributable production as a strategic inventory. The Ulba factory appears to maintain a similar level and policy objective, but fabricated materials are directed to a single customer (CGN), so are classed as illiquid. In contrast, the IAEA LEU fuel bank is considered liquid and mobile, subject to a request for supply meeting the criteria set by the IAEA Board of Governors.

7.6.4. Russian Federation

Within Rosatom, access to the various volumes and forms of reserves is determined by the current production needs of TVEL, both for its own customers and for those of TENEX. As such, any inventories are highly liquid and mobile, dependent upon the processing capacities of the Russian enrichment and fabrication industries.

Global access to the fuel bank of low enriched uranium under IAEA control at the IUEC at Angarsk nominally determines the liquidity/mobility of that material. Theoretically, this material is available to any IAEA member state in good standing who are unable to procure fuel for political reasons, but the process of drawdown has not been put to the test.

7.6.5. Uzbekistan

All Navoiyuran inventories held as current assets are deemed necessary to implement near-term deliveries to customers, including in Canada, India, Japan and Republic of Korea. As such, they are mobile, but illiquid.

8. REGIONAL REPORT: EUROPE

8.1. OVERVIEW OF EUROPE

- The European nuclear power markets are diverse, covering 16 countries. Most (i.e. 13 countries) are represented by the European Union (EU) and governed by EURATOM Treaty requirements.
- EURATOM Supply Agency’s (ESA) prescribed stock policy advises two years of inventories as well as supply diversification. However, individual inventory policies vary by country.
- Inventories that were the result of over-purchasing of nuclear fuel since 2010 have gradually been drawn down by utilities and suppliers alike. Also, the impacts of early reactor closures on surpluses are finally working through in Belgium, Germany, and Sweden.
- Appreciable amounts of inventory are held by front end suppliers, but these are not reported by ESA.
- As of 31 December 2023, total inventories within Europe (including WIP/pipeline material) are valued at some US $14.3 billion, as detailed in Table 7, a figure that has increased appreciably since 2021 (corrected).
- More than 55% of total inventories are held by French entities. Many other utility holdings include WIP/pipeline quantities, so truly strategic reserves and surpluses are limited.
- Suppliers' holdings total approx. US $2.7 billion (some of which are integrated into national utility stocks; i.e. in Belgium, France and Spain, but otherwise are often dedicated to underpinning their respective international orderbooks).
- With a financial entity holding over US $1.8 billion of the stated European inventories, this limits reserves that are considered to be uncommitted/liquid or mobile.
- EU/UK suppliers fuel most of the EU15 LWR fleet. Aside from France, there is little evidence of significant buffer stocks at production locations.
- Meanwhile, reliance on domestic fabrication exists for the UK advanced gas cooled reactors (AGRs) and Romanian CANDU operators, where some reserves are evident.
- There is a significant dependence on TVEL for European VVER operators. Most have built inventories to mitigate any impacts from the current geopolitical uncertainties and are seeking to diversify in tandem with completing their contractual commitments. In some cases this is leading to instances of double purchasing.

The total declared values for European entity inventories increased 16% on 2021, driven by uplifts in every supply chain segment. Particularly significant instances of stockpiling occurred in the Czech Republic, France, Hungary, Romania, Sweden and the United Kingdom. Conversely, notable drawdowns took place in Belgium, Finland, Germany, The Netherlands, Slovakia, Switzerland and Ukraine.

The downward trends were in part due to cyclical factors, exacerbated by first core movements or reactor closures due to retirement or phase-out policies. As such, they masked a concerted effort by VVER operators to build strategic inventories of fabricated fuel. Since Q1 2022 there has been an increasing effort by European VVER operators to comply with an ESA edict to diversify fuel supplies away from TVEL.

TABLE 7. SUMMARY OF EUROPEAN INVENTORY STATISTICS

Country	Nuclear entities reviewed	Value of inventories (US $ millions)	Value of inventories Reported (R) or estimated (E)	Estimated volumes (tU)	Assessed material form [a]
Belgium	1 utility/supplier	332	R	701 107	UF_6 EUP
Bulgaria	1 utility	219	R	120	Fabricated fuel
Czech Republic	1 utility	454	E	255	Fabricated fuel
Finland	2 utilities	330	R	1 532 108	U_3O_8/UF_6 Fabricated fuel
France	1 utility	6 296	R	34 882 1 061 710	U_3O_8/UF_6 (incl. RepU) EUP Fabricated fuel
	2 suppliers	1 416	R	5 662 1 388 38	U_3O_8/UF_6 EUP Fabricated fuel
Germany	3 utilities [b]	- 0	- R	- 0	UF_6 Fabricated fuel
	2 suppliers	-	-	-	-
Hungary	1 utility	389	R	185	Fabricated fuel
Netherlands	1 utility	45	R	22 6	EUP Fabricated fuel
	1 supplier	-	-	-	-
Romania	1 utility	76	R/E	134 127	U_3O_8 Fabricated fuel
	1 supplier	39	R	86	Fabricated fuel
Slovakia	1 utility	201	R	97	Fabricated fuel
	1 State body	8	E	4	Fabricated fuel
Slovenia	1 utility	4 1	R	3 0	EUP Fabricated fuel
Spain	3 utilities	401	R	219	Fabricated fuel
	1 supplier	25 276	E R/E	276 178	U_3O_8/UF_6 EUP
Sweden	2 utilities	226 184	R R	150 110	EUP Fabricated fuel
	1 supplier	126	R	891 37	UF_6 EUP

TABLE 7. SUMMARY OF EUROPEAN INVENTORY STATISTICS (cont.)

Country (non-EU)	Nuclear entities reviewed	Value of inventories		Estimated volumes (tU)	Assessed material form [a]
		(US $ millions)	Reported (R) or estimated (E)		
Switzerland	2 utilities	59	R	576	U_3O_8/UF_6
		121	R	77	EUP
		178	R	89	Fabricated fuel
Ukraine	1 utility	62	R	405	U_3O_8
		425	R	280	Fabricated fuel
	1 supplier	3	R	22	U_3O_8
United Kingdom	1 utility	165	R	90	Fabricated fuel
	2 suppliers	334	R	3 204	UF_6
		172	R	115	EUP/enriched UO2
	1 financial entity	1 834	R	7 714	U_3O_8
European totals	All	14 425		55 998	tU natural and reprocessed uranium
				3 138	tU as EUP/enriched UO_2
				2 533	tU as UO_2 (fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

Localization of VVER fuel fabrication is well underway. For European Union LWR and PHWR operators, the knock-on effects of a bifurcated market has been to stimulate a more risk averse approach to security of supply. Meanwhile, the implementation of de facto controls outside of the European Union (i.e. in Switzerland, Ukraine and the United Kingdom) has also led to their respective utilities revisiting their nuclear fuel supply chain relationships and implementing further commercial diversification.

One further consequence reflected in the European region is the increasing interest from financial entities in building a position in the upstream segments of the nuclear fuel cycle. In particular, yellow cake has added 27% to its physical inventories and recognised an increase in value of 176%. Evidently this represents a speculative holding that does not in itself benefit the security of the regional supply chain.

8.2. BACKGROUND FOR EUROPE

In 2023, the European region consisted of 16 nuclear power countries: Belgium, Bulgaria, Czech Republic, Finland, France, Germany (since removed), Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom.

As of 31 December 2023, European operators had approx. 118 GWe (net) of nuclear power in service. Total gross demand for nuclear fuel products was estimated to total 17 082 tU as U_3O_8, 16 897 tU as UF_6, 2 172 tU as EUP and 2 357 tU as UO_2 in fabricated fuel as shown in Table 8.

TABLE 8. EUROPEAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

Country (EU members)	**NPPs** (operating/temporary shutdown + under construction) **and generating capacity** [a]	Estimated annual demand in 2023 [b] (tU)	Fuel cycle component (tU as)
Belgium	5 PWRs;	516	U_3O_8/UF_6
	3 916MWe (net)	63	EUP/fabricated fuel
Bulgaria	2 VVER-1000;	334	U_3O_8/UF_6
	2 006MWe (net)	40	EUP/fabricated fuel
Czech Republic	6 VVER-440/1000;	715	U_3O_8/UF_6
	3 934MWe (net)	90	EUP/fabricated fuel
Finland	2 VVER-440/2 BWRs/1 EPR; 4 394MWe (net)	616	U_3O_8/UF_6
		82	EUP/fabricated fuel
France	56 PWRs (+1 EPR)	8 783	U_3O_8/UF_6
	61 370MWe (net)	1 098	EUP/fabricated fuel
Germany	Phase-out completed	0	U_3O_8/UF_6
	4 055MWe (net) closed by April 2023	0	EUP/fabricated fuel
Hungary	4 VVER-440s;	320	U_3O_8/UF_6
	1 916MWe (net)	38	EUP/fabricated fuel
Netherlands	1 PWR;	69	U_3O_8/UF_6
	482MWe (net)	8	EUP/fabricated fuel
Romania	2 PHWRs;	185	U_3O_8
	1 300MWe (net)	185	Fabricated fuel
Slovakia	5 (+1) VVER-440s;	443	U_3O_8/UF_6
	2 308MWe (net)	49	EUP/fabricated fuel
Slovenia	1 PWR;	127	U_3O_8/UF_6
	688MWe (net)	15	EUP/fabricated fuel
Spain	6 PWRs/1 BWR;	1 155	U_3O_8/UF_6
	7 123MWe (net)	138	EUP/fabricated fuel
Sweden	2 PWRs/4 BWRs;	932	U3O$_8$/UF$_6$
	6 944MWe (net)	120	EUP/fabricated fuel
Switzerland	3 PWRs/1 BWR;	412	U_3O_8/UF_6
	2 973MWe (net)	51	EUP/fabricated fuel
Ukraine	2 VVER-440s/13 (+2) VVER-1000s;	1 567	U_3O_8/UF_6
	13 107MWe (net)	215	EUP/fabricated fuel
United Kingdom	8 AGRs/1 PWR (+2 EPR);	908	U_3O_8/UF_6
	5 883MWe (net)	165	EUP/fabricated fuel

[a] IAEA PRIS database

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

8.3. LOCAL UTILITY INVENTORY POLICIES AND STATUS

For the purposes of the analysis, the European region is divided into EU and non-EU countries. The former reports in a consolidated manner through the ESA, while three non-EU countries (Switzerland, the United Kingdom and Ukraine) are assessed separately.

European Union (EU) countries with ESA oversight include: Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain and Sweden.

ESA publishes data on utility nuclear fuel inventories held within the EU [35]. The latest data for 2023 indicates that stocks (expressed in tonnes of natural uranium equivalent (tUe)) have increased 5% to approx. 37 500 tUe after dropping 3% in 2022. These quantities include WIP destined for the next scheduled reloads, but excludes RepU. ESA estimates demand for 2024 annual reloads at approx. 11 900 tUe, so the net level of unirradiated inventories going into 2024 is closer to approx. 25 600 tUe or just greater than two years' requirements (approx. 24 000 tUe).

While the year-on-year increase is potentially modest, this will have been depressed by a number of specific events in 2022 and 2023. These one-time examples include:

- A continued inventory drawdown in Belgium as Tihange 2 and Doel 3 closed and in anticipation of Doel 1 and 2 going offline by 2025;
- Consumption of the Mochovce 3 first core by Slovenské Elektrárne.
- Final reloads being taken for the last operating German units (Isar 2, Neckarwestheim 2 and Emsland).

Within the ESA survey population of 14 reporting bodies:

- Four utilities hold 3–4 reloads per unit in hand;
- Six utilities have 2–3 reloads;
- Four utilities have 1–2 reloads.

The specific holdings are explored in more detail in the section that follows, but evidently, some utilities have only their next reload available and therefore no buffer stock. Looking at the data from a nominal perspective:

- Seven utilities held quantities of material lower than 1 000 tUe (with four of them holding less than 500 tUe);
- Three utilities held quantities of material between 1 000 and 2 000 tUe;
- Two utilities held quantities of material between 2 000 and 3 000 tUe;
- The remaining two held quantities above 3 000 tUe, with a combined total of at least 22 500 tUe. However, within this category the largest EU operator (Électricité de France (EDF)) is assumed to hold the majority.

Therefore, while on average EU utilities hold approximately two and a half years' worth of annual demand in inventories, the fact that two out of the 14 operators hold more than 60% of the reported quantities may imply lower coverage amongst the remaining 12 operators. Furthermore, it is typical for uranic inventories to be spread evenly across the fuel cycle due to processing lead times. This is demonstrated by Fig. 10, where ESA reports that the material is held in the following forms:

Fabricated fuel	39%	(14 665 tUe in approx. 1 856 tEUP[16])
UO_2 powder	3%	(1 208 tUe in approx. 153 tEUP)
EUP	25%	(9 415 tUe in approx. 1 191 tEUP)
Natural uranium hexafluoride (UF_6)	22%	(8 092 tUe)
U_3O_8 concentrates	11%	(4 140 tUe)

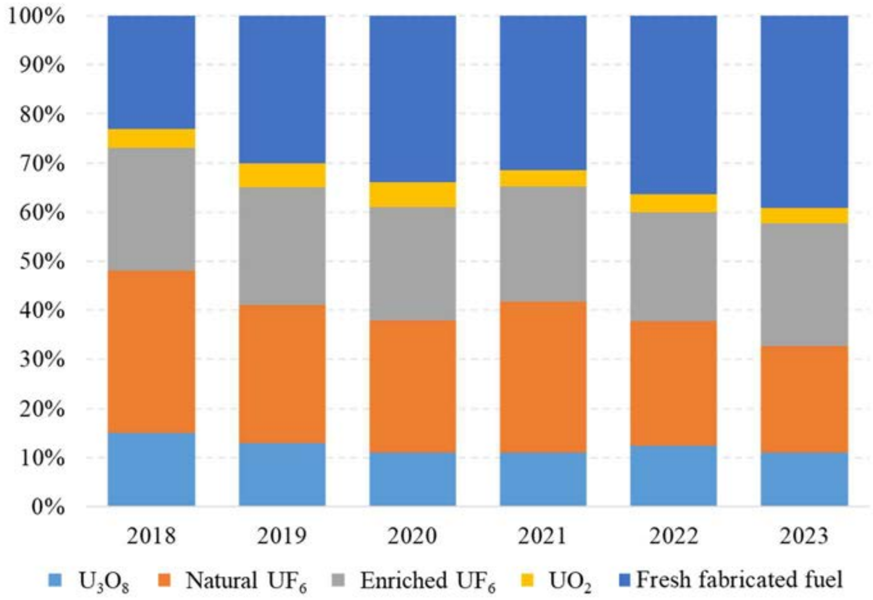

FIG. 10. EU utility inventories by form (tUe.)

Evidently there was enough UO_2 and fabricated fuel at the respective reactor sites or fabricators to service 2024 requirements (11 896 tUe, gross) [35], plus about 21% of the following year's needs. EUP within the supply chain is about 67% of what is required in 2025 and uranium amounts to 91% of the respective 2026 demand. However, these levels would largely match expectations for processing hold-up rather than strategic stocks and do not take into account that a number of utilities report excesses due to reasons of policy or prudence.

In order to qualify the status of WIP, strategic or surplus stocks it is therefore necessary to review individual utility statements in the countries across the EU.

16 tU as EUP or UO_2 calculated using product and tails assays of 4.1wt% and 0.22wt% respectively

8.3.1. Belgium

Synatom supplies nuclear fuel to the reactors operated by Engie, with its procurement policy based on diversification. It also manages a strategic stock in line with ESA recommendations. In total these resources are expected to cover two years of demand [36]. Synatom has seen stocks grow over the early part of the last decade (in nominal values) following extended outages and unscheduled shutdowns at its Doel and Tihange plants. Inventories peaked in 2018, but since then Synatom has been constantly adjusting its coverage strategy in order to achieve an appropriate stock level after the closure of all but two operating units by 2025.

As of 31 December 2023, Synatom's stock (including WIP) was valued at €307 million (down €101 million since 2021) [37]. Engie (which effectively overlaps/mirrors Synatom's stockpiles) also states values for uranium inventories of €307 million at the end of 2023 [38]. Within that figure, €89 million would have been considered surplus to requirements, if Belgium had continued with its phase-out policy. However, the 10 year life extensions for Tihange 3 and Doel 4 have resulted in a re-evaluation of the ongoing requirement for a strategic inventory. Any material will reportedly be held at enrichment facilities, split between UF_6 feed and EUP stocks. Based on data from the Long Term Operation Fuel Supply Agreement put in place by Engie at the end of 2023 [39], a one-third-two-thirds split by value is applied to these two forms, giving 2023 levels of stock sufficient to cover the forward demand of the two remaining units.

8.3.2. Bulgaria

One of the four pillars for nuclear material under the Bulgarian government's Strategy for Sustainable Energy Development is to maintain a sufficient reserve of fuel at the Kozloduy nuclear power plant site [40]. All inventories are held as finished fuel, currently sourced from TVEL. In addition, supply diversification has seen operational requirements for Kozloduy Unit 5 being covered by Westinghouse Sweden from 2024. From import data and annual report statements, it appears that Kozloduy nuclear power plant has accumulated additional buffer stocks of finished fuel that now represents three years' worth of fuel inventories. In their 2023 annual report [41], BEH Kozloduy nuclear power plant noted the following:

- Fresh fuel stocks = BGN 397 million (approx. US $219 million);
- The 2023 fuel reloads (2 x 20 tU) cost approx. BGN 118 million (US $65 million).

It would therefore appear that fuel stocks equate to six or seven reloads, two of which are presumably to satisfy the next annual requirement. This data corroborates statements by BEH that indicate Unit 2 is covered with TVEL fuel until Framatome is able to undertake the fuel supply, which may not be until 2029 [42]. The implication is that TVEL fuel for Unit 5 will be stockpiled as Westinghouse fuel is loaded into that reactor in 2024 and 2025.

8.3.3. Czech Republic

CEZ Group aims to have a strategic inventory of nuclear fuel in line with the Czech Republic's government policy. The National Energy Concept in 2015 called for long term stocks amounting to four years' worth of demand to be in place by 2040 [43]. Under proposals outlined on 4 November 2022 by the Ministry of Industry and Trade, CEZ will now be required to hold reserves of nuclear fuel, fuel assemblies or other necessary/related equipment that allow its nuclear power plants to operate for at least three years. Any new law would allow the mandatory three years' nuclear fuel reserve to be reduced to 18 months “in the case where the operator can demonstrate that it has contractual agreements in place allowing replacement supplies”.

CEZ acted between 2015–2023 to bolster fabricated fuel inventories and mitigate the impacts of a potential supply interruption. Consequently, CEZ now aims to have a strategic reserve equivalent to five years of operations for each of its four Dukovany VVER-440 reactors, increasing from three years at present. This is being accommodated by a new facility at Dukovany capable of holding 554 fuel assemblies. CEZ also maintains an inventory of two reloads for both of the Temelin VVER-1000 units [44], which can ensure three years of operations on 18 month cycles.

Evidently this exceeds ESA’s recommendations relating to security of supply. Based on WNA demand data, this equates to approx. 280 tU of UO_2 in fabricated fuel and is potentially in addition to purchases related to the next reloads. Inventory data from its 2023 Annual Report [45] indicates that CEZ may already have secured the majority of these quantities. Furthermore, CEZ has indicated that its strategic inventories across the front end of the fuel cycle have been reduced in favour of additional fabricated inventories [43].

8.3.4. Finland

Finnish law apparently requires up to one year’s nuclear fuel requirements to be held in stock per reactor. There is no central stockpile of nuclear fuel, so each utility provisions for its own requirements at the respective plants. According to 2023 financial reports for Olkiluoto (OL1-3) operations, Teollisuuden Voima Oyj is holding the following at year end:

- €183 million of uranium (raw and natural) (approx. 1 500 tUe), with a replacement value close to €565 million (these values have increased 98% and 255% respectively in just one year;
- €239 million of nuclear fuel, including the OL3 first core which was transferred into inventories from CAPEX investments.

Annual safeguard declarations (which are made public) by the Finnish Radiation and Nuclear Safety Authority (STUK) [46] confirm that the above values of nuclear/fabricated fuel inventories include in-core material. In terms of strategic fabricated fuel holdings, the quantities total 31.8 tU and 14.3 tU for OL1 and OL2 respectively. OL3 fabricated inventories include 44.8 tU as a strategic reserve, having been delivered in 2021. Both sets of data fit with the expected 7–12 months of buffer inventories prescribed.

Meanwhile, Fortum has stated that for Loviisa “[t]he power plant's current nuclear fuel storage is sufficient for a maximum of two years” [47].

Reporting by STUK indicates a strategic inventory of 17 tU as fabricated fuel at the plant, which equates to 80–90% of annual demand and so is in line with national policy. In addition, Fortum notes in its 2023 accounts [48] that its new fuel contract with Westinghouse is a parallel supply to that of TVEL, indicating that surpluses may be accumulated until the TVEL contracts end in 2027/2030.

8.3.5. France

As a major nuclear power user and fuel cycle supplier, the inventory status of France is somewhat complicated. Quantities of national stockpiles are reported by ANDRA [48]. Their statistics reportedly cover the inventories of Électricité de France (EDF), Orano Cycle, Framatome and also the French Alternative Energies and Atomic Energy Commission, although their respective holdings are not identified. The latest report of French-owned front end quantities states that at the end of 2022:

- Natural uranium stocks totalled 35 900 tU, down 1 900 tU on 2021, but up 20 000 tU since 2010;
- Reprocessed uranium stocks totalled 34 600 tU, up 400 tU on 2021 and up 10 500 tU since 2010;
- Enriched uranium stocks totalled 3 540 tU, up 250 tU on 2021 and up 590 tU since 2010;
- Fresh fuel stocks totalled 874 tU, up 141 tU on 2021 (not reported separately from enriched uranium in 2010).

By tracking fuel cycle movements in France during 2023 (imports, exports and domestic production and consumption), it is possible to adjust the above to provide a figure for each category as of the end of 2023. As a result (in lieu of ANDRA data) the following is estimated:

- Natural uranium stocks increased by approx. 2 415 tU to 38 315 tU;
- Enriched uranium stocks decreased by approx. 140 tU to 3 400 tU;
- Fresh fuel stocks decreased by approx. 47 tU to 827 tU.

While third party holdings are reportedly segregated within the ANDRA statistics, the data on natural uranium may well comingle supplier stocks pledged to foreign customers with domestic inventories. Therefore, the aggregated data potentially gives an inflated figure for U_3O_8 and UF_6 holdings. Independent Orano statements note that France has natural uranium stocks on its territory equivalent to two years' worth of domestic reactor demand [49]. This could equate to some 17 000 tU on French soil, but leave more to be accounted for elsewhere (specifically at foreign enrichers and converters). These quantities may also be supplemented by WIP holding by French suppliers to support their international orderbooks. This would indicate that while the majority of stocks reported by ANDRA are French owned, although the exact proportion is not clear. The ANDRA data is therefore taken as a maximum value for national inventories, which requires qualification against individual commercial declarations. For utility holdings, it is possible to triangulate regional data (for which France represents a significant proportion) with EDF annual accounts.

In its accounts, the EDF Group (including EDF Energy in the UK[17]) reported an increased net value for nuclear fuel on its books of €11.329 billion in 2023 [50]. €9.235 billion of these stocks will not be consumed within one year, so are considered to primarily relate to upstream fuel cycle components (i.e. RepU, Natural U_3O_8 and UF_6 or EUP). Current assets, mostly assumed to be fresh nuclear fuel, represent €2.1 billion. For the purposes of analysis, all segments of

[17] The extent to which EDF inventories overlap with UK-dedicated stocks is unclear. For the purposes of analysis they are assumed to be fully consolidated, so UK stocks have therefore been deducted from French declarations.

component material have been discounted by the value of partly-burned nuclear fuel in the cores of the French fleet (estimated to be €4.1 billion). EDF notes that “The change in inventories in 2023 is principally explained by the increase in nuclear fuel inventories”.

At EDF’s current average rates of consumption (€1.4–1.8 billion/year), their unirradiated inventory quantities represent about four to five years of stocks in various forms. OECD/NEA demand data [6] estimates that EDF’s French fleet requires approx. 1 000 tEUP in fresh fuel annually (plus approx. 100 tHM/a as MOX) and approx. 6 000 tU as UF_6. That being the case, it is likely that the ANDRA fresh fuel stocks belong predominantly to EDF and represent annual variations in WIP related to upcoming reloads, whilst impacted by reactor/fleet performance.

The EUP and uranium inventory levels reported by ANDRA are well beyond French annual requirements (being more than four and six times demand, respectively) and so could either be identified as generous strategic holdings or significant WIP holdings on behalf of EDF and French suppliers (see Section 8.4.1). A reconciliation of ESA data indicates that EDF inventories could represent a maximum of only 40% of the ANDRA quantities, but are likely much closer to 30% or approx. 9,900 tU as NatU and 1 060 tU as EUP.

One further stockpile to be recognised in the case of France is reprocessed uranium (RepU). EDF has recommenced the use of its increasing RepU holdings through conversion by TVEL at the Siberian Chemical Combine in Seversk. Since the U_3O_8 from La Hague is readily substitutable for natural uranium, the EDF RepU stockpiles amounting to >25 000 tU and Orano stockpiles of almost 7 000 tU are noted within French inventories[18].

8.3.6. Germany

Under the German Atomic Law, the last three operating reactors were shut down in April 2023. During stretch-out operations, the cores were reshuffled and part-burned fuel reused, but the absence of fabricated fuel deliveries mean that no new fuel was loaded according to VGB [51]. As of 31 December 2023, the following status is assumed:

- Natural and enriched uranium – RWE notes in its annual report [52] that it still has commitments to purchase uranium, conversion, enrichment and fabrication, so may own an undetermined quantity of material that could be resold.
- Fabricated fuel – VGB reports that onsite fuel inventories were fully depleted at the last operating reactors.

8.3.7. Hungary

The Hungarian government’s policy is to have two years’ worth of fuel supply as inventory to run the Paks station. This material is held in dry storage, the capacity of which is understood to be greater than the current inventory levels at the site. Fuel airlifts in 2022 from the Russian Federation may have increased the amount of material held at the plant [53], deliveries that are now being supplemented by imports by sea [54]. MVM Paks stopped reporting on its nuclear fuel inventories since 2021, such that at the end of 2023 the inventory amounts can only be quantified from trade volumes and annual demand since 2021. This results in the following estimates:

[18] Reported to be a combined 34,600 tU by ANDRA in 2022 and estimated to be almost 35,000 tU in 2023 after further reprocessing and exports.

- About 65% of inventories are held as finished fuel (approx. US $270 million), where annual reloads of US $90 million indicate that fabricated stocks represented three years' worth of demand [55].
- WIP expressed as 'nuclear technology' amounting to approx. US $120 million equated to one or two years' worth of demand and presumably reflects the advances paid to TVEL for future deliveries from Russia.

Consequently, MVM Paks appears to have at least two years of inventories in finished fuel, plus its next reloads and pipeline commitments. This assessment was corroborated by press statements from the end of 2023 [56] which confirmed that almost three years' worth of fuel was in stock and imminent deliveries in 2024 would increase that level to just above three years.

8.3.8. Netherlands

Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ) takes fuel made from Enriched Natural Uranium (ENU), Enriched Reprocessed Uranium (ERU) and Mixed Oxide (MOX) [57] in the ratio of 30:30:40 respectively. It also receives fabricated fuel from three fabricators; Framatome Lingen, TVEL MSZ and Orano Melox in larger quantities than can be used in any single refuelling[19]. The total amount of fresh and spent nuclear fuel permitted at Borssele is limited to a maximum of 200 t, a level which is maintained through storing new fuel in the pond and recycling assemblies at Le Hague on an annual basis [58]. EPZ's financial accounts are consolidated within Zeeuwse Energie Houdstermaatschappij (ZEH) reporting and show the amount of fresh fuel inventory it holds as of 31 December 2023 [59]:

- Total inventories amounted to €81 million as fissile materials. Within that figure, advanced purchases of nuclear fuel were €30 million.
- Assuming that the latter is valued at approx. US $1 500/kgU, advanced purchases equate to 22 tU and have been accumulated by EPZ soliciting for EUP on a buy-and-hold basis;
- The remaining €51 million is assumed to be both fresh fuel and in-core material.
- Based on 50% of imported fuel values, the core represents approx. €40 million, so the remaining fresh fuel is estimated to be equivalent to 6 tU, which matches 2023 imports.

With at least 20–25% of the core is reloaded, up to 10 tU may be fresh UO_2 or MOX fuel awaiting insertion. This indicates that EPZ is holding little in the way of buffer stocks at Borssele, but has a pipeline of material equivalent to at least two years of requirements.

8.3.9. Romania

Nuclearelectrica reports that according to its strategic policy, the implementation of the annual fuel production plan requires the provision of a 'reserve inventory' [60]. In late 2022, a decision by the Romanian Ministry of Energy to transfer uranium concentrates from the "safety and consumption stocks established in the period 2009–2011" under the control of the National Uranium Company to Nuclearelectrica [61] apparently added to these inventories.

[19] The core of Borssele is comprised of 121 assemblies with a total of 38.8MTU; each reload comprises of 22–28 assemblies (8-10MTHM).

Nuclearelectrica Cernavoda PHWR Units 5 and 6 consume approx. 10 800 bundles each year (approx. 205 tU). The utility records the impact of the delivery and consumption of fuel to on-site stocks on a monthly basis. Fresh fuel stocks at the station were 6 522 assemblies as of 31 December 2023, supplemented by depleted fuel stocks of 182 assemblies (in total equating to approx. 127 tU, worth RON 178 million (approx. €36 million). As such, these two units have approximately seven months of onsite stock. The U_3O_8 inventories transferred by the State in 2022 were not declared, but are believed to have originally amounted to approx. 134 tU. Therefore, Nuclearelectrica alone holds 17 months' worth of stocks for Cernavoda's in various forms (and not including Nuclear Fuel Plant Pitesti working stocks – see Section 8.4.3).

8.3.10. Slovakia

The State Material Reserves Administration of the Slovak Republic (SŠHR) is obliged to maintain a minimum reserve of nuclear fuel, in addition to material balances held by Slovenské elektrárne (SE). A plan was developed in 2014 to increase stocks of fresh nuclear fuel in Slovakia. However, as of early 2016 it was stated that:

> "The reserve management considers the current situation to be unsatisfactory and will address the issue of the number of stored fuel [assemblies] in the nuclear reactor as a matter of priority ... [so that] … together with stocks and reserves owned by the nuclear operator, [SE would be able] to operate the reactors for a certain period without its nuclear fuel supplies [from TVEL]" [62].

As of 31 December 2023, SE reported the following:

- €185 million of nuclear fuel stocks [63];
- Annual transfers of approx. €10 million between 2005–2023 from SE into the State Materials Reserve.

Based on average annual fuel consumption (€64 million), SE appears to hold an amount equivalent to approx. three years' worth of fuel. Fuel revolving through the State Reserves amounts to less than one VVER-440 reload (noting that the average consumption of Bohunice units 3 and 4 and Mochovce units 1 and 2 is 240–280 assemblies per annum or approx. 40 tU as EUP). Meanwhile, the first core supplies to Mochovce units 3 and 4 are 349 assemblies each [64] or 42 tU as EUP per core. SE took larger than normal deliveries from the Russian Federation in 2012, 2014, 2016 and 2018, presumably for reactor start-ups. Therefore the €185 million figure above is likely to include approx. 42 tU as EUP in fabricated first core fuel for Mochovce Unit 4.

Therefore, while recent fuel airlifts reportedly assured that the Slovak economy now has reserves of another strategic commodity, stocks were only estimated to be enough for 2024 and 2025. Consequently, in August 2022 the Slovak Cabinet approved the spend of around €8 million on purchase of 36–47 nuclear fuel assemblies to bolster the country's State Material Reserve [65].

8.3.11. Slovenia

From the Nuklearna elektrarna Krško (NEK) annual report it would appear that the utility does not declare any stocks of nuclear fuel as WIP. NEK states that [66]:

> "Due to the nature of production, we do not hold unfinished production or half-finished or finished stock among inventories. Inventories consists only of material, including only nuclear fuel, spare parts and material."

Their reported stock as of 31 December 2023 was €52.4 million, of which it is estimated that €48 million is part-burned fuel. As such, NEK retains little in the way of finished fuel inventories at Krško. However, the utility has created a €4 million strategic inventory of enriched uranium in 2023, which may equate to 2–3 tU as EUP.

8.3.12. Spain

ENUSA S.A., S.M.E. and the three of the four Spanish nuclear utilities (Endesa, Iberdrola and Naturgy) represent the main holders of uranium inventories in Spain[20]. The Spanish government decrees the need for a basic reserve of 721 tU_3O_8 and 363 tSWe [67] (60 tU as UO_2 at 0.3 wt% tails). This implies that there will be enough uranium stock to manufacture fuel for two reloads of a 1 000 MW reactor in the Spanish nuclear fleet. The electricity companies also keep what is known as a 'voluntary strategic uranium stock'. If there were an interruption of international uranium supply, this would allow for the continued operation of the entire nuclear Spanish fleet.

As of 31 December 2021, each utility recorded the following stock levels in their accounts:

- Iberdrola had €65 million [68];
- Endesa had €255 million [69];
- Naturgy has €52 million [70].

These utility stocks (assumed to be fabricated fuel) translate into 19 months of average demand (220 tU/annum) and will include the next reload for each reactor[21].

8.3.13. Sweden

Sweden liquidated a national EUP inventory held by the Swedish Nuclear Fuel and Waste Management Company, SKB in the late 1990s (then determined as fuel equivalent to the production of 35 TWh and equivalent to approx. 100 metric tonnes UO_2 or 8–12 months' supply [71]). Since 2000, the Swedish utilities have managed their own inventories. Vattenfall purchases nuclear fuel components on behalf of Forsmark AB and Ringhals AB as independent companies and Uniper/OKG buys for Oskarshamn 3 (OKG3).

Vattenfall's nuclear fuel inventory was SEK 7.573 billion as of 31 December 2023 (approx. US $714 million), but this includes part-burned fuel [72]. This value has jumped by SEK 2 billion in 2023, after being relatively static for four years and having peaked in 2012. Extracting 503 tU in-core material and based on average fleet consumption of approx. 110 tU as EUP/year (and assuming conservative values of approx. US $1 500 /kgU based on imports), the current inventory appears to mostly represents normal pipeline/WIP volumes.

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[20] Energias de Portugal, S.A. (EDP) also claims to hold inventories of €15 million, specific to the Trillo NPP (https://www.edp.com/sites/default/files/2024-06/Part%20II%20-%20Financial%20Statements%20and%20Notes%202023.pdf)

[21] NB. Each utility is expected to have the next reload ready two months in advance of the recharge.

OKG reports inventories totalling SEK 1.792 billion (US $169 million) as of 31 December 2023 [73]. It is believed to keep a minor proportion of annual demand (approx. 24 tU as EUP) as strategic inventory for OKG3. However, through a combination of contractual commitments and the premature closure of Oskarshamn units 1 and 2, OKG was left holding large stocks in late 2015, including 4–5 reloads of ERU fuel from TVEL. Drawdown is assumed to have been ongoing and may now be accelerated with the cessation of Russian EUP contracts in mid-2022. It is also likely that partly burned fuel from the 120 MTU core of OKG3 is declared in the above values. Adjusting for this, cuts down fabricated fuel inventory values by approx. US $80 m, accounting for 54 tU as EUP.

Non-EU Countries: Switzerland, Ukraine and the United Kingdom are considered below.

8.3.14. Switzerland

Swiss utilities maintain strategic stocks, in lieu of a national policy. Axpo confirms holding a stockpile of natural uranium and slightly enriched uranium (SEU) in Western Europe for emergencies, while Kernkraftwerk Gösgen-Däniken AG (KKG) has existing uranium reserves which it intends to draw down. Reporting by the Federal Energy Office (FEO) [74] confirms significant holdings of natural uranium and EUP outside of Switzerland, with nuclear material owned by the operators of Swiss nuclear installations being located in Germany, France, Sweden and the United Kingdom. Changes in stocks result from the procurement and processing of uranium into fuel elements. These depend on economic and operational requirements, so are deemed to include pipeline/WIP.

As of 31 December 2023, Swiss utilities held the following amounts of uranium in the international supply chain:

- Natural uranium: 852 t (= 576 tU if reported in the form of UF_6);
- EUP: 114 t (= 77 tU if reported in the form of UF_6).

In comparison, the two utilities carried the following amounts of fuel inventories on their books:

- Axpo (Beznau and Leibstadt) – CHF102 million (US $116 million) [75];
- KKG (Gösgen) – CHF122 million (US $82 million), of which CHF67 million is estimated to be part-burned fuel, thereby leaving CHF55 million as fresh fuel [76].

Some of the monetary values above are likely to represent include volumes additional to those reported for safeguards purposes, as it is assumed that the EUP contained in imported fuel assemblies is not counted by the FEO. On that basis, Axpo data indicates more than one year's stock of fuel (approx. 58 tU) and KKG has at least one year's supply for Gösgen in its inventories (approx. 31 tU).

8.3.15. Ukraine

Energoatom made the decision to create a two year fuel reserve in 2014, when a security mission from the USA was working in Ukraine assessing the risks of a conflict with the Russian Federation. In 2020, Energoatom reported that it had 1.5 years' worth of fresh fuel reserves [77]. More recently, the head of Energoatom has made statements assuring that Ukraine had enough nuclear fuel for its power plants to last two years. It was confirmed that the country would not suffer any shortage of fuel over that period, even in the absence of replenishment of reserves.

Before the start of the conflict, Ukraine bought small amounts of (reserve) fuel from TVEL, but most of the fabricated fuel stocks have been supplied by Westinghouse Sweden. Since the beginning of the conflict, Energoatom has completely abandoned Russian nuclear fuel, but still claims to have a large stock in its warehouses, which can be used over the next five to six years [78][22]. As of 31 December 2023, recent imports net estimated demand indicated the following:

- Since 2016, Energoatom has accumulated a net inventory of fabricated fuel of approx. 300 tU, including the next annual reloads.
- Some of this inventory (including Westinghouse Sweden-manufactured fuel) is believed to be located at Zaporozhe.
- This is more than twice annual fleet demand of 130 tU (excluding Zaporozhe).

Energoatom's 2023 annual report [79] concurs with these findings. It indicates that the utility holds nuclear fuel inventories (net of in-core fuel) valued at US $425 million (UAH 15.6 billion). At US $1 520 /kgU fabricated (based on average FIFO import prices declared since 2016), this would equate to approx. 280 tU of stocks. It also corroborates the lower usage figure by declaring an annual consumption value of UAH 6.6 billion = US $180 million (approx. 120 MTU).

An additional US $62 million recorded by Energoatom as nuclear materials could represent ownership of VostGOK uranium or non-Russian EUP supplies (approx. 405 tU as U_3O_8). The cycling of such values in recent years would tend to indicate that this pipeline/WIP material.

Clearly the impacts of the conflict in Ukraine and the status of the Zaporozhe station will have changed the evaluation of stocks and security of supply for Energoatom, particularly if reserves are held at the occupied facilities. However, the usefulness and deployment of a two year strategic reserve appears to be evident at the current time.

8.3.16. United Kingdom

There does not appear to be any national policy directive in terms of UK commercial uranium inventories. Nevertheless, NDA reports UK commercial inventories at the end of FY 2022 [80] as part of its publicly available safeguards remit. As such the UK has approx. 90 tU in unirradiated fuel, split between the AGRs (50 tU) and Sizewell B (40 tU) [81].

Meanwhile, statements by EDF Energy also confirm that they hold fuel inventories for the UK AGR and PWR fleet [[82], which overlaps with the NDA data. In May 2022, EDF Energy confirmed Sizewell B held stocks of two years of fuel from Russian sources [83] (supplied as ERU and EUP via Lingen).

In its 2023 Annual Report, EDF Energy records the following:

[22] Presumably reflecting the full operating cycle for the fuel of 4–5 years in core

- £1 239 million in unburned fuel. This likely relates to the in-core inventory of approx. 1 600 – 1 700 tU[23] for the entire fleet [80], plus material that remains unconsumed at the time of unit closures[24].
- Other nuclear fuel and uranium (including reprocessed materials) is valued at £370 million. This is assumed to be split between the 90 tU of unirradiated fuel in the NDA report and approx. 3 150 tU of uranium.

With early foreclosures of some of the remaining AGRs, EDF Energy has been proactive in conserving resources. For instance, in 2023, unused nuclear fuel built at Dungeness B (where the fuel stringers were assembled) was returned to Springfields for reuse across the AGR fleet, recovering approx. £25 million of value.

All of the above quantities have been subtracted from the accounts of EDF Group, to ensure that uranic materials are not double-counted. Spent fuel data EDF Energy's sustainability reports [84] indicate that annual demand of 130–140 tU, so currently AGR fuel inventories are assess at less than 6 months (including WIP). In essence, EDF Energy only holds JIT stocks for its reactors, plus reprocessed uranium at Sellafield. Upstream front-end components are all held within the portfolio of EDF Group, so the UK supply guarantee is largely premised upon access to French-managed stockpiles.

To summarise the overall European market position:

- The 14 EU utilities inevitably make up the majority of European inventories. Most have at least one reload in hand as well as having the next reload in EUP or UO_2/fabricated fuel form.
- A similar situation exists for the Swiss, Ukrainian and UK operators, albeit that reporting only highlights the downstream sectors of the fuel cycle (i.e. mostly EUP/UO_2 and fabricated fuel).

Figure 11 is a summary of European utility uranic inventories by form.

For EU 27 members, the alignment between reported inventories and ESA data is generally within ± 5% for each material form, so is considered a robust representation of utility holdings. However, one notable omission from the above chart is the EDF Group's RepU inventories, which amount to >25 000 tU as U_3O_8. Evidently, their recognition would significantly skew the coverage of annual demand reported in the ESA data, but they are an important constituent of French primary supply as long as the supply chain is available to process the material.

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23 As of 1 April 2022, the AGRs had approx. 1 520 tU and Sizewell B had approx. 90 tU

24 EDF Energy has to provision for unburned fuel upon station closure, representing 39.3% of a reactor core. This quantity is valued at £255 million in current and £1 698 million in non-current liabilities.

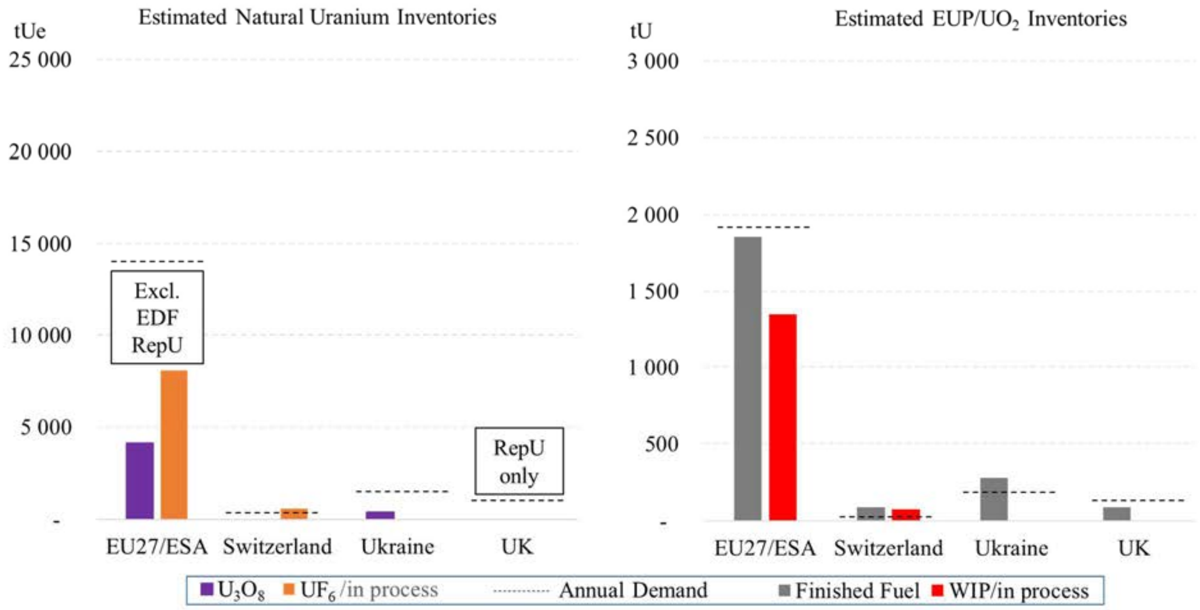

FIG.11. European utility uranic inventories by form.

8.4. MAJOR LOCAL SUPPLIER AND TRADER INVENTORIES

8.4.1. France

Orano Chimie-Enrichissement's predecessor AREVA NC built stockpiles in the late 2000s as the closure of two production facilities approached (i.e. Comurhex 1 and George Besse 1). These were intended to guarantee contractual performance before the startup of the Philippe Coste and Georges Besse II plants. From observing movements in national inventories, the position since 2010 indicates that it has been difficult to work down these stockpiles, due to the impacts of the accident at the Fukushima Daiichi nuclear power plant and the subsequent market downturn.

The latest accounts issued by Orano Chimie-Enrichissement state the following values and forms for their front end inventories [85]:

- €116 million in raw materials (U_3O_8 for conversion), estimated at approx. 1 330 tU;
- €207 million in converted UF_6, estimated at approx. 2 040 tU;
- €613 million in WIP (mostly attributed to separative work units (SWU) purchased from Urenco[25]), estimated to be approx. 1 310 tU as EUP[26].

Meanwhile, Orano Mining declares stocks of €198 million, estimated at 2 290 tU [86].

Framatome Group provides limited data on its inventories, simply stating a value of €557 million [87], up €69 million on 2022 levels. However, these inventories are not specific to the

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25 As stated in Orano Chimie-Enrichissement's 2021 accounts

26 As the uranium component value is not declared, the SWUs are assumed to be carried on quantities of non-Orano-owned uranium. The conversion to EUP volumes is made at 4.2wt% U235 product assays and 0.22wt% U235 tails.

Fuel Division and support a global orderbook, so for the purposes of analysis they have been reduced pro-rata to segmental revenues. This results in only approx. €175 million in inventories for the Fuel Division, equated to approx. 115 tU in various stages of production. A similar exercise on 2022 data gives €141 million in inventories, equated to 90 tU. That said, Framatome note in their latest annual report that (with reference to Group inventories) 'Excluding contributions, the increase in inventories mainly comes from Fuel activities'. On that basis, the above-derived addition of only €34 million to inventories is likely to be a conservative assessment.

The above interpretation of financial reporting by Orano and Framatome would imply supplier inventories of enriched material of approx. 1 430 tU as EUP in various forms, or approx. 40% of ANDRA-reported quantities. Therefore, ANDRA stocks are very likely to include approx. 910 tU as EUP of supplier-held material pledged to international utility customers or possibly the French government. Presuming the former, they have been excluded from the regional and global analysis to avoid double-counting. The fact that they have been largely static as a component of the ANDRA data since at least 2010 tends to indicate that the function is as a strategic/immobile stockpile.

8.4.2. Germany

ANF Lingen independently publishes its inventories (which are also consolidated into the Framatome Group accounts – see above). For 2023, ANF Lingen declared €31 million of raw materials, €12 million of WIP and €20 million in finished products [88]. All have increased on 2022 levels.

Urenco Deutschland GmbH's independently publishes its inventories (which are likewise included in consolidated statistics - see separate Urenco Group analysis in Section 8.4.6). In 2023, Urenco Deutschland declared €10 million of raw materials and €468 million in finished goods [89]. Both have increased on 2021 levels.

Urangesellshaft mbH (a subsidiary of Orano Mining) also confirmed that its inventory holdings fell to zero at the end of 2023 (U_3O_8 and UF_6), down from 454 tU in 2021 [90].

Due to Group consolidations, none of the above figures are added to the totals for European supplier inventories.

8.4.3. Romania

Since start-up, Nuclear Fuel Plant Pitesti (NFP Pitesti) has manufactured 240 066 bundles of natural and depleted UO_2 fuel, but only delivered 235 555 to the Cernavoda reactors. Most of the 4 511 assembly surplus has been generated since 2015 (3 989 assemblies), such that NFP Pitesti could now be holding approx. 86 tU as a buffer to fabricated fuel production. This represents 40–50% of annual national requirements. Combined with Nuclearelectrica's inventories, Romanian reserves could amount to approx. 350 tU, representing almost two years' worth of uranium stocks, including operational WIP and strategic reserve inventories at various stages of the CANDU fuel cycle.

8.4.4. Spain

Spain has legislated that ENUSA guarantees a Uranium Reserve Stock ("Stock Básico") for its nuclear fleet. Original quantities were high (5 000 tU_3O_8 and 3 000 tSWe), but since the mid-1980s these amounts have been steadily reduced. In 1985 the levels were prescribed by RD

1611/1985 at a maximum of 2 000 tU_3O_8 and 1 300 tSWe. Currently (under an order from 2005), Spanish legislation demands a minimum inventory of 721 tU_3O_8 and 363 tSWe (60 tU as UO_2 at 0.3 wt% tails, including approx. 600 tUe). This implies that there will be enough uranium stock for ENUSA to manufacture fuel for two reloads of a 1 000 MWe reactor in the Spanish nuclear fleet.

Enriched uranium is imported into Spain as UO_2 (as ENUSA is unable to locally deconvert enriched UF_6) and limited deliveries of fuel assemblies have come from Germany and Sweden. Fuel exports are predominantly made to Belgium, Finland, France and Sweden, resulting in a net trade outflow of fabricated fuel. Based on ENUSA/Foro Nuclear annual statements, exports and imports (net of domestic demand) show a modest drawdown of domestic stocks over the last 12 years. ENUSA's current stocks are €268 million [91], including the Uranium Reserve Stock of 60 tU as UO_2. Any additional material is assumed to be at various stages of the fuel cycle, but is likely to be held upstream at levels in excess of the 'basic' reserve in order to guarantee export contracts from Juzbado. For the purposes of analysis, quantities additional to the fixed uranium reserve (i.e. in excess of 276 tU as uranium and approx. 60 tU as UO_2) are assumed to be held as EUP outside of Spain and equate to approx. 120 tU.

8.4.5. Sweden

Westinghouse Sweden does not declare specific uranic inventories, but had WIP amounting to SEK591 million (approx. US $56 million) and raw materials of SEK 998 million (approx. US $94 million) in 2023 [92]. The former quantities may well overlap with Uranium Asset Management (UAM) materials (see below summary for the United Kingdom) and are not for near-term sale. They have been equated to approx. 890 tU as UF_6 and approx. 37 tU as EUP respectively.

To summarize the level of inventories in the EU supply chain; most front end component stocks are held by French entities (ignoring hedge fund volumes). Across the nuclear fuel cycle industry there is little available material to backstop utility requirements, if it experiences a supply chain interruption of much more than six months duration.

8.4.6. Ukraine

Most uranium domestically mined at VostGOK between 2010 and 2021 was sent to Russia for conversion and enrichment at the International Uranium Enrichment Centre (IUEC) in Angarsk. According to the WNA [93], 8 300 tU was produced between 2012 and 2021. Since then, output has been directed to Western converters such as Cameco. The resulting uranium concentrate is largely used for the needs of the domestic Ukrainian nuclear reactor fleet. In 2023, VostGOK was reported to have UAH 121 million as WIP and finished products [94], which are estimated to be equivalent to about 20 tU [95].

8.4.7. United Kingdom

The Urenco Group covers three jurisdictions: the USA, ESA/EU and the United Kingdom. The imports and exports of UF_6 feed, depleted uranium (DU) and enriched uranium appear in four country's statistics (Germany, the Netherlands, the USA, the United Kingdom), making separate identification difficult from a trade flow perspective. The sole reference used is therefore Urenco Group's financial reports. Urenco Limited declares its inventories as values of raw materials, WIP, SWU Assets and Finished Goods [96]. Since SWU assets are dedicated to fulfilment of customer orders, this category in WIP can be ignored for the purposes of assessing inventories, as it will overlap with global utility data. Actual inventories include inaccessible WIP and finished goods, where timing of sale completion goes beyond the current period. As such truly liquid inventories have been reduced in recent years to relatively modest quantities. In relation to these categories, Urenco's reported inventories as of 31 December 2023 were:

- Raw materials (mainly UF_6): €92 million;
- WIP (plant operational inventory of SWU): €190 million;
- Finished goods (incl. uranium trades): €71 million.

Within these values, the UK operations at Capenhurst reported [97] the following as of 31 December 2023:

- Raw materials (mainly UF_6): £39 million;
- WIP (plant operational inventory of SWU): £45 million;
- Finished goods (incl. uranium trades): £4 million.

As such, group raw materials could equate to approx. 1 060 tU as U_3O_8 and 1 880 tU as UF_6[27]. This material is owned by Urenco and considered available for resale or for use internally. WIP as plant hold-up and rolling buffer stocks is an operational inventory and in effect is inaccessible in the medium to long term. Finished goods may represent approx. 50 tU as EUP and may already be committed under contract, so are potentially inaccessible.

Springfields Fuels Limited/Westinghouse UK rely on Uranium Asset Management (UAM) for their uranic supply. Under this role, UAM both buys/sells and leases natural uranium and enriched uranium on their behalf. UAM reported [98] end of year 2021 holdings of US $96 million. It planned to sell surpluses amounting to US $22 million but hold a further US $67 million (approx. 40–45 tU as EUP) for at least 12 months[28]. Meanwhile, Springfields Fuels Limited has a modest range of consumable stocks [99], but it is assumed that any uranic material is owned by customers.

One additional entity of significance in the United Kingdom is the Yellow Cake investment fund. This is a London-quoted company listed on the Alternative Investment Market (AIM), headquartered and incorporated in Jersey. As of 31 December 2023 it reportedly held 7 714 tU as U_3O_8 valued at £1.475 billion [100]. The physical material resided in accounts at Cameco's Port Hope/Blind River facility in Ontario, Canada and in Orano Cycle's Malvési/Tricastin in France. The most significant portion of its inventory is purchased under a 10 year framework agreement with Kazatomprom. As a commodity fund, the material is not destined for resale.

8.5. EUROPEAN INVENTORY LIQUIDITY AND MOBILITY

Figure 12 summarizes estimates of European supplier uranic inventories by form. Given current geopolitical events and the efforts undertaken by certain operators during the last five years to secure an inventory position to avoid disruptions in supply, it would be reasonable to assume that few utilities have any truly surplus inventories. Some have gone beyond ESA

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[27] This does not include customer uranium, which is an off-balance sheet item
[28] Possibly relating to a WIP loan to Westinghouse Sweden

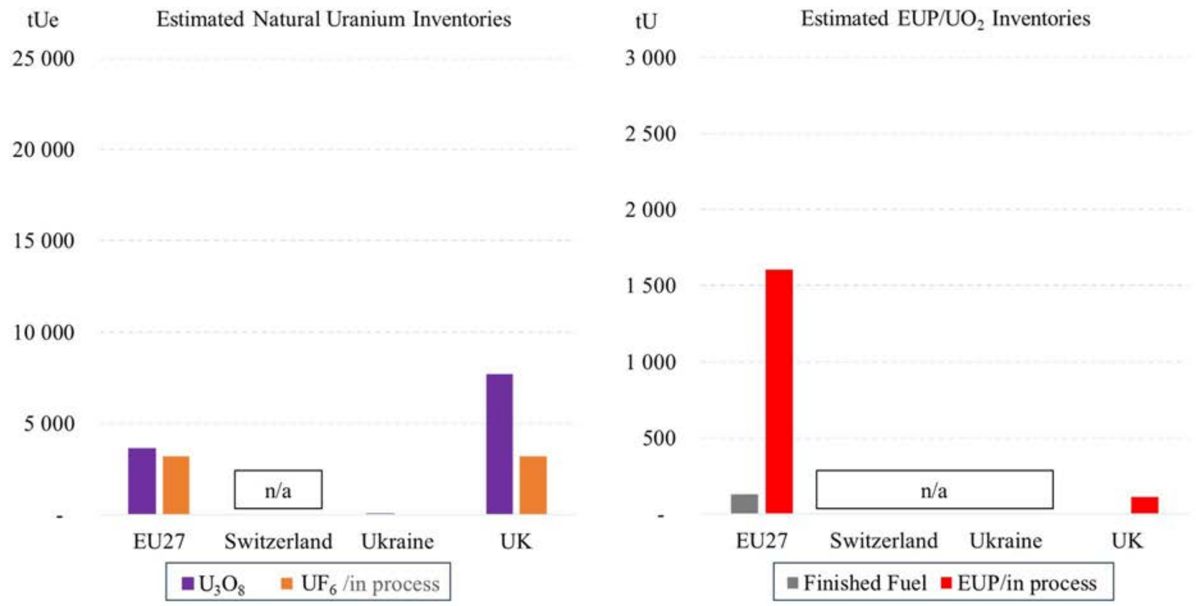

FIG. 12. European supplier inventories by form (n/a =not applicable).

recommendations to provide an additional level of assurance, in particular, EDF/Orano and the VVER operators in Central and Eastern Europe. Others such as Vattenfall, ENUSA and Synatom have likely seen prescribed inventory plans frustrated by uncertainties over continued reactor operation, but are now able to plan ahead for stable domestic consumption. General liquidity is therefore determined to be low within Europe, with stock mobility limited to reshuffling quantities between units as they retire, within the same regulatory jurisdiction (for example in the UK).

In terms of suppliers, a similar process to utilities in terms of re-optimizing their positions during the 2010s has apparently left few with significant inventories that can backstop utility demand for a protracted period. However, the inventories that do exist can be deployed globally, so these are considered more liquid and mobile than those of their local customers. Clearly some of the major suppliers are boosting inventory levels, as diversification from Russian imports has exposed limited excess capacity in Western Europe. The implied existence of a large inventory of domestic and internationally-owned EUP stocks in France also indicates a degree of surplus material and liquidity within the global supply chain.

9. REGIONAL REPORT: NORTH AMERICA

9.1. OVERVIEW OF NORTH AMERICA

— The North American countries represent a single interdependent region in terms of fuel security and supply chain logistics.
— Most utilities largely rely on proximity of primary fuel cycle suppliers and open commercial markets to procure fuel on a diversified basis.
— In the USA, a progressive drawdown of stocks since 2010 means that simple commercial solutions may be insufficient to avoid any potential supply disruption. While only limited federal agency reserves exist, there has been a significant increase in policy interest in security of supply since the first quarter of 2022 and a focus on the accessibility of these reserves.

- Meanwhile, Mexico relies on the USA for fuel supply guarantees and Canadian brokering of Russian material, rather than independent strategic stockpiling.
- In contrast, Canada can domestically satisfy most utility needs, with security of supply based on local uranium reserves and domestic processing capacity.
- As of 31 December 2023, total regional inventories were estimated to be worth US $17.7 billion, as detailed in Table 9. Much of this value is held in utility inventories, which includes pipeline material or fuel destined for internal consumption. Few utilities hold an overtly strategic stockpile of material to mitigate a supply interruption and available utility information also points to relatively illiquid inventory holdings.
- Supply chain inventories recorded by the EIA in the USA are estimated to be worth over US $1.8 billion and are almost matched by similar federal holdings and reserves. The former is presumed to support the supplier's backlog of commercial commitments, so is relatively illiquid. Meanwhile the latter is designed to be accessible to the markets under certain call-off conditions and protocols.
- Canadian suppliers are also understood to have devoted commercial resources to backstop utility fuels supplies and plant operations.
- Potentially more significant is the world's largest uranium fund (Sprott Physical Uranium Trust (SPUT)), which has recently taken up a considerable amount of surplus material (as U_3O_8) into state that is less accessible from an end user standpoint.

TABLE 9. SUMMARY OF NORTH AMERICAN INVENTORY STATISTICS

Country	**Nuclear entities reviewed**	**Value of inventories (US $ millions)**	**Value of inventories: Reported (R) or estimated (E)**	**Estimated volumes (tU)**	**Assessed material form [a]**
Canada	3 utilities [b]	29	R/E	288	U_3O_8
		33		188	UO_2
		306		975	Fabricated fuel
	2 suppliers	803	R	4 823	U_3O_8, UF_6 or UO_2
	1 financial fund	5 750	R	25 130	U_3O_8
Mexico	1 utility	46	R	31	Fabricated fuel
USA	21 utilities [b]	7 476	R/E	8 058	U_3O_8
				11 838	UF_6
				2 447	EUP
				231	Fabricated fuel
	Suppliers/traders	1 835	E	13 770	U_3O_8
				1 166	UF_6
				141	EUP
	Federal agencies (DOE/NNSA)	1 502	E	3 400	UF_6
				670	EUP
Totals	All	17 717		68 660	tU Natural uranium
				3 258	tU as EUP/enriched UO_2
				1 237	tU as UO_2 (fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

Combined inventory holdings in the USA and Mexico demonstrated one of the largest upward shifts in the intervening two years since 2021. Values climbed to an estimated US $ 10.9 billion, up 14%, with all components showing increases while recognising a proportionately greater addition of inventories by suppliers and traders. However, some of this growth may well be cyclical, and the aggregated reduction in fabricated fuel inventories continues to point towards very limited buffer stocks in this downstream fuel cycle segment. The overt intervention by the United States Department of Energy (US DOE) to boost domestic stockpiles of uranium and enriched uranium (including HALEU) though public tenders indicates a recognition of the vulnerability of the domestic supply chain, particularly at a time of geopolitical tensions and deglobalization. Meanwhile, the Canadian supply chain continues to demonstrate robustness, particularly through supplier inventory increases since 2021 and strong integration with local PHWR utility customers.

As a distinct category, the two Canadian domicile financial funds also posted strong uplifts in their inventory holdings (by value and volume). However, neither directly contributes towards security of supply in the region.

9.2. BACKGROUND FOR NORTH AMERICA

The North American region consists of three countries with commercial nuclear power programmes, namely Canada, Mexico and the USA.

As of 31 December 2023 the region's operators had approx. 111 GWe (net) of nuclear power in service. Total demand for nuclear fuel products in 2023 was estimated to total 19 764 tU as U_3O_8, 18 282 tU as UF_6, 2 249 tU as EUP and 3 562 tU as UO_2 in fabricated fuel as summarized in Table 10.

TABLE 10. NORTH AMERICAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

Country	**NPPs** (operating/temporary shutdown + under construction) **and generating capacity** [a]	**Estimated annual demand in 2023** [b] **(tU)**	**Fuel cycle component (tU as)**
Canada	19 PHWRs; 13 661 MWe net	1 482	U_3O_8
		1 313	Fabricated fuel
Mexico	2 BWRs; 1 522 MWe net	237	U_3O_8/UF_6
		30	EUP/Fabricated fuel
USA	62+1 PWR/31 BWR; 95 835MWe net	18 045	U_3O_8/UF_6
		2 219	EUP/Fabricated fuel

[a] IAEA PRIS database.

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

Together, these countries currently represent the largest combined regional nuclear market in the world, but with ageing fleets that have seen numerous retirements during the last 10 years. As such, lifetime extension applications and refurbishment programmes represent a major focus for the local industry.

9.3. LOCAL UTILITY INVENTORY POLICIES AND STATUS

9.3.1. Canada

The country has a general policy of self-sufficiency for its front end nuclear cycle, which includes domestic uranium mining, conversion and fabrication to support the indigenous CANDU reactor market. However, the Canadian government does not provide a strategic stockpile of nuclear fuel. Nuclear power utilities therefore independently hold natural uranium, UO_2, WIP and finished fabricated fuel to ensure their security of supply. In order to buffer against supply shocks, natural uranium and other downstream services are purchased years in advance, allowing time for a number of processing steps before a finished fuel bundle arrives at the power plant [8]. There are no significant quantities of enriched uranium in Canada and there are no utility-owned uranic inventories held outside of Canada.

Considering the three operators in turn:

(1) Bruce Power does not publicly state its inventory policy or holdings [101]. The two Bruce generating stations are leased from Ontario Power Generation (OPG). Bruce Power may rely in part on their dedicated fuel supplier Cameco for buffer stocks, but are also believed to have a finished fuel inventory for security of supply that is conservatively estimated to be six months of fuel (approx. 360 tU).

(2) New Brunswick Power (Engie NB Power) values its nuclear fuel inventory at CAD $49 million at the end of March 2024 [102]. Over the last three years, nuclear fuel purchases averaged CAD $23 million, implying a reasonable stockpile when considering their inferred annual requirements, which is estimated to be approx. 145 tU. The utility states that "normally about one year's supply of new fuel is kept at the plant" [103]. Based on a CANDU 6 annual demand of approx. 75 tU, this would imply that the utility is holding a further years' worth of stock as a buffer.

(3) OPG held CAD $243 million worth of nuclear fuel inventory at the end of March 2024 [104], compared to a fuel expenditure of CAD $269 million. In their 2020 Uranium Procurement Plan [105], OPG's Target Inventory Policy stated an intent to hold a minimum strategic and working inventory of 288 tU as U_3O_8. In addition, OPG seeks to maintain individual inventories at each downstream stage of its fuel supply chain:

- An inventory of finished fuel bundles equivalent to 12 months expected forward usage to allow continued refuelling (approx. 750 tU);
- A working inventory of three months' supply of UO_2 to feed the manufacturing process (approx. 188 tU);
- Their uranium conversion supplier is also contractually required to maintain an inventory of UO_2 for OPG's use in the event of any supply interruption.

On the basis of the minimum inventories outlined above, as assuming that OPG's additional inventories are currently held as fabricated fuel, this would equate to approx. 470 tU. Life extension/refurbishment work at the Darlington and Pickering units has added to both fuel procurements and inventory requirements, in particular due to a reversal of the closure policy for Pickering units 5–8 that was due to be enacted in 2024. Upon restart, each unit receives a full core of fresh fuel (approx. 85–120 tU depending upon the CANDU reactor design), which has temporarily lifted inventory levels. However, OPG is likely to retain its target 288 tU minimum after 2026, rather than action the previously planned reduction to 225 tU.

From aggregating the utility financial statements, the utility inventory position is considered to be in excess of 1 220 tU in fabricated bundles, which represents approximately 11 months of fuel. These quantities are required to ensure continuous refuelling.

9.3.2. Mexico

The nuclear operator, Comisión Federal de Electricidad (CFE) Mexico, buys finished fuel for the two Laguna Verde units from GNF-A [106] in the USA and procures EUP by public tender. Most recently Nukem/Cameco (brokering on behalf of Russia's TENEX) combined to win the contract for EUP supply to the two BWR units between April 2022 and June 2025. Notwithstanding independent procurement, GNF-A is contractually bound to guarantee EUP supply if there is a failure of CFE's own supplier or a tender collapse. Presumably this backup gives CFE a degree of comfort and security of supply, protecting against the length of the international supply chain for its nuclear fuel.

As of 31 December 2023, CFE held nuclear fuel in inventories valued at Ps 2.99 billion (US $169 million) at Laguna Verde [107]. This financial value has been as high as Ps 4.2 billion during the last 10 years. It is assumed to include in-core inventories of unburned fuel[29], the former representing approx. Ps 2.2 billion. This leaves Ps 817 million equating to approx. 30 tU as fresh fabricated fuel. On that basis, the nuclear fuel inventories are assumed to be limited to the next planned reload, with CFE potentially relying on JIT deliveries by GNF-A.

9.3.3. United States of America

Utilities in the USA buy all of their fabricated fuel from one or more of the domestic fuel fabrication suppliers (i.e. Framatome in Richland, GNF-A in Wilmington or Westinghouse in Columbia). A significant proportion of their enriched uranium needs are also covered by supplies from Urenco's Louisiana Energy Services (LES) enrichment plant in Eunice, New Mexico, as are the necessary supplies of UF_6 from ConverDyn/Honeywell in Metropolis, Illinois. Consequently, the downstream segments of the nuclear fuel supply chain inventories are largely conducted within the USA. However, supplies of mined uranium are almost entirely sourced from outside of the USA, due to limited domestic production capacity.

The collective ownership of front end inventories is tracked and reported on by the United States Energy Information Administration (EIA) in its Uranium Marketing Annual Report [108]. Data from the EIA includes utility fuel intended for the upcoming reloads of the US commercial nuclear fleet and WIP for the primary suppliers. Therefore, it potentially represents an inflated view of the US nuclear fuel inventories. For the end of 2023, the inventory quantities provisionally reported were as follows:

[29] Each core takes approx. 81tU and CFE typically refuels 25–30% of the core

Owned by operators of nuclear power plants[30]:

- U_3O_8 21.1 mlbs U_3O_8 = 8 060 tUe (US $0.8 billion)
- UF_6 30.9 mlbs U_3O_8e = 11 840 tUe (US $1.4 billion)
- EUP 53.0 mlbs U_3O_8e = 20 290 tUe = 2 450 tU as EUP[31] (US $4.6 billion)
- Fabricated fuel 5.0 mlbs U_3O_8e = 1 920 tUe = 230 tU as EUP[32] (US $0.5 billion)
- Total 110.0 mlbs U_3O_8e = 42 099 tUe (US $7.3 billion)

Owned by suppliers and traders:

- U_3O_8 36.0 mlbs U_3O_8 = 13 770 tUe (US $1.4 billion)
- UF_6 and EUP 6.1 mlbs U_3O_8e = 2 330 tUe

Assuming that the latter category is split equally, this would equate to 1 170 tU as UF_6 and 140 tU as EUP[33] (valued at US $140 million and US $260 million respectively).

When compared to annual demand for each component in the USA (approximately 16 810 tU of natural uranium and 2 030 tU as EUP), EIA data demonstrates that utilities have 14 months of uranium inventories and EUP in all forms. Meanwhile, suppliers may have 10–11 months of uranium and approximately one month's worth of EUP on hand. Given that the combined supply chain would normally hold 12 months requirements at each stage of the cycle (concentrates/conversion, enrichment and fabrication), then the above data indicates that little is held by way of excess. The fact that US suppliers also export to international clients may further highlight the limitations of available material.

This outcome is further emphasized by individual utility financial data. However, such data sources rarely reference distinct strategic inventories and instead often capitalizes nuclear fuel investments as plant assets 'in core'. Where nuclear fuel inventories are separately reported, quantities tend to equate to annual demand in the same way as EIA data. For instance, the largest US nuclear operator Constellation (representing more than 20% of the US nuclear fleet) reports in its 2023 10-K filings report:

- At the end of 2023, Constellation had US $5.503 billion in nuclear fuel assets, of which US $2.484 billion were amortised (i.e. partly burned or spent fuel).
- Additionally, US $1.265 billion was stated to be in the form of fresh fuel or at the processing stage.
- Therefore, US $4.238 billion of fuel was in reactor cores, of which 59% is amortized.

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30 EIA reports in millions lbs (mlbs) or uranium as U_3O_8. Values expressed are at average reported EIA prices for U_3O_8 and SWU over the last 10-years (US$116.13/SWU; US$39.83/lbU_3O_8)

31 Evaluated at average assays of 4.43wt% ^{235}U for product and 0.2073wt%^{235}U for tails material (implied by EIA data)

32 Using the average assays quoted above

33 Using the average assays quoted above

Assuming that volume is proportionate to value, about 20–25% of the total volume of fuel necessary is held as WIP or finished fresh fuel. Based on approx. 2 480 tU in reactor cores at Constellation's plants (including the newly acquired South Texas Project units), at an average cost of approx. US $1 750 /kgU as fabricated fuel can be extrapolated. This implies that with US $1.265 billion in fresh fuel/components, then a minimum of approx. 730 tU of nuclear fuel is available to Constellation in its front end supply chain, which equates to about 140% of their average annual fuel requirements. Therefore, strategic stocks may be embedded in the supply chain, but are chiefly dedicated to near-term requirements. From evidence gathered from all but one of the US utility 10-K filings and further breakdowns provided in Federal Energy Regulatory Commission (FERC) submissions, this situation does not appear unusual with only 22% of the declared inventory values designated as true stock rather than WIP.

A second example is TVA. The utility only states amortized fuel inventories and annual purchases of US $1.364 billion and US $291 million during 2023 respectively. However, with TVA fleet cores containing approx. 760 tU as EUP and based on a generic residual value of US $900 /kgU, partly burned fuel would only equate to approx. US $685 million, leaving US $679 million for inventories as WIP and strategic stocks. Such inventories will include pipeline fuel costing on average approx. US $350 million/a plus inventories of approx. US $330 million. The latter amount is close to TVA's declared fuel inventories (all types) of US $354 million and could in part equate to expenditures towards down-blending under the US DOE's tritium programme. The creation of a 10 reload reserve of EUP for TPBAR[34] fuelling under the Down Blending Offering for Tritium (DBOT) programme was slated to cost US $770 million value and run between 2019 and June 2027 [109][35].

Based on the above and further investigation into FERC records, the US utilities hold material estimated to be worth US $7.5 billion, a figure comparable to the values extrapolated for the above EIA quantities. Companies known to hold meaningful inventories include:

- Dominion/SCE&G (residual from surplus Summer units 2 and 3 first cores being directed to Summer unit 1 and a contingency reserve [110]);
- Energy Northwest (from US DOE tails upgrading and discretionary purchases);
- Southern Company (Alabama Power and Georgia Power) which during 2023 included the Vogtle unit 4 first core;
- TVA that manages US DOE's down-blending and tails upgrading materials, largely to feed the US DOE/NNSA tritium production programme (as noted above);
- Evergy Kansas Central (Wolf Creek Nuclear Operating Company);
- Xcel (Northern States Power).

Evidently, the status of most of these stocks is well-defined in terms of end use. As a consequence, much of the US fleet is apparently relying on the proximity of the fabrication supply chain to ensure deliveries, despite that supply chain itself having little in the way of commercial buffer stocks to mitigate upstream supply disruptions.

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[34] Tritium Producing Burnable Absorber Rods

[35] Two further years were added to the contract in February 2024 (https://www.bwxt.com/news/2024/02/14/BWXT-Subsidiary-Awarded-122-Million-Contract-Extension-for-Uranium-Downblending-Services)

To summarize the overall market positions in the region: Canada's three operators appear to apply a mixed regime of long lead times/supply chain assurances together with prescribed inventory and buffer stock policies to fuel the fleet of CANDU units. Meanwhile, the 20 utilities in the USA typically have their next reload in EUP or UO_2/fabricated form plus the requisite amount of feed to support the next year's delivery. However, truly strategic physical stockpiles are almost non-existent. Where held, there are concentrated in a small number of utilities, few of which appear to follow an espoused strategic holdings policy. The remaining utilities have diversified their contracting to limit any single disruption event, but otherwise would look to the US DOE-funded reserves (see Section 9.4.2) to mitigate shortfalls. Similarly, Mexico's national operator largely relies on the proximity of the supply chain in the USA and its commercial guarantees, plus access to an open commodities market to ensure the regularity of fuel supplies.

Figure 13 summarizes North American utility uranic inventories by form.

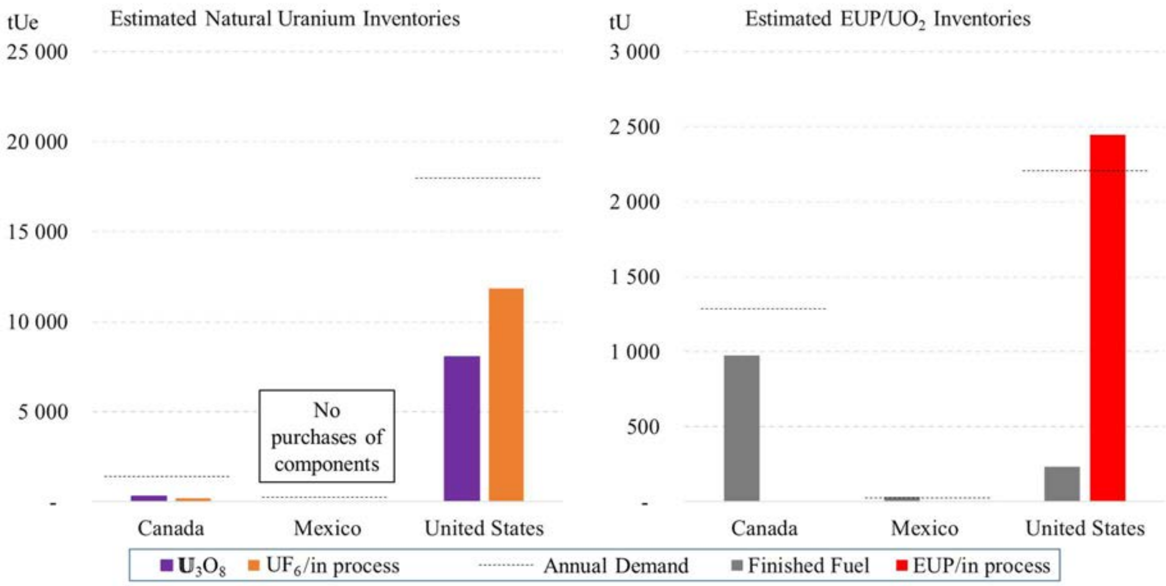

FIG. 13. North American utility inventories by form.

Changes since 2021 are largely confined to increased enriched uranium holdings by utilities in the USA, with a commensurate fall in fabricated fuel inventories. Both may simply be a reflection of cyclical demand, which is driven by utilities operating on 18 and 24 month cycles.

9.4. MAJOR LOCAL SUPPLIER AND TRADER INVENTORY POLICIES AND STATUS

9.4.1. Canada

BWXT Peterborough is dedicated to PHWR fuel supply for OPG [111]. It does not make any public statements on its uranic inventories, but is presumed that they comply with OPG's requirement to hold WIP and buffer quantities to manufacture the fuel to reload the Darlington and Pickering reactors.

At Cameco's mines and conversion facilities, utility and other supplier inventory mainly constitutes WIP. These quantities are routinely destined for other conversion and/or enrichment facilities, with Cameco only holding a minor strategic inventory that is not available to the market. This quantity is presumably included in the 10.3 mlbs U_3O_8e (approx. 3 940 tUe) stated as inventory in its 2023 annual accounts [8]. Most is held as U_3O_8 (CAD $512 million), with a minority as processing material for the fuel services segment (CAD $109 million) which is assumed to be 80:20 weighted towards uranium conversion inventories.

Denison Mines reportedly holds 2.3 mlbs U_3O_8 of physical uranium in North American storage facilities as a long term investment expected to enhance access to future project financing for Wheeler River [112]. In addition, modest amounts of U_3O_8 and mill WIP are recorded in the annual accounts (approx. CAD $3.9 million).

By 2023, SPUT had accumulated purchases U_3O_8 amounting to approx. 63.2 mlbs U_3O_8 (approx. 24 170tU). They remain a significant purchaser of U_3O_8 inventories on the spot market. However, their prospectus states that there is no redemption of trust units, which renders this a source of secondary supply relatively illiquid [113].

Uranium Royalty Corp. (URC) is similarly investing in physical uranium assets. As of 31 January 2024 [114], URC had accumulated 2.5 mlbs U_3O_8e (approx. 960 tU), worth CAD$180 million.

9.4.2. United States of America

It is believed that ConverDyn, Framatome, GNF-A, Urenco LES and Westinghouse all hold limited stocks beyond operational WIP. Westinghouse holds US $141 million of uranium stocks in current and non-current inventories [115] and LES declares US $13 million as raw materials and US $79 million as SWU in EUP [116]. Otherwise, none of the above declare their stocks in publicly available financial filings and are instead consolidated into parent entity accounts.

The five domestic miners[36] with public declarations have confirmed inventories as U_3O_8 totalling US $117 million. One broker, Centrus Energy, makes limited statements about its inventories, which totalled US $22 million as SWU (approx. 600 tSWe) and US $200 million as feed/uranium (approx. 1 000 tU) at the end of 2023 [117]. EIA data is presumed to include all available American inventories held by suppliers, brokers and traders.

Meanwhile, DOE-related stocks amount to significant holdings of EUP and UF_6. However, while primary suppliers have access to inventories linked to Federal stockpiles, they are not reported in the EIA data. These programmes include:

- USA Assured Fuel Supply (230 tU as EUP);
- MOX Backup (173 tU as EUP);
- Surplus and National Security HEU to the DBOT programme (270 tU as EUP out of a possible 500 tU was assumed to have been generated at the end of 2023) [118];
- DOE surplus uranium disposition barters (3 400 tU as UF_6, with release dependent upon Secretarial Determinations);
- ‘Strategic Uranium Reserve’ purchases of up to 1 mlbs U_3O_8 from US-mined origins [119], plus conversion services [120];
- Further stocks exist, but in increasingly inaccessible forms, such as the redundant fresh fuel from the DOE’s N-reactor programme (946 tUe).

[36] enCore energy, Energy Fuels, Peninsula, UEC and Ur-Energy

In total, the Federal EUP stockpiles that are accessible on extended lead times could backstop approximately one third of US demand for one year, albeit subject to call-off constraints and other commercial terms. Further moves by the US government to boost the 'Strategic Uranium Reserve', plus LEU and HALEU stockpiles are ongoing under tenders in 2023.

Figure 14 summarizes North American supplier uranic inventories by form.

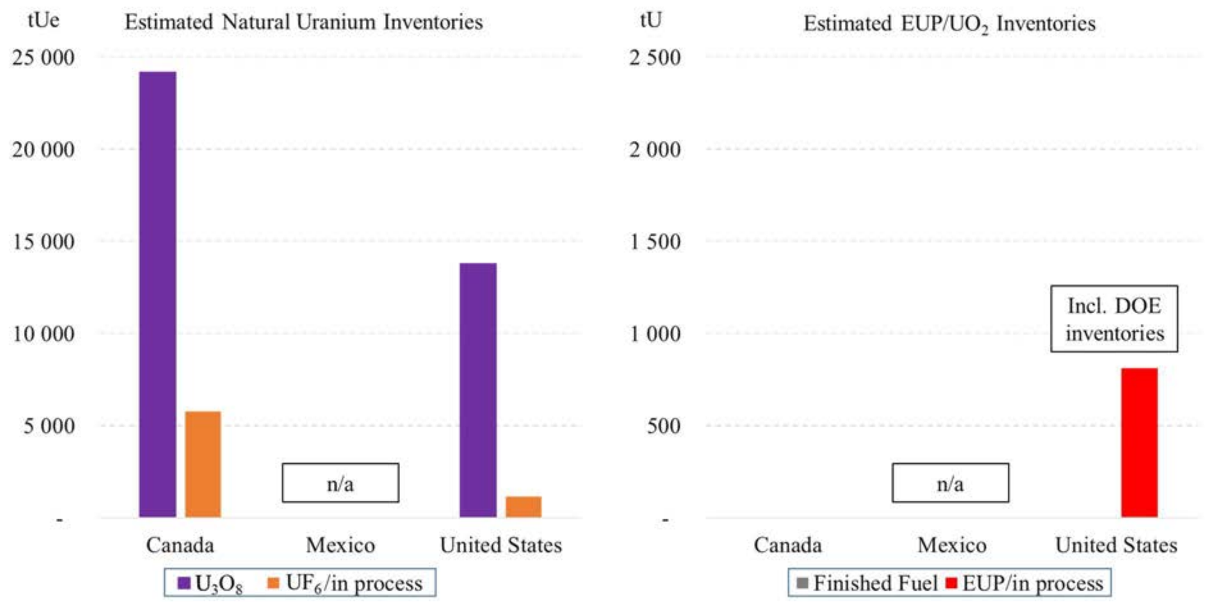

FIG. 14. North American supplier inventories by form (n/a=not applicable).

Significant purchases of uranium inventories by financial institutions have driven up Canadian U_3O_8 holdings by over 9 000 tU since 2021. This trend has been accelerated by the entry of Uranium Royalty Corporation into the market that timeframe. Meanwhile, according to EIA, utility stocks of UF_6 in the USA have declined. While U_3O_8 stocks have risen by a modest amount to compensate, it is evident that there is a greater risk posed by a lack of Western conversion services compared to 2021. The concentration of inventories at the lowest level in the value chain is therefore doing little to improve the security of supply for LWR operators.

9.5. NORTH AMERICAN INVENTORY LIQUIDITY AND MOBILITY

9.5.1. Canada

Neither the Canadian government nor local utilities could be regarded as a notable source of secondary supply to the market. The utilities tend to their own requirements with stocks to ensure continued operation, so are essentially immobile and illiquid.

Cameco's fuel service facilities host third-party uranium accounts that could be liquidated, but only to the extent that surpluses exist and there is a willingness to trade these quantities. Meanwhile, BWXT's output is dedicated to the particular customers in the domestic market. The impact of Sprott and URC on a thinly traded market has been noticeable, taking up surplus production into a relatively inaccessible repository. Therefore, any secondary supplies in Canada is considered largely immobile for utilities, suppliers and financial institutions alike.

9.5.2. Mexico

Based on the available evidence, any nuclear fuel held by CFE is assumed to be a minimal strategic buffer stock of spare assemblies, specifically designed for the Laguna Verde BWRs and therefore not readily transferable or commercially liquid.

9.5.3. United States of America

Domestic utilities are mostly operating under a JIT regime for nuclear fuel supply, buffered by contract diversification and commercial lead times. It appears that local fuel cycle suppliers have little in the way of surplus/strategic inventories to go beyond providing a short term buffer to these domestic utilities in the event of a supply disruption. That said, both parties have the logistical opportunity to make liquid large amounts of Japanese inventory that reside in the USA (also see Section 11). This may be bolstered by federal agency stocks, but these are not immediately liquid due to commercial constraints. Irrespective of these limitations, they have the ability to mitigate a limited and predictable supply disruption with at least one year's notice.

10. REGIONAL REPORT: SOUTH AMERICA

10.1. OVERVIEW OF SOUTH AMERICA

- The South American region exhibits a localization of the nuclear fuel industry (i.e. deconversion/fabrication), such that the supply chain is in effect vertically integrated with the domestic utility in both countries.
- Upstream demands for uranium, conversion and most of the required enrichment are imported into South America, increasing the need for WIP and some buffer stocks.
- Fuel cycle suppliers and utilities reporting on inventories overlap to some degree and so have been evaluated on that basis in an attempt to avoid double-counting volumes.
- As of 31 December 2023, total uranic inventories within South America (including pipeline/WIP material) were valued at some US $599 million, as detailed in Table 11.
- Argentinian inventories are estimated to average the amounts required for annual nuclear fuel production at each component stage (i.e. largely signifying JIT procurement).
- Brazilian inventories are estimated to equate to up to two years' worth of the components required for annual nuclear fuel production, so point to some strategic holdings in excess of nation policy requirements and working inventory. Also, military propulsion and research unit offtake in Brazil may have led to non-civil inventories, although these are beyond the scope of this publication.

Given that the South American market is relatively small, modest changes in inventory levels have the potential to translate into large proportional swings. On that basis, comparisons with 2021 levels of inventories need to be contextualized beyond the reporting of simple changes. Reported values have grown 23% over the last two years, although some of that change may be due the difficulty in interpreting the recent currency depreciation in Argentina. In contrast, enriched uranium inventories held as EUP or fabricated fuel were relatively static and reflect the predictable progress of working inventories. The drop in natural uranium volumes may also be related to cyclical factors, particularly with the execution of new uranium contracts in Argentina.

TABLE 11. SUMMARY OF SOUTH AMERICAN INVENTORY STATISTICS

Country	Nuclear entities reviewed	Value of inventories (US $ millions)	Value of inventories: Reported (R) or estimated (E)	Estimated volumes (tU)	Assessed material form [a]
Argentina	1 utility/supplier	32	R	213	U_3O_8
		49		203	Nat UO_2
		70		168	Fabricated fuel
	1 supplier [b]	10	R	57	U_3O_8
		14		67	Nat UO_2
Brazil	1 supplier	24	R	252	U_3O_8
		139		53	EUP/UO_2
		36		11	Fabricated fuel
	1 utility	225	R	68	Fabricated fuel
Totals	All	599		792	tU Natural uranium
				53	tU as EUP/enriched UO_2
				247	tU as UO_2 (Fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated
[b] Financial data as of 31 December 2022

10.2. BACKGROUND FOR SOUTH AMERICA

The South American region consists of only two commercial nuclear power countries; Argentina and Brazil. As of 31 December 2023, the region's operators had approx. 3.5 GWe (net) of nuclear power in service.

Total demand for nuclear fuel products in 2023 was estimated to total 508 tU as U_3O_8, 339 tU as UF_6, 70 tU as EUP and 202 tU as UO_2 in fabricated fuel, as summarized in Table 12.

TABLE 12. SOUTH AMERICAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

Country	NPPs (operating or in temporary shutdown + under construction) and generating capacity [a]	Estimated annual demand in 2023 [b] (tU)	Fuel cycle component (tU as)
Argentina	3 PHWR; 1 641MWe (net)	169	U_3O_8
		30	Slightly Enriched Uranium
		162	Fabricated fuel
Brazil	2 PWRs (+1);	339	U_3O_8/UF_6
	1 884MWe (net)	40	EUP/fabricated fuel

[a] IAEA PRIS database.

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

10.3. LOCAL INVENTORY POLICY AND STATUS

Both Argentina and Brazil have pursued policies of relative self-sufficiency for their respective nuclear fuel needs. This includes localized deconversion and fabrication in Argentina operated by DIOXITEK and CONUAR respectively and uranium mining, enrichment, deconversion and fabrication operated by Industrias Nucleares do Brasil (INB) in Brazil. These organizations have a symbiotic dependency with their local national nuclear utility, but also engage in sales between the respective markets as well as some military offtake from INB in Brazil.

Irrespective of localization, both countries rely heavily on imports of uranic material in various forms (natural uranium, SEU and EUP) to meet their domestic needs. DIOXITEK, CONUAR and INB regularly tender for international supplies of U_3O_8, UF_6 and uranium enrichment. This lengthens the processing times for each fuel reload and necessitates a commercial policy of inventory management to ensure the timely delivery of nuclear fuel to the power stations.

Figure 15 summarizes the estimates for South American uranic inventories by form.

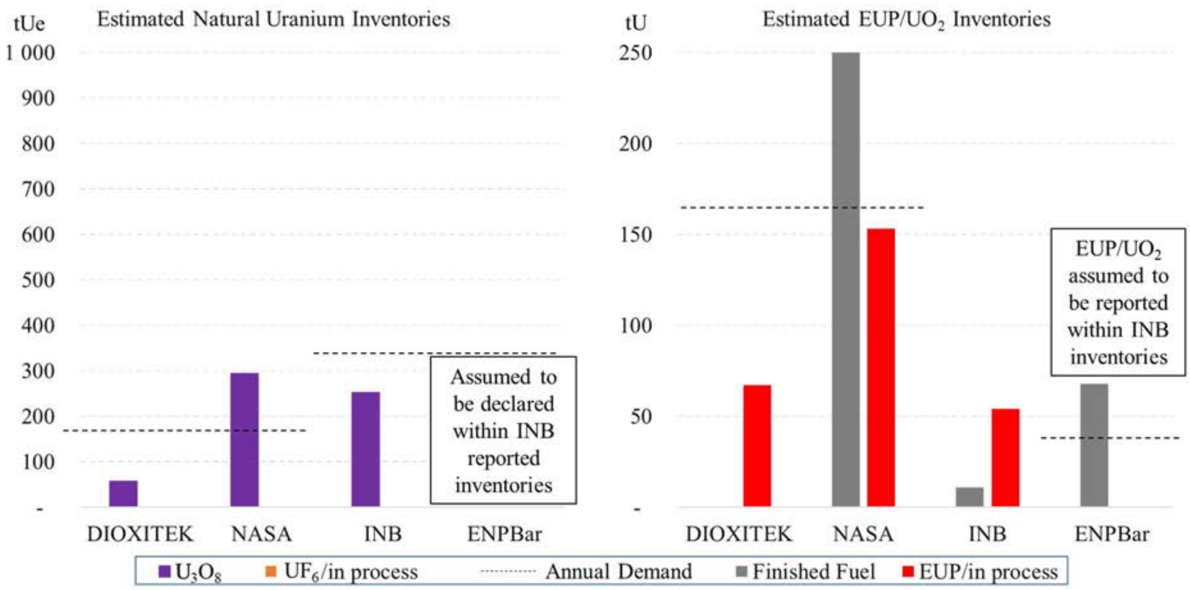

FIG. 15. South American uranic inventories by form.

10.3.1. Argentina

Nucleoeléctrica Argentina S.A. (NASA) [121] and DIOXITEK [122] report holding natural uranium, UO_2 and also finished fabricated fuel to ensure supply of approx. 200 tU of nuclear fuel every year. Pipeline/in process inventories have increased since 2021, after reducing in 2020 due to some drawdown of surplus stocks by DIOXITEK. At the end of 2022/23 these totalled 7–8 months' worth of stocks at different stages of the fuel cycle (approx. 440 tU divided equally between as U_3O_8 or UO_2). Also, DIOXITEK has engaged in refeeding scrap material (as it did in 2023). However, other than WIP, NASA has no distinct holdings of dedicated buffer stocks or strategic inventories of fabricated fuel.

10.3.2. Brazil

Management of nuclear material inventories in Brazil has recently been assumed by the Brazilian National Nuclear Security Authority from the Brazilian National Nuclear Energy Commission. Under that governance structure, INB has an obligation to maintain a minimum stockpile of enriched uranium and also holds uranium inventories, which tend to vary with the Caetité mine output. Electronuclear also declares a mix of inventories [123], which are believed to overlap with INB's statements [124]. These inventories include 252 tU as U_3O_8, 53 tU of enriched materials as WIP and 79 tU as finished fuel. These quantities equate to 1–2 years of stocks at each fuel cycle stage. Within the finished fuel category, the pre-fabrication of Angra Unit 3 fuel in anticipation of commercial operation has led to a quantity of surplus material that is available for units 1 and 2. This has proved opportune, given the recent fuel oxidization issues suffered by Angra Unit 2 fuel that meant early replacement of part-burned fuel.

10.4. SOUTH AMERICAN INVENTORY LIQUIDITY AND MOBILITY

Localized processing of uranium dedicated to in-country demand has provided reasonable assurances to both NASA and Electrobras in terms of security of supply for their ongoing nuclear fuel needs. As finished fuel and WIP is exclusively for domestic use, the ability of the end user to treat the inventories as liquid or commercially mobile is currently limited to trades between Brazil and Argentina. Consequently, the stocks held in both countries are not considered to be available to the global market.

11. REGIONAL REPORT: SOUTH AND EAST ASIA

11.1. OVERVIEW OF SOUTH AND EAST ASIA

- South and East Asia is seeing positive developments for nuclear power, with installed capacity growth in Bangladesh, China and India plus the reversal of a phase-out policy in the Republic of Korea. Consequently, the reduction in nuclear capacity seen in Japan and Taiwan, China since 2010 has been more than offset.
- Generally, a conservative approach has been taken to ensuring security of supply, either through asset ownership or supply chain management. In particular, localization of fabrication and enrichment technologies and the ownership/acquisition of foreign front end suppliers compensates for a lack of domestic uranium resources in the region.
- Prescribed stock policies and/or strategic inventory levels vary. Current inventories held by utilities and fuel cycle entities in the region are the highest globally. Significant accumulations have taken place over the last decade, although some were unintended.
- Over-purchases resulting from operating suspensions and local shutdowns/phase-outs led to a drawdown of uranic inventories in the Republic of Korea, Japan and Taiwan, China. Any third-party resales are governed by market conditions and regulatory constraints. Meanwhile, China and India continue to bolster their sizeable reserves.
- As of 31 December 2023, total inventories within South and East Asia (including pipeline material and some reprocessed material) are valued at some US $43 billion, as detailed in Table 13.
- Major strategic inventories are held in India, the Peoples Republic of China and the Republic of Korea in support of growing nuclear fleets.
- Surpluses of material across the front end are owned by Japanese and Taiwanese entities. In the case of Japan, these may be inflated due to the inclusion of reprocessed fuels, but irrespective they represent a potential overhang to the market that cannot readily be consumed despite planned unit restarts.
- The liquidity and mobility of the Japanese inventories is governed not only by location but also by commercial constraints. Therefore, resale may be considered as a last resort, particularly in the face of geopolitical and market uncertainty as well as the Japanese government’s recommitment to nuclear power.

TABLE 13. SUMMARY OF SOUTH AND EAST ASIAN INVENTORY STATISTICS

Country	Nuclear entities reviewed	Value of inventories		Estimated volumes (tU)	Assessed material form [a]
		(US $ millions)	Reported (R) or estimated (E)		
Bangladesh	1 utility	139	R	79	Fabricated fuel
Peoples Republic of China	3 utilities [b]	2 688	R	1 470	Fabricated fuel
	2 suppliers	18 463	E	141 512	U_3O_8
				2 833	EUP
India	1 utility/supplier	940	R/E	13 347	U_3O_8 and UO_2
		61		41	EUP
		89	E	61	Fabricated fuel
	1 supplier	8	R	109	U_3O_8
Japan	11 utilities	17 209	R [c]	45 266	U_3O_8 and UF_6
				2 412	EUP
				1 792	Fabricated fuel
	4 suppliers	84	E	532	UF_6
Republic of Korea	1 utility	2 058	R	9 128	U_3O_8
				912	EUP
				347	Fabricated fuel
	1 supplier	257	R	176	U_3O_8
				91	EUP/ Enriched UO_2
				38	Fabricated fuel
China [d]	1 utility	576	R/E	2 551	UF_6
				347	Fabricated fuel
Totals	All	42 572		211 624	tU Natural uranium
				6 289	tU as EUP/enriched UO_2
				4 134	tU as UO_2 (fabricated fuel)

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

[c] Values likely to include reprocessed materials

[d] Taiwan

Since 2021, physical inventories of upstream (natural and enriched) uranium have grown, in part due to drawdowns from fabricated fuel stockpiles and in anticipation of ongoing demand from newly commissioned reactors. Geopolitical events have also played a part, with OECD members bolstering their energy security and husbandry of resources, while exporting BRICS countries have taken advantage of the bifurcated market trends to build working stockpiles at attractive economic terms. These factors appear to have led to a decrease in the value of overall inventory holding, albeit by a modest 5%.

11.2. BACKGROUND TO SOUTH AND EAST ASIA

The South and East Asia region consists of six commercial nuclear power countries: Bangladesh, India, Peoples Republic of China, Japan, Republic of Korea and Taiwan, China. As of 31 December 2023 the region operators had approx. 120 GWe (net) of nuclear power in service.

Total demand for nuclear fuel products in 2023 was estimated to total 20 834 tU as U_3O_8, 119 788 tU as UF_6, 1 902 tU as EUP and 2 545 tU as UO_2 in fabricated fuel as summarized in Table 14.

TABLE 14. SOUTH AND EAST ASIAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

Country	**NPPs** (operating or in temporary shutdown, and under construction) **and generating capacity** [a]	**Estimated annual demand in 2023** [b] **(tU)**	**Fuel cycle component (tU as)**
Bangladesh	+2 VVER1200	371	U_3O_8/UF_6
	n/a	0	EUP/Fabricated fuel
China	+2 FBR/1 HTGR/48+23 PWRs/2 PHWRs/4+4 VVERs	11 303	U_3O_8
		11 118	UF_6
	53 202 MWe (net)	1 144	EUP
		1 329	Fabricated fuel
India	2 BWRs/20+3 PHWRs/ 2+4 VVER-1000s/+1 FBR;	1 408	U_3O_8/UO_2
		804	UF_6
	6 920 MWe (net)	50	EUP
		650	Fabricated fuel
Japan	17+2 BWRs/16 PWRs	3 343	U_3O_8/UF_6
	31 710 MWe (Net)	367	EUP/fabricated fuel
Republic of Korea	23+2 PWRs/3 PHWRs;	4 105	U_3O_8/UO_2
	25 825 MWe (net)	3 848	UF_6
		304	EUP
		529	Fabricated fuel
Taiwan, China	2 PWRs	304	U_3O_8/UF_6
	1 874 MWe (net)	57	EUP/fabricated fuel

[a] IAEA PRIS database.

[b] WNA 2023 Nuclear Fuel Report or domestically reported quantities

Given the symbiotic relationships between many of the respective utilities and their domestic fuel cycle suppliers, where appropriate the two sectors have been considered from an integrated point of view in the following sections.

11.3. LOCAL INVENTORY POLICIES AND STATUS

11.3.1. Bangladesh

Construction of the first of two VVER-1200 units at Rooppur by Nuclear Power Plant Company Bangladesh Limited is nearing completion. Under the related fuel contract signed in 2019, the first core for Rooppur Unit 1 was delivered by TVEL in September and October 2023, comprising 168 assemblies and 79 tU. The value of the first core is reported to be US $139 million. As of 31 December 2023 the material was in storage on site awaiting the start of commissioning work in late 2024 or early 2025. Similar advanced deliveries of first core fuel will accompany the commissioning of the second unit at Rooppur. According to press statements [125] TVEL will provide the fuel for the plants till 2027 as part of the construction and commissioning. Supply guarantees from Russia are believed to be in place for the extended period of reactor operations.

11.3.2. China

The rapid growth of nuclear power in China has been accompanied by an increasingly mature domestic nuclear fuel industry, accompanied by a clear strategic policy towards security of supply. For the first time in 2007, the National Defence Science, Technology and Industry Commission announced that the 'Eleventh Five-Year Plan for the Development of the Nuclear Industry' will include the formation of a national strategic reserve and a commercial reserve system for natural uranium [126]. Consequently, each stage of the nuclear fuel cycle has attempted to establish an appropriate level of domestic self-sufficiency, while also engaging with the global industry of primary suppliers in uranium, conversion, enrichment and fabrication. This has ensured the coverage of existing needs, but is also directed at providing for suitable levels of WIP and strategic stockpiles under the guidance of China National Nuclear Corp./China Nuclear Energy Industry Corp. (CNNC/CNEIC) and the Chinese nuclear utilities (China Nuclear Power Co. Ltd. (CNP), China General Nuclear Power Co. Ltd. (CGN) and the State Power Investment Corp. Ltd. (SPIC).

The key element for the domestic nuclear fuel supply chain for China is access to natural uranium. Chinese mines have limited reserves, so the international market has been a focus of Chinese investments and contracting, particularly in Africa and Kazakhstan. The importation of material has exceeded the ability of the domestic conversion industry at Hengyang and Diwopu to process the material into UF_6, so national stockpiles have emerged in the form of U_3O_8, primarily stored at the conversion plants. China's National Science and Technology Commission was understood to have begun stockpiling strategic uranium inventories in 2007 [127] and by 2015 levels of 85 000 tUe were believed to have been accumulated [128]. By 2023, these levels were estimated to have grown to more than 137 600 tUe, as shown below, which is equivalent to more than 12 years of current demand. Chinese sources have indicated that the level of inventories will need to reach to 250 000 tUe to support the country's growth of nuclear power.

Figure 16 provides estimates of Chinese inventories of U_3O_8 from 2007 to 2023.

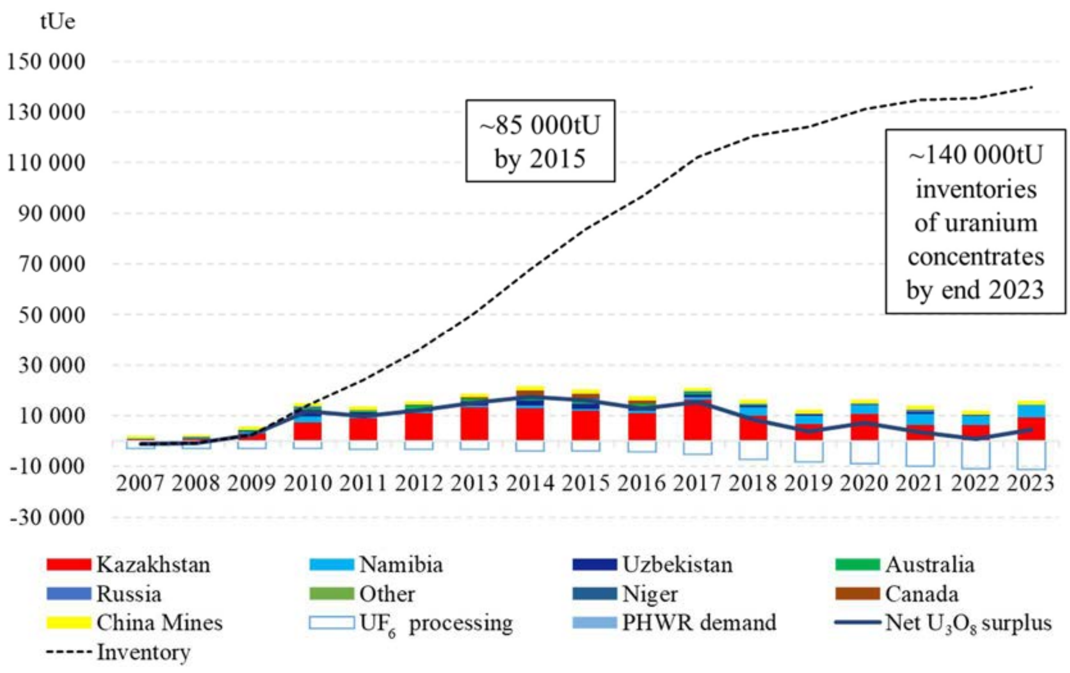

FIG. 16. Estimates of Chinese domestic inventories of U_3O_8.

In addition, both CGN Mining Company Limited and China National Uranium Corporation declare inventories for African mining operations, which as of the end of 2023 amounted to approx. US $90 million each. These holdings outside of China could well mean that Chinese inventories are closer to 140 000 tUe.

In terms of EUP, initial strategic inventories were believed to have already been in place before 2010 to guarantee supplies to the existing nine LWRs. This stock is estimated to be approx. 750 tU as EUP (five years of forward demand in 2010), as shown in Fig. 17.

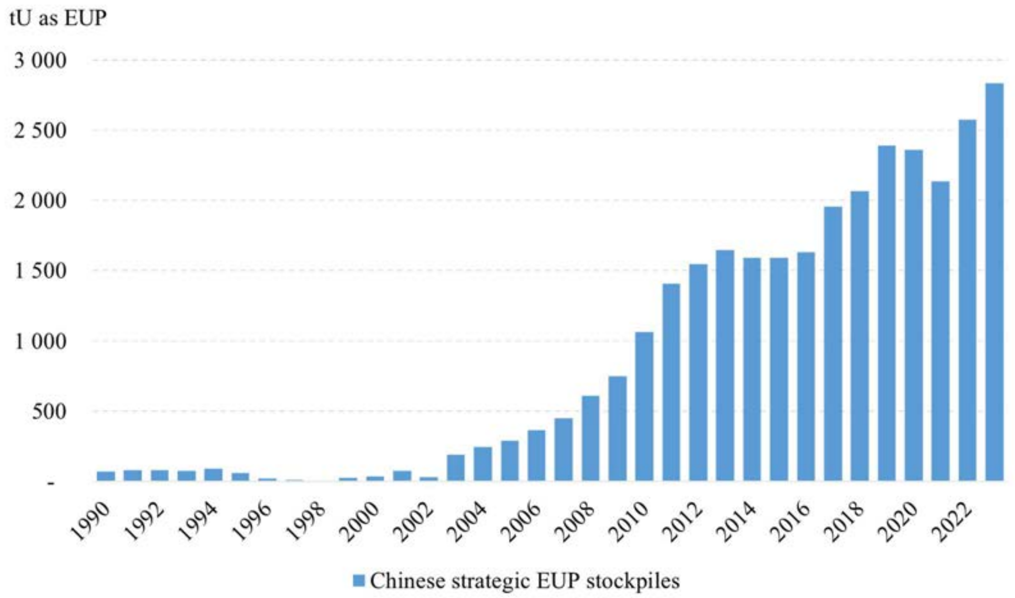

FIG. 17. Estimates of Chinese inventories of EUP since 1990.

Since then, China has continued to be a net importer of EUP and fabricated fuel to supplement its domestic enrichment capacity, as shown in Fig. 18.

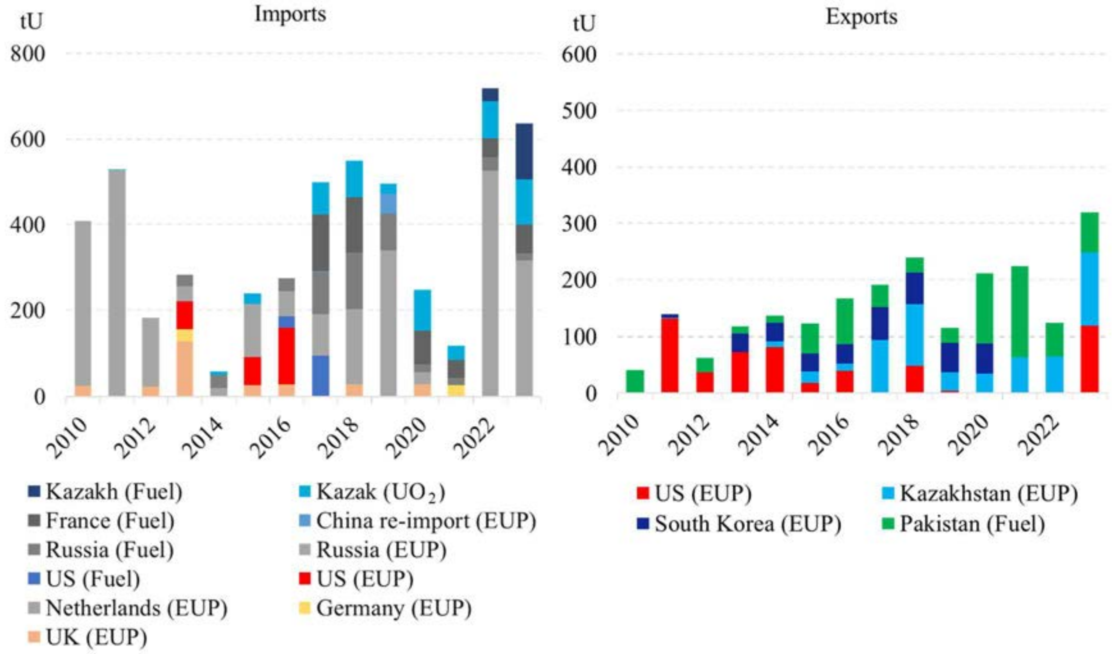

FIG. 18. Chinese trade in EUP, UO_2 and fabricated fuel.

These net imports alongside domestic production has generated a cumulative surplus of approx. 2 830 tU as EUP by the end of 2023 (equivalent to 250% of current domestic demand). However, this quantity represents only a fraction of what is needed to achieve the same level of strategic coverage that is targeted for natural uranium. Consequently, in 2021 there was a call from local enrichment industry management for action to increase the inventory quantities in China, in order to backstop the expansion of domestic processing capacity [129]. Significant deliveries from Russia in 2022 and 2023 may be part of that initiative, including material that is imported into China from Kazakhstan and the USA as fabricated fuel containing Russian EUP.

Insights into fabricated fuel stocks are provided by the two largest nuclear utilities, CNP and CGN. Each refers to inventories in their financial accounts, with CNP declaring ¥6.5 billion in nuclear fuel assets at the end of 2023 [130] and CGN's reporting nuclear fuel inventories of ¥12.5 billion (US $920 million and US $1.77 billion respectively) [131]. Assuming such inventories are held as fabricated fuel, they could equate to a minimum of 500 tU as EUP and 970 tU as EUP respectively. However, it is worth noting that first cores add disproportionately to reported inventory levels and also that one third of the first core is often retained as inventory under Chinese accounting rules throughout the first operating cycle. Therefore, and given current demand levels of approx. 550 tU of fuel for each utility, these quantities appear likely to be referring to immediate first core and reload demands, rather than a significant strategic inventory. Stocks may therefore be limited to small backup quantities to replace failed fuel at individual stations.

11.3.3. India

Historically, reactors operated by Nuclear Power Corporation of India Ltd (NPCIL) have experienced operational availability problems due a shortage of domestically mined uranium and a lack of access to international commercial markets. However, since 2008 when the Nuclear Suppliers Group lifted the sanctions imposed upon India, international suppliers have been able to conclude contracts with the Indian Department of Atomic Energy (DAE) and export uranium to the country's safeguarded reactor fleet. Consequently, uranium required for PHWRs under IAEA safeguards has been imported from Canada, France, Kazakhstan, and the Russian Federation. Additionally, the enriched fuel requirements of the Tarapur BWRs (currently suspended) and Kudankulam VVER1000s have been fulfilled through imports from Russia (as UO_2 pellets and fabricated fuel bundles respectively) in bulk shipments. According to India's government officials, the country has also entered into forward uranium purchase agreements with Canada, Kazakhstan, the Russian Federation and Uzbekistan. India's domestic uranium production is being carried out by the Uranium Corporation of India Limited, a public sector enterprise under the DAE. This material is used for the reactors that are not covered under the IAEA safeguards. Access to global markets has also allowed India to build buffer inventories for its reactors under the government's strategic policy to guarantee operational availability.

The Indian government planned to build on this strategic uranium reserve to ensure that there is no shortage of fuel for its expanding fleet. During the period 2010–2023, India imported approx. 20 000 tU and the cumulative inventory change is estimated to be approx. 14 300 tU. These estimates of annual and cumulative inventories of natural uranium in India account for domestic mining and imports of EUP, less the uranium consumed, and are shown in Fig. 19.

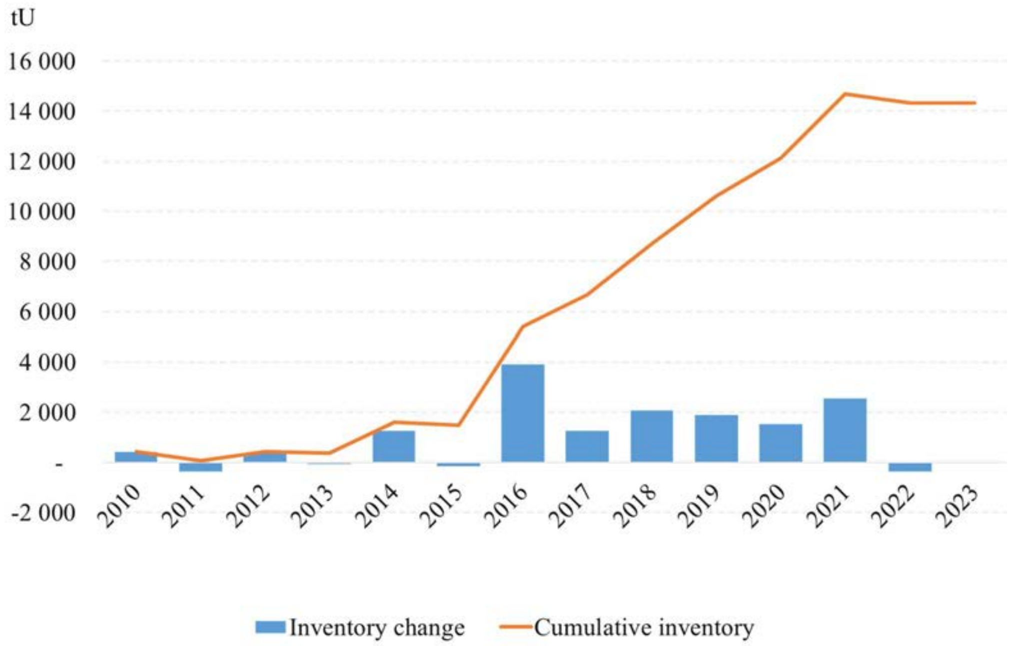

FIG. 19. Indian inventories of natural uranium.

This rise in inventory has largely occurred since 2015 and is in line with DAE targets to build a stockpile of approx. 15 000 tU to achieve supply security of fuel for its plants. NPCIL independently reports inventories of ₹20.8 billion, including approx. 41 tU as EUP for the Tarapur BWRs and 761 tU as natural UO_2 [132]. Uranium Corporation of India Limited (UCIL) is also understood to hold ₹631 million as working inventories [133]. Portions of both declared inventories are likely to be within the inventories accumulated by the DAE. Periodic imports of fabricated fuel for the Kudankulam VVER units are also recorded in customs data, with NPCIL holding three reloads in hand (61 tU as fabricated fuel) at the end of 2023.

11.3.4. Japan

Prior to the accident at the Fukushima Daiichi nuclear power plant, the Japanese government undertook the decision to sponsor the accumulation of a national inventory of 120 tU as enriched uranium for the purposes of contributing to the stable supply of international uranium fuel and domestic emergency measures [134]. Some 30 tU had been accumulated at Mitsubishi Nuclear Fuel Co., Ltd. by 2015, by which point the programme was curtailed to only 60 tU and its implementation suspended as the government had accepted that early restarts were unlikely and inventories were not an urgent priority [135].

The upstream security of supply still largely falls to the Japanese utilities. The Japanese nuclear fleet consists of both PWRs and BWRs, with all but one of the 11 utilities (i.e. JAPC) concentrating on one or other technology. This focus has led to very different inventory policies being pursued by the respective utility groupings; a distinction that has been highlighted by the accident at the Fukushima Daiichi nuclear power plant in 2011.

Following to the accident at the Fukushima Daiichi nuclear power plant and the subsequent stand-down of the entire fleet, domestic holdings of nuclear materials reached site operating limits at GNF-J, MNF and NFI very quickly as reactors stopped accepting fuel. Consequently, upstream international supply chains for uranium, conversion, enrichment and deconversion were also backed-up with partly processed material. For BWR utilities, the quantities affected were largely related to short to medium term deliveries, due to the necessity for relatively near-term planning for bespoke assay BWR reloads. Therefore, surplus inventories were initially low. Meanwhile, standardized assay reloads for PWRs allowed for a much longer supply chain (up to 4–5 years in advance of requirements), so volumes of material held up in the PWR utility's supply chain were high. That said, the suspensions and shutdowns enacted since the accident at the Fukushima Daiichi nuclear power plant have disproportionately impacted BWR utilities (particularly TEPCO and Tohoku), resulting in a large proportion of stranded material both inside and outside of Japan. The result is that the inventory values relative to the size of the Japanese fleet is increasing [136].

The Japanese Nuclear Regulatory Authority (NRA) and the Japanese Atomic Energy Commission safeguards declarations for nuclear material holdings inside Japan [137] provide an insight into the current domestic situation. Figure 20 shows that end users have dramatically slowed imports since 2010 to match reactor operating requirements and the inability to process material. The NRA data shows that the domestic fuel cycle inventories have remained steady at around 1 400 tU as EUP in WIP. Additionally, the remaining fleet of 33 operable reactors plus those undergoing decommissioning have stocks of fresh fuel equivalent to a further 1 750 tU as EUP, a figure that has dropped some 400 tU since 2021. This is in part due to approx. 226 tU in redundant fresh fabricated fuel being exported for processing (defabrication) and eventual reuse since 2012. When combined, these movements result in estimates equivalent to some 3 150 tU as EUP in various forms being held in Japan.

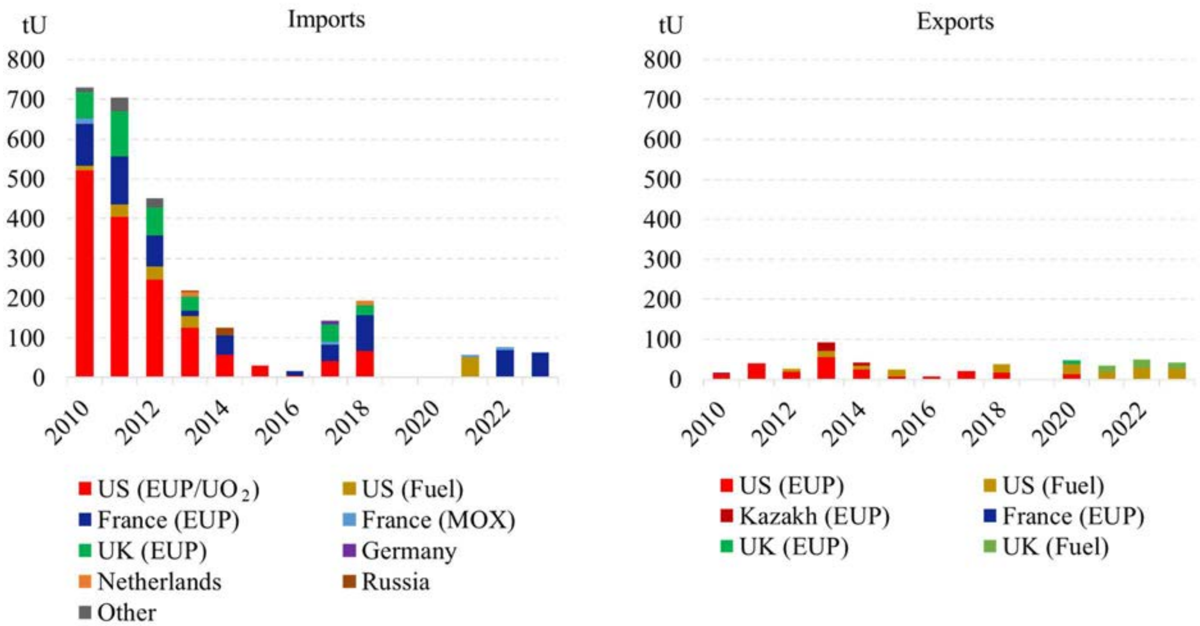

FIG. 20. Japanese trade flows in enriched uranium and MOX 2010–2023.

However, the above statements only reflects a proportion of the global inventories belonging to Japanese entities. Figure 21 demonstrates that in-process inventories remain high. Most utilities continued to add to front end inventories through 2015 due to contractual commitments. Much of the drop since then has been the result of asset write-downs as reactor retirements were announced. Buildups then continued, as few utilities were able to consume fuel due to limited restarts. Third-party sales have occurred [138], but for many they were effectively precluded due to the potential for a recognition of book losses on low mark-to-market values.

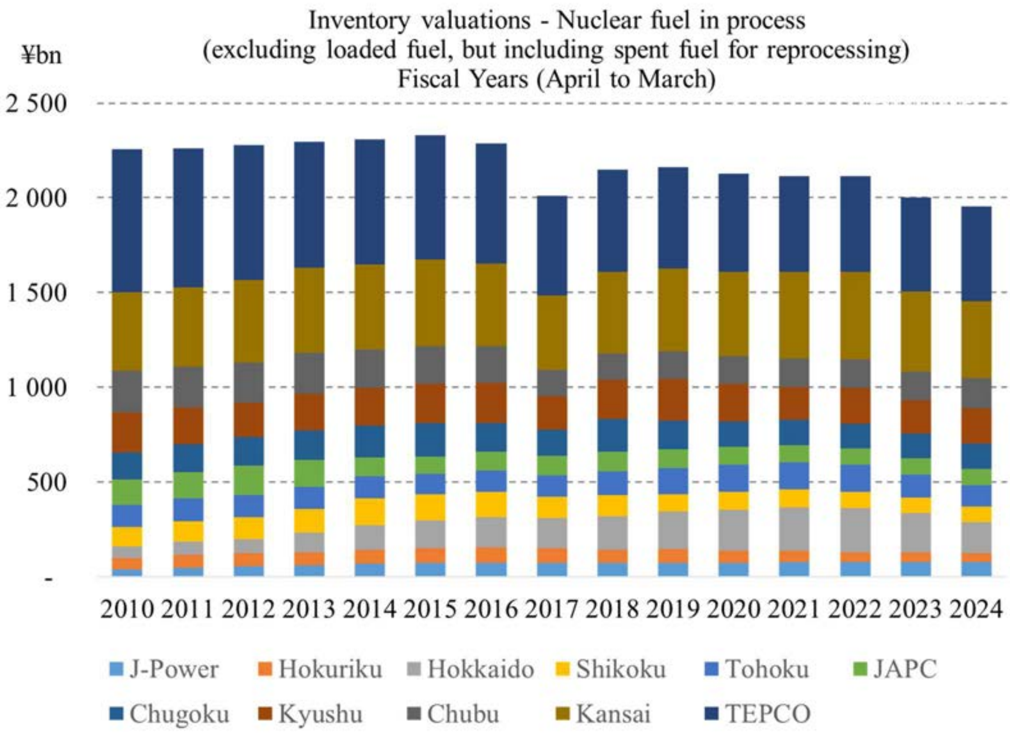

FIG. 21. Japanese utility financial statements on inventories from March 2010–March 2024.

Due to the inclusion of reprocessed material in the above statistics, it is difficult to extract the front end holdings for each utility. Recent pronouncements by the Ministry of Economy, Trade and Industry (METI) and the Federation of Electric Power Companies (FEPC) indicated in 2022 that Japanese supply chain inventories excluding the potential ongoing requirements of the operable fleet amount to approx. 2 400 tU as EUP and that they could only be drawn down over a protracted period. It implies that approx. 1 000 tU as EUP is held outside of Japan (i.e. excluding domestic WIP of 1 400 tU as EUP), which may now include the 226 tU as EUP material exported for defabrication and reuse. This material is likely held at American and European fabricators, enrichers and converters.

Also, a large upstream volume of UF_6 and U_3O_8 would likely accompany any Japanese utility portfolio of nuclear fuel processing contracts. A gap analysis on the value differences between the aggregated utility statements and NRA/METI declarations points to other front end inventories of up to approx. 45 000 tU worth approx. US $7 billion, for which there is evidence of quantities greater than 26 000 tU in eight utility submissions to the NRA. It is reasonable to assume that almost all of this front end inventory resides outside of Japan. Sales of this material have occurred infrequently, but transactions amounting to approx. 2 000 tUe are known to have taken place in 2022 and 2023 and further disposals have since been recorded in 2024 filings.

11.3.5. Republic of Korea

Until 2017, Korea Hydro & Nuclear Power (KHNP) was engaged in a diversified procurement strategy for nuclear fuel that included a policy of building strategic inventories, aligned to its growing nuclear fleet of PWRs and existing PHWRs. KHNP also ensured its security of supply through management of supply chain flexibilities, backed-up by various equity interests in uranium mines, a uranium production company and an enrichment plant. These policies facilitated a regular supply of enriched and natural uranium to the domestic fuel fabricator KEPCO Nuclear Fuel (KNF) in Daejon.

However, a change in government policy in 2017 saw the premature closure of two nuclear units (Kori 1 and Wolsong 1 in 2017 and 2019 respectively) and protracted delays in the construction of new APR1400 reactors. The utility ended its proactive accumulation of stocks, but despite this move KHNP was left with significant unplanned surpluses throughout its front end supply chain due to reduced demand.

Natural U_3O_8/UO_2 for KHNP's three PHWRs comes from Australia and Canada, while enriched uranium for its 23 PWRs is supplied primarily by Rosatom, Urenco, Orano and (until recently) CNEIC. Analysis of trade statistics (see Fig. 22) indicates that over the period 2010–2023, from a starting stockpile assumed to be approx. 210 tU in 2010, PHWR fuel inventories of U_3O_8 or UO_2 as natural uranium located in the Republic of Korea dipped through 2014, but then increased to well above previous levels. Meanwhile, EUP inventories (as UF_6, UO_2 or in fabricated fuel) rose during the decade from a minimum starting stockpile of 136 tU as EUP, adding over 800 tU as EUP since 2010 once domestic demand and exports to the United Arab Emirates have been extracted. This analysis puts domestic natural uranium stocks at over 300 tU and enriched uranium stocks at over 950 tU as EUP. International stocks of natural uranium in the PWR fuel cycle (as U_3O_8 or UF_6) are not visible to this reconciliation, so require estimates to be made from financial data.

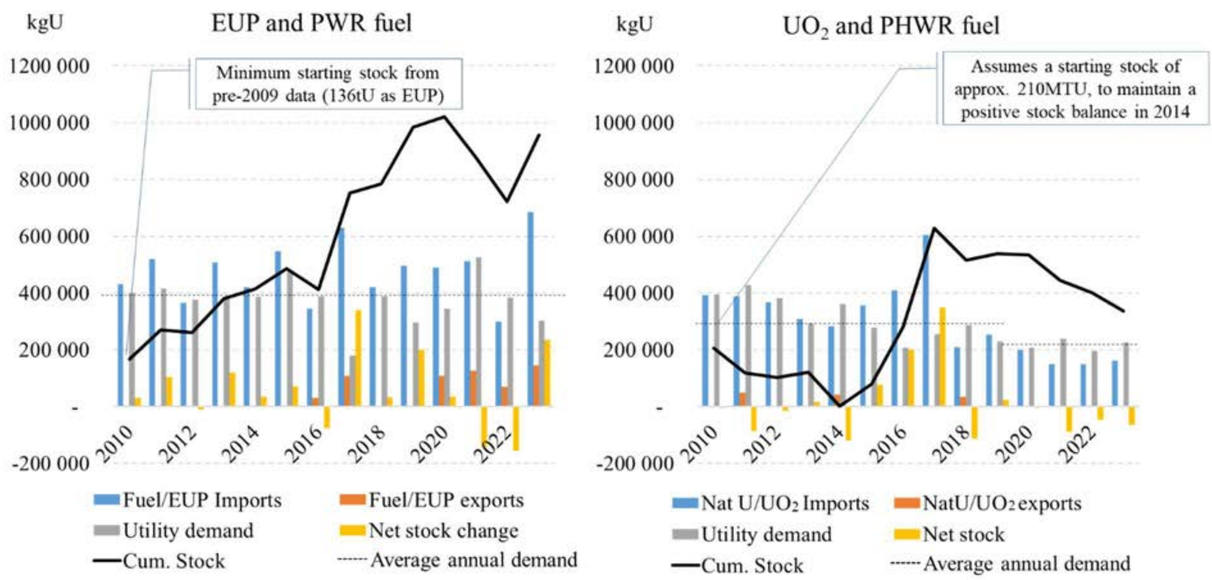

FIG. 22. Korea, Republic of fuel inventory movements by form.

Extracts from KHNP's and KNF's financial reports provide reasonable indications of total uranium and fabricated inventories. In 2023, KHNP recorded approx. US $2.8 billion in raw materials and supplies (assumed to refer to natural and enriched uranium), plus transfers of nuclear fuel from inventories to stores amounting to approx. US $630 million. A further US $1.9 billion in fabricated fuel is assumed to be loaded and part-burned [139]. Meanwhile, KNF reported approx. US $260 million in inventories, including fuel in transit [140].

These combined values are interpreted as equating to approx. 9 300 tU as natural uranium, approx. 1 000 tU as enriched uranium and 385 tU as fabricated fuel. As with other utilities, the financial value of supply chain inventories (identified as 'raw materials' and 'supplies yet to be imported') is in line with fleet pipeline/WIP requirements, indicating a PWR nuclear fuel purchasing lead time of two to three years that also incorporates some strategic inventories. Net of the quantities needed for the next reloads, these values would equate to strategic inventories of at least 1.25 years' worth of natural uranium and 2.25 years' as fabricated fuel or EUP. Based on average annual EUP consumption of approx. 390 tU in its PWRs, this assessment is supported by statements of coverage by the Korea Institute for International Economic Policy (KIEP) [141] and KHNP [142], with cite KHNP as holding a total of 2.7 years' of EUP requirements in stocks. That EUP figure also corresponds reasonably well with the analysis behind Fig. 22.

Following the reversal of the nuclear phase-out programme by the current Republic of Korea government, more new units have been approved and there has been a resumption of the construction of mothballed projects. If the fuel security policy of KHNP then reverts to its previous approach, the current levels of inventory will be below those desired and the expectation will be for further inventory accumulation. Anecdotal data already suggests that inventories have increased to more than three years' worth of enriched uranium [143] by early 2024. Significant deliveries reported in customs statistics during the first half of 2024 would also indicate further accrual.

11.3.6. Taiwan, China

Taipower has historically maintained a strategic inventory of nuclear fuel in line with its government's policy to mitigate supply interruptions. The quantities involved are equivalent to three years' demand for uranium, plus up to one years' demand as fabricated fuel, with the latter held at each operating unit [144]. In addition, Taipower pre-purchased both the Lungmen units 1 and 2 ABWR first cores, which were on site by 2010 [145, 146]. However, Lungmen construction was subsequently suspended in 2014. Taipower paid $260 million for the Lungmen fuel, which in total consisted of 1 744 assemblies/318 tU as UO_2 [147]. Since the Lungmen fuel was by then out of manufacturer warranty, it was progressively repatriated between July 2018 and December 2020 to the original fabricator (GNF-A, Wilmington) at a cost of US $24 million. It was still in storage at the end of 2023.

Taiwan's nuclear phase-out policy will result in the various surplus quantities being liquidated. It was expected that a managed drawdown of strategic inventories would transpire, in line with expiring operating licences. However, early reactor closures due to spent fuel storage capacities being reached have resulted in surpluses of fresh fuel. As a consequence, in early 2021, 121 unused assemblies from shutdown units were sent to Framatome Richland for defabrication (containing approx. 21 tU)[37]. In its most recent statements (August 2018) Taipower confirmed that it also held residual stocks at both Kuosheng and Maanshan, totalling approx. 41 tU in fabricated fuel and some 4 550 tU of natural uranium [148]. These are assumed to have been progressively run down in recent years so that Taipower is left with approx. 2 550 tU as uranium and 29 tU as fabricated fuel at Maanshan the end of 2023 (not including the Lungmen cores).

11.4. REGIONAL SUMMARY

Fig. 23 shows estimates for natural and enriched uranic inventories in the six nuclear countries in the South and East Asia region. However, there are a number of caveats to be applied for some countries.

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[37] http://portal.sw.nat.gov.tw/APGA/GA30E_LIST

For China, whilst uranium inventory estimates match with anecdotal evidence, the estimates for EUP inventories accumulated before 2010 do not have similar corroboration. Therefore, the analysis is likely to carry a risk of over-estimation based on assumptions of local enrichment supply availability.

In Japan, reported figures only provide clear visibility on domestically located materials. Estimates of quantities, particularly in the case of foreign natural uranium holdings, are made to complete the analysis but introduce a margin of error[38].

Given the inventory accumulation policy pre-2015, starting stockpiles in 2010 were also likely to exist in the Republic of Korea. They have been estimated using financial statements, but aggregation of KHNP's inventory reporting means that the form of inventories between PWR and PHWR supply chains is indeterminate.

Regardless of these uncertainties, the nuclear fuel cycle suppliers and utilities in the region are considered to hold the largest inventories across the global nuclear fuel cycle, as shown in Fig. 23. Traditionally this would be expected, due to the lack of access to indigenous uranium resources. However, the levels have been exacerbated in recent years due to the premature shutdown of operating reactors, or the slower than expected restart or commissioning of new units.

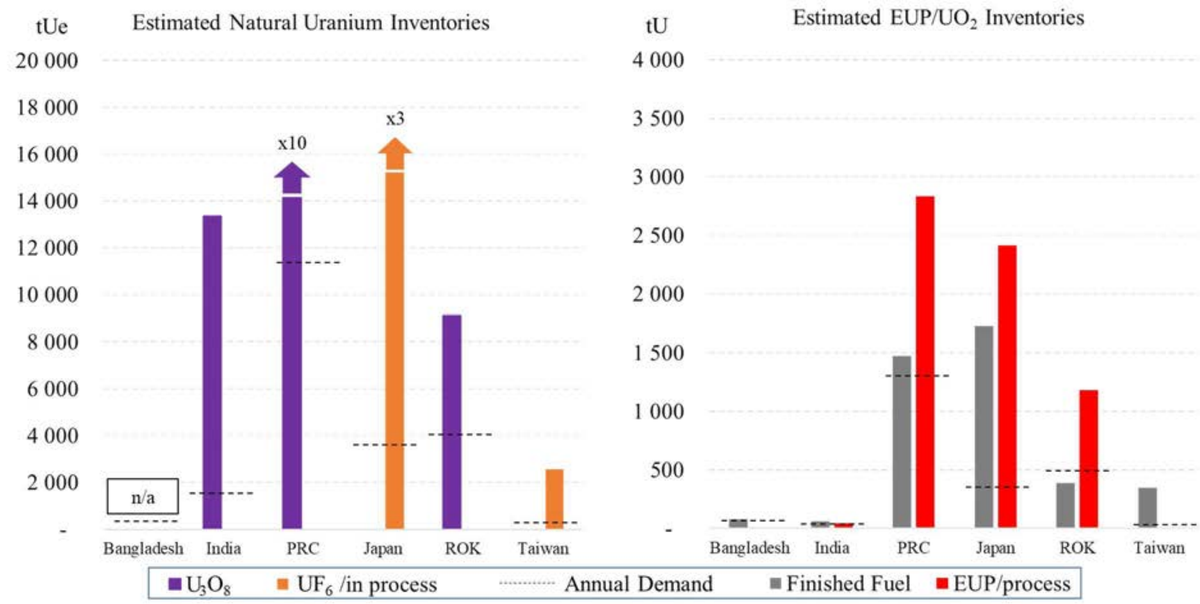

FIG. 23. South and East Asia inventories by form.

In terms of the absolute levels of stockpiles, they represent many multiples of the respective national demand quantities. In China and India, this is due to a national inventory policy. However, for Japan the domestic utilities are faced with over-purchasing under existing contractual commitments at a time when the operable fleet has declined by one-third and the availability of the operating fleet is still relatively low. Meanwhile, in the Republic of Korea and Taiwan, China the national nuclear operators have been attempting to adjust stock levels in

[38] Note that reprocessed materials are not included in Fig. 23.

response to government policies towards nuclear power, albeit that they are now facing differing longer term outcomes.

11.5. SOUTH AND EAST ASIAN INVENTORY LIQUIDITY AND MOBILITY

11.5.1. Bangladesh

The initial core for Rooppur unit 1 is destined for in-country use in late 2024 or 2025. Further imports from TVEL are assumed to be equally intended for domestic consumption.

11.5.2. China

China's uranic inventories are largely deemed to be intended for domestic use. However, attempts by CNEIC to expand sales in international markets and the need to ensure supplies for dependent customers (such as in Pakistan) means that some of the uranic material is by definition liquid and mobile in order to support new export contracts in OECD markets. That said, security of supply for the domestic nuclear power sector will inevitably take priority in the event of any supply interruption, so it would be reasonable to assume that the largest share of inventories would backstop the domestic supply chain. A further build-up of WIP and strategic stocks is also likely to represent a significant level of additional demand on the international markets for some years to come, particularly if domestic processing capacity at any stage of the fuel cycle remains at a level below 100% of Chinese utility demand.

11.5.3. India

Given the historic circumstances, it is highly unlikely that India will be willing to export its uranium stock, even less so if there is a perceived supply deficit for natural uranium on world markets. That being the case, the stockpile is deemed to be both illiquid and immobile. This is even more applicable to the material destined for NPCIL's unsafeguarded reactors.

11.5.4. Japan

The location of materials and end users are important factors when evaluating the liquidity and mobility of Japanese inventories. Firstly, material held in Japan is largely illiquid and immobile, unless there is a defined need to export the material for processing. Even then, the utilities who have so far elected this option intend to reuse the material domestically. Resale has been a last resort for many inventory holders and given that recent geopolitical events have tightened supply to the Western market, this may now be an even less attractive option. Furthermore, much of the identified surplus quantities are believed to have been locked into commercial loan agreements in the intervening 10 years, which may take a reasonable period of time to end.

That said, certain end users without a confirmed requirement due to decommissioning commitments have elected to liquidate international holdings as market prices recover. It is assumed that BWR operators are in this category, given that recent financial reports have indicated a drop in upstream nuclear fuel inventories.

11.5.5. Republic of Korea

The major part of KHNP's inventory is believed to be enriched uranium with a range of assays specific to their reactors. Their inventory, plus those of KNF, are largely dedicated to meeting domestic requirements or to backstop KNF's relatively small export contractual commitments. Therefore, the liquidity and mobility of this stock is relatively low and may become even more so, if renewed expansion of nuclear power is promoted and international reactor sales come to fruition.

11.5.6. Taiwan, China

Taipower's residual natural uranium inventories are being drawn down in lieu of new purchases and some of the surplus fuel is being recycled in the remaining three operating units. Strategic stock use for the final reloads at each unit (assuming Kuosheng Unit 2 and Maanshan Units 1 and 2 still have such stocks in hand) will be completed under the nuclear power phase-outs in 2023 and 2025, respectively.

However, Lungmen fuel reuse may be more problematic and protracted. Direct resale is not possible; there are currently no new ABWRs planned where the first core has not already been purchased (and the fuel is out of warranty). Also, defabrication was (prior to 2022) considered uneconomic (at a cost of approx. US $90 million [149]), potentially leading to an asset write-down. The market price recovery seen in 2022 and 2023 may alter the results of that financial evaluation, but bilateral constraints may still preclude its resale beyond the USA. Any final stocks of natural uranium that remain after the shutdown of the Maanshan units will presumably be resold.

In conclusion, from available evidence, the South and East Asia region holds the greatest quantities of inventory material, and some stocks are potentially beyond domestic needs to ensure a security of supply. Material from Japan and Taiwan, China could therefore re-enter the commercial market for reuse, if considered commercially attractive to its owners.

12. SUMMARY AND CONCLUSIONS

12.1. VOLUME AND LOCATION OF SECONDARY SUPPLIES

The global nuclear fuel market is evaluated to hold significant front end inventories, with an aggregated value of almost US $80 billion at the end of 2023, as summarized in Table 15. Gross coverage of demand is shown in terms of months, as well as the coverage period net of one year's worth of demand. This is used to represent WIP for the next reloads at each stage of the fuel cycle, which maintains the integrity of the supply chain. It demonstrates that, while natural uranium volumes exceed annual demands by a number of multiples, the enriched materials and fabricated fuels segments hold insufficient amounts to buffer against a disruption in the immediate supply chain. There are significant regional differences in relation to coverage, which are explored further in this section. Irrespective, this research suggests that natural uranium is predominantly held as U_3O_8, representing the lowest form in the nuclear fuel processing chain and situated before a bottleneck in the conversion stage of the fuel cycle.

Table 15 presents the outcomes of the inventory analysis at a global level. As such, the monthly and yearly coverages are only indicative of the industry's aggregated position. Tables 16–21 provide further regional breakdowns, but a more complete breakdown of these regional statistics and a like-for-like comparison to restated 2021 data is available in the Annex to this publication.

Since 2021, estimated inventory values have risen 10%, driven largely by additional natural uranium and enriched uranium stocks, which are up 8% and 12% respectively. Meanwhile, fabricated inventories have reduced by 5%, in part due to first core loading that resulted in the amount of material held as first cores dropping by 39%.

TABLE 15. GLOBAL INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	80 053	349 043	14 22	8 782
2023 demand	36 265	67 146	7 432	9 705
First cores in hand				1 077
Months' cover (excl. FCs)		62	23	10
Years' cover (gross)		5.2	1.9	0.8
Years' cover (net WIP/next load)		4.2	0.9	0.0

One contradiction to note is that natural and enriched uranium inventories have increased despite primary uranium production remaining below the level of global annual demand over the period 2022–23. To some extent this results from the liquidations of the fabricated fuel stocks noted above. It could also be an indicator of more inventories becoming visible to this analysis as higher prices encourage transactions that reveal previously unidentified holdings. However, it could also signify the impact of a repurposing of Russian primary enrichment capacity from tails upgrading to underfeeding in order to significantly increase exports of enriched uranium and fabricated fuel.

This global picture also hides a spectrum of varying inventory quantities at a regional level, from South and East Asian entities that hold 53% of stocks by value, to South American and African and Middle East countries that hold much lower amounts (< 1% each). A mixture of private and government inventories in North America and the application of Euratom edicts for EU-utility stock planning in Western Europe indicate that these regions are somewhat better covered, with 18% and 22% of inventories respectively. However, the relative sizes of those nuclear power markets would contradict that conclusion, in that the inventories are insufficient to cover a significant proportion of their respective needs. In Eurasia, strategic holdings of Russian-made fuel represent 5% of global inventories but also signal a dependence upon one primary/OEM supplier due to reactor technology and geopolitical influence. Table 16 breaks down the global uranium inventories by region.

TABLE 16. REGIONAL INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)			Global
	US $ millions	Natural	Enriched	Fabricated	Share
Africa and Middle East	530	0	41	297	0.7%
Eurasia	4 211	11 969	1 441	335	5.3%
Europe	14 425	55 998	3 138	2 533	18.0%
North America	17 717	68 660	3 258	1 237	22.1%
South America	599	792	53	247	0.7%
South and East Asia	42 572	211 624	6 289	4 134	53.2%
	80 053	349 043	14 220	8 782	100%

From the research, distinct types of strategic inventory and secondary supply reliance at a regional level have emerged. These are due to several factors:

1. The diversity of nuclear fuel purchasing;
2. The local abundance or lack of uranium resources;
3. The proximity of downstream stages of the nuclear fuel processing supply chain;

4. The growth or decline of a country's nuclear power programme;
5. Whether the local industry (supplier or end user) is nationally owned and financed.

These characteristics have played a significant role in forming specific country inventory policies since 2010 (the last time that the fuel cycle approached an equilibrium state that saw the need for proactive strategic inventory management and policy making).

Since 2021 the relative positions of the six regions in terms of assessed inventories has changed, with North America now having greater volumes and values than Europe, despite European entities having also increased their holdings. Also, Eurasia has seen a relatively large increase in inventories, largely due to Russian inventory growth. Africa and Middle East now represents the smallest holdings, although a low confidence in relation to some country data could imply that they may have unrecognized stocks. In contrast to value growth in almost every other region, South and East Asian stockpiles experienced a modest fall of 5%. Aside from the use of fabricated fuel inventories in Japan and Taiwan, it is specifically attributable to China importing large quantities of enriched uranium at legacy market prices. Consequently, while its natural uranium and enriched uranium holdings have grown in volumes by 5% and 16% respectively, South and East Asia now only makes up 53% of inventory values globally (down eight percentage points).

Africa and Middle Eastern utilities have long lead-time fuel supply chains, which makes them vulnerable to supply interruptions as shown in Table 17. Without provisioning for strategic reserves, they are effectively procuring fuel on a JIT basis.

TABLE 17. AFRICA AND MIDDLE EASTERN INVENTORIES SUMMARY

	Estimated Values	**Uranium volumes by form (tU)**		
	US $ millions	**Natural**	**Enriched**	**Fabricated**
Inventory	530	0	41	297
2023 Demand	1 004	2 282	227	227
First cores in hand				79
Months' Cover (excl. FCs)		0	2	1
Years' cover (gross)		0.0	0.2	1.0
Years' cover (net WIP/next load)		0.0	0.0	0.0

The relative size of the Africa and Middle East market means that small changes in nominal inventories can produce big swings in indicators. Therefore, an increase in enriched uranium holdings of 45% since 2021 is not to be taken out of context. That said, limited data on upstream components held by some utilities in the region is hampering a clear perspective on their fuel cycle planning and inventory management. The most robust indicator is fabricated fuel holdings, which has changed by only -1% since 2021. Within that figure was a significant reduction in first core holdings (down 58%) as new units were commissioned, implying that operational inventories have likely increased to support a growing fleet and this will in turn result in increases in holdings of upstream components.

Table 18 is a summary of Eurasian uranium inventories. Eurasian utilities are heavily reliant on one fuel cycle supplier, Rosatom's TVEL. For utilities outside of Russia, strategic inventories of finished fuel have been put in place, further backstopped by regional and international fuel banks. Meanwhile, Russia's integration of the domestic nuclear fuel and power industries means that stockpiles (where they exist) are governed federally.

TABLE 18. EURASIAN INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	4 211	11 969	1 441	335
2023 Demand	3 439	6 676	813	813
First cores in hand				0
Months' Cover (excl. FCs)		22	21	5
Years' cover (gross)		1.8	1.8	0.4
Years' cover (net WIP/next load)		0.8	0.8	0.0

Much of the change in Eurasia has been driven by developments in Russia and since the conflict began in Ukraine. Irrespective of a currency devaluation between 2021 and 2023, Russian inventories are deemed to have increased significantly (i.e. in both Rouble value terms and derived volumes), a change that has consequently driven the large increases in some of the aggregated regional holdings. Eurasian inventories of uranium have increased 5% and also seen a 53% uplift for enriched uranium. In contrast, fabricated fuel has declined 42%, impacted to a large degree by use of first cores in Russia and Belarus. Although many of these stockpile increases may be for consumption outside of Eurasia, the fact that Russia as an OEM is the nuclear fuel supply guarantor for all of the regional operators might indicate a further strengthening of that role in recent years.

Table 19 presents a summary of European uranium inventories. It reflects that there is a mix of well-stocked State-owned utilities and other utilities who hold reserves due to national regulations. However, few privately held entities have permanent stocks of any significance. As such, inventories are unevenly distributed, both across the region and the supply chain.

TABLE 19. EUROPEAN INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	14 425	55 998	3 138	2 533
2023 demand	9 443	17 082	2 172	2 357
First cores in hand				299
Months' cover (excl. FCs)		39	17	11
Years' cover (gross)		3.3	1.4	0.9
Years' cover (net WIP/next load)		2.3	0.4	0.0

The perceived vulnerability of the supply chain for VVER fuel in Central and Eastern Europe and the geopolitical impacts of the conflict in Ukraine have been significant drivers to inventories changes in this region since 2021. Inventory values have increased 15%, supported by increased holdings in each segment of the supply chain. Europe is one of only two regions to see an increase in stockpiles of fabricated fuel (up 4%), largely furnished by TVEL. Furthermore, supplier diversification and potential double-purchasing has meant that natural uranium and enriched uranium holdings are also 8% and 6% respectively higher than they were in 2021. The potential for further supply chain disruptions from the forced closure of mines in Niger has yet to be reflected in the above data.

In the USA and Mexico, few private utilities hold material beyond WIP/pipeline and are reliant on supplier’s commercial backups and modest federal reserves. In contrast, Canadian utilities make provisions to a greater extent. Table 20 is a summary of North American inventories.

TABLE 20. NORTH AMERICAN INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	17 717	68 660	3 258	1 237
2023 demand	12 056	19 764	2 249	3 562
First cores in hand				0
Months' cover (excl. FCs)		42	17	4
Years' cover (gross)		3.5	1.4	0.3
Years' cover (net WIP/next load)		2.5	0.4	0.0

In terms of North America, the region is also heavily impacted by two large uranium investment funds in Canada that have both grown since 2021. Their recent acquisitions largely explain a 21% increase in natural uranium holdings. For enriched uranium, the USA has solely driven an increase of 22% in volumes, mostly attributed to utility stocks. A decline in regional fabricated fuel holdings of 9% is predominantly explained by the first core loading of Vogtle 4 and normal reload cycles. However, since much of the fabricated fuel inventories are held by Canadian utilities (as Natural UO_2), this leaves United States of America utilities acutely vulnerable to supply interruptions and a dependency and JIT fabricator production.

In South America, the integrated nature of the fuel cycle industry and utility end users mostly drives a JIT procurement strategy and a policy of limited inventories. Table 21 summarizes the South American inventories.

TABLE 21. SOUTH AMERICAN INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	599	792	53	247
2023 demand	530	508	70	202
First cores in hand				2
Months' cover (excl. FCs)		19	9	15
Years' cover (gross)		1.6	0.8	1.2
Years' cover (net WIP/next load)		0.6	0.0	0.2

As a relatively small producer and user of nuclear fuel, batch production and bulk shipments of uranium can mean that South American utilities experience significant swings in inventory volumes. Over the past two years, natural uranium holdings have reduced by 30% and fabricated fuel by 8%, while conversely enriched uranium inventories have increased 20%. This may be a combination of demand changes and cyclical factors, which do not necessarily result in a lower level of aggregate coverage in the region.

Meanwhile, in South and East Asia, Indian and Chinese entities have large national reserves that are a backup to significant domestic nuclear power programmes. The Republic of Korea has followed a similarly strategic approach, albeit interrupted by a nuclear phase-out policy that has only recently been reversed. Meanwhile, in Japan and Taiwan, China, the impacts of 12 years of operational standstill or phase-out of nuclear power has led to purchasing overcommitments and resulted in some of the only genuine surplus stockpiles across the global industry. Table 22 is a summary of these large South and East Asian uranium inventories.

TABLE 22. SOUTH AND EAST ASIAN INVENTORIES SUMMARY

	Estimated Values	Uranium volumes by form (tU)		
	US $ millions	Natural	Enriched	Fabricated
Inventory	42 572	211 624	6 289	4 134
2023 demand	9 792	20 834	1 902	2 545
First cores in hand				697
Months' cover (excl. FCs)		122	40	16
Years' cover (gross)		10.2	3.3	1.4
Years' cover (net WIP/next load)		9.2	2.3	0.4

The inclusion of pre-2010 accumulations of uranium and enriched uranium inventories in China has affected both 2021 and 2023 data sets, by respectively adding 2 300 tU as U_3O_8 and 750 tU as EUP to Chinese starting stocks in 2010. However, more recent market activity has had a much greater impact, with China importing enough EUP as UF_6 and fabricated fuel to cover its current annual reload requirements. This alone has driven a 16% increase in regional enriched uranium holdings since 2021, albeit at average prices significantly lower than in previous years. This growth has been supplemented by further natural uranium imports, to boost China’s national strategic stockpiles. In contrast, Indian and Republic of Korea inventories remained relatively flat, whilst Taiwan, China and Japanese have pursued drawdowns through internal use or resales. Together with lower average EUP prices, drawdowns have led to a 5% reduction in the values of overall regional inventories.

These changes and the developing variances in regional inventories above (or below) annual requirements are summarized in Fig. 24. Significant changes since 2021 are highlighted by the red boxes (increases or falls). Evidently, there is significantly more material being accumulated in lower value forms (i.e. natural and enriched uranium). For the more bespoke stage of the nuclear fuel cycle (fabrication), a somewhat closer alignment in regional holdings to actual annual needs can be observed.

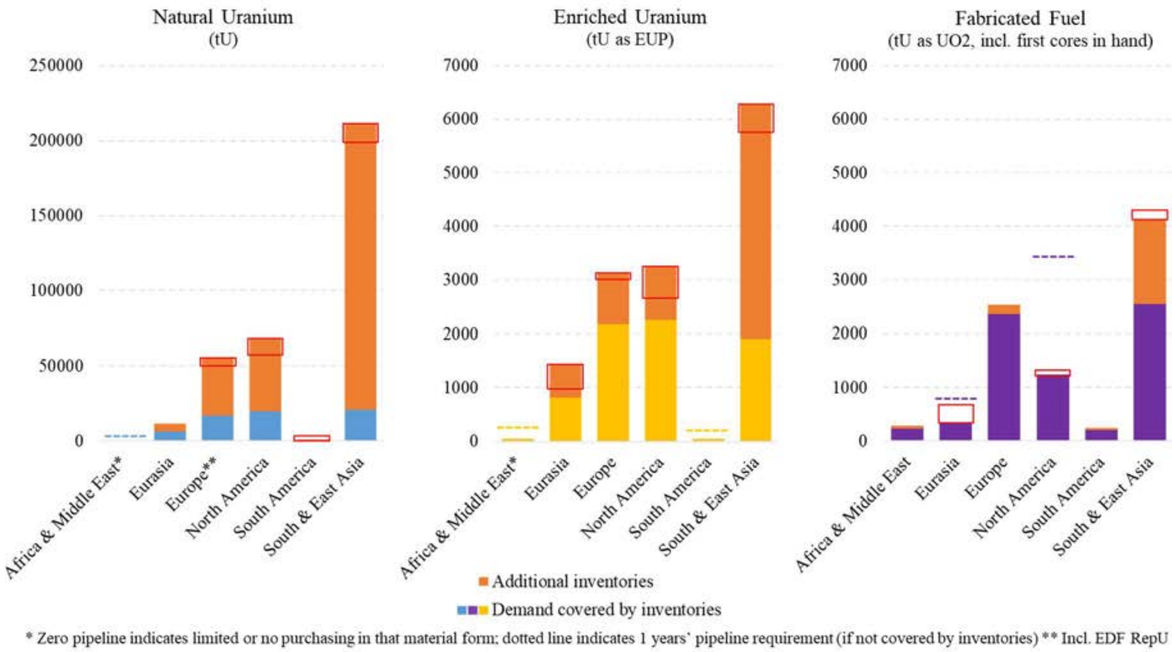

FIG. 24. Regional inventory coverage at the end of 2023, compared to 2021.

Most of the largest recorded changes since 2021 concern enriched uranium holdings, with all major regions showing an increase of inventories above annual demand. Falls in regional holdings of fabricated fuels are either due to stock drawdowns or first core loadings. Uranium inventory increases are primarily related to strategic accumulation in China and financial institution purchases in Canada.

The consequences of stock accumulation also need to be considered in terms of mobility and liquidity to fully appreciate the potential market impact of inventories. The Expert Group noted a dynamic period between 2021 and 2023, within which one key trend was the increasingly risk-averse nature of inventory management. This has led to increasing strategic inventory allocations in many markets. However, where there is a speculative element of demand such as from funds in Canada and the United Kingdom, this can give the impression of increased security of supply. In reality, these fund inventories represent a potential market overhang that does not benefit the country in which the fund is domiciled.

12.2. LIQUIDITY AND MOBILITY OF SECONDARY SUPPLIES

It is evident from the form and regional spread of the estimated inventories that their mobility and liquidity may also not be uniform. Analysis indicates that most inventories have an end user already prescribed, particularly in Western countries. Meanwhile, those countries with available surpluses may find it difficult to readily liquidate their holdings, as any transaction would be a subject to:

- An audit of its financial impact;
- The material form and homogeneity/specification;
- Tangible commercial and operational practicalities (e.g. obligation or origin codes, contractual restrictions, etc.);
- Import and export restrictions;
- National regulatory controls.

For material to be liquid, it needs to be easily transferable (presumably between countries with comprehensive bilateral trade and nuclear regulatory regimes) and in a form that can be readily processed for a different end user. The ability of the nuclear fuel cycle suppliers to disaggregate higher added value material into its component parts for resale is of significant benefit, but certain practical restrictions may still impact the transfer of the material. Similarly, transport swaps and code swaps can facilitate material mobility, providing there are willing counterparties to a transaction.

Figure 25 considers the same data as Fig. 24 but allocates function to the inventories by form and region. This is done on the following basis:

- Where undefined utility inventories cover one years' worth of demand, they are considered to be WIP.
- Supplier inventories are also generally considered to be WIP unless specifically designated otherwise. This is a necessary assumption as global supplies are backing up international orderbook for utilities that may not independently recognise upstream inventories (i.e. for those who buy fabricated fuel).

— Any resulting utility surpluses (i.e. inventories net of WIP) are considered strategic, unless the entity holds significant excess material when compared to long term requirements.
— For Japan and Taiwan, Chinese material destined for closed reactors is considered surplus and mobile. For Japan, significant surpluses of fabricated fuel allocated to potentially operable units are considered immobile (i.e. being held as non-current assets for drawdown).
— Declared strategic material is considered as such, whoever holds it and in whatever form.
— Fund's inventories are considered surplus, but currently immobile.
— Trader inventories are considered surplus and mobile.

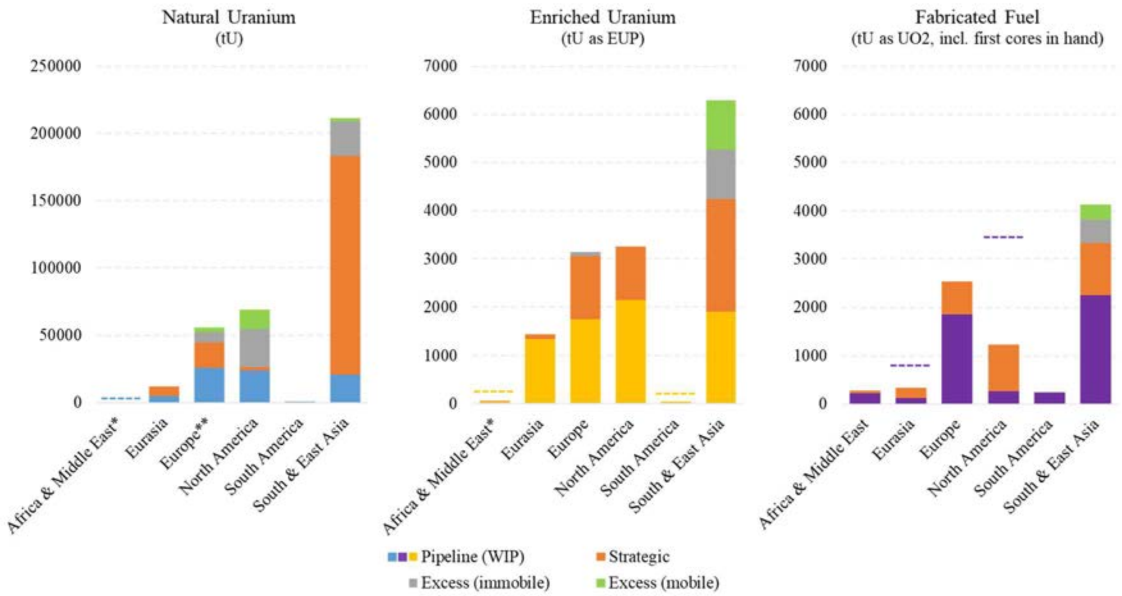

FIG. 25. Regional inventories by form and function at the end of 2023.

The results detailed in Table 23 are significant for a number of reasons:

— Whether owned by utilities or suppliers, there is enough WIP in the world to furnish the uranium and enrichment segments of the fuel cycle with almost a full years' worth of stock (i.e. 114% and 97%, respectively). This result supports the assumption that the suppliers of utilities who buy bundled fuel hold WIP on their customers' behalf.
— For fabrication, the data appears to point to a WIP level of 6 months (51% demand) but come closer to one years' worth in certain regions when adding in revolving strategic inventories.

In terms of the surplus mobile material:

— Uranium surpluses are largely attributed to Taiwan and US/European traders.
— EUP surpluses reside almost exclusively with Japanese utilities (specifically material residing outside of Japan).

— Fabricated fuel inventories belong to Japanese and Taiwanese utilities, although in most cases the former group could recycle the fuel components internally over the very long term unless pending reactor restart permissions are refused.

TABLE 23. REGIONAL INVENTORIES BY FORM AND FUNCTION AT THE END OF 2023

Form	Function	Africa and Middle East	Eurasia	Europe	North America	South America	South and East Asia	Global Totals	Global Demand	WIP coverage
Uranium										
(tU as U_3O_8, UF_6 or UO_2)										
	WIP/Next reload	0	4 727	25 973	24 033	792	20 977	76 502	67 146	114%
	Strategic	0	7 242	19 107	2 327	0	162 325	191 001		
	Surplus immobile	0	0	7 714	28 530	0	25 772	62 016		
	Surplus mobile	0	0	3 204	13 770	0	2 551	19 524		
Enriched Uranium										
(tU as EUP or UO_2)										
	WIP/Next reload	37	1 351	1 744	2 138	53	1 906	7 229	7 432	97%
	Strategic	4	90	1 319	1 120	0	2 338	4 871		
	Surplus immobile	0	0	74	0	0	1 023	1 097		
	Surplus mobile	0	0	0	0	0	1 023	1 023		
Fabricated Fuel										
(tU as fabricated fuel)										
	WIP/Next reload	239	126	1 851	262	236	2 250	4 963	9 705	51%
	Strategic	58	209	682	975	0	1 080	3 004		
	Surplus immobile	0	0	0	0	11	486	497		
	Surplus mobile	0	0	0	0	0	318	318		

12.3. CONCLUSIONS

The absence of significant liquid inventories in the front end of the nuclear fuel cycle implies that the historical reliance on secondary uranium supplies to supplement the nuclear fuel supply chain is unlikely to continue at the same levels. This is due to a combination of factors including; supply chain deglobalization, clear indications of renewed inventory building and non-utility (i.e. financial institution) demand. This would suggest that in the future any policy for strategic fuel management needs to involve greater prudence and a multi-faceted approach to security of supply. A diversified portfolio of suppliers can only protect the supply chain to a limited degree if a disruption is not localized. Furthermore, the need to have material in higher processed forms to ensure continued operation of a reactor goes beyond holding a limited number of fuel bundles onsite to cover for fuel failures.

There is a spectrum of possible mitigations to guard against supply chain risks; from national reserves of uranic materials to extended fuel cycle lead times and strategically placed material buffers or commercial mechanisms such as loans and flexibilities. The adoption of such measures may well be more urgent in the current geopolitical environment and regardless may become an emerging trend if the market deglobalizes in the longer term.

To further inform this debate, additional research could potentially improve the analysis of global inventories of secondary uranium supplies. This could include:

— Improved data gathering of demand, to replace WNA models which have a tendency to favour the upside potential for nuclear fuel markets rather than corroborating historical information;
— Greater access to South and East Asian supplier data, to better assess individual countries' inventory policies currently applied on behalf of national utilities;
— A more comprehensive analysis of locally reported trade statistics, including a detailed analysis of uranic material types and values to ensure that misreporting is minimised;
— Establishing rules for extracting residual values for spent nuclear fuel and back end reprocessing from financial statistics, thereby providing clearer estimates for nuclear fuel WIP/pipeline inventories;
— Soliciting additional information from regulatory bodies, for example to better ascertain government policy on inventories and the implementation thereof;
— Requesting that IAEA Member States consider providing additional transparency and public access to relevant uranic inventory reporting, including the information provided to the IAEA in Safeguards Declarations or databases such as the Nuclear Material Management and Safeguards System (NMMSS) in the USA.

REFERENCES

[1] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium Resources, Production and Demand, OECD Publishing, Paris (2025).

[2] MINING.COM, World Uranium Production and Demand Chart (2016), http://www.mining.com/web/uranium-collapse-signals-2020-positive-supply-shock-goviex-ceo/world-uranium-production-and-demand-chart/.

[3] WORLD NUCLEAR ASSOCIATION, The Nuclear Fuel Report - Global Scenarios for Demand and Supply Availability 2023-2040, WNA, London (2023).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA-TECDOC-2030, Global Inventories of Secondary Uranium Supplies, IAEA, Vienna (2024).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA-TECDOC-1613, Nuclear Fuel Cycle Information System, IAEA, Vienna (2009).

[6] NATIONAL ATOMIC COMPANY KAZATOMPROM JSC, Operating and Financial Review for 2023, NAC Kazatomprom JSC, Astana (2023).

[7] NAVOIURAN STATE COMPANY, Financial Statements and Independent Auditor's Report - For the Year Ended 31 December 2023, Navoiuranium State Company, Navoiy (2024).

[8] CAMECO CORPORATION, Energizing a clean-air world – 2023 Annual Report, Cameco, Saskatoon (2024).

[9] BUNDESANSTALT FÜR GEOWISSENSCHAFTEN AND ROHSTOFFE, The major uranium producing countries in 2022, BGR, Hannover. https://www.bgr.bund.de/EN/Themen/Energie/Bilder/EnergyStudy2023/ene_uranium_production_g.html;jsessionid=2360E23E33C1B70912267C256FDACE11.internet972?nn=1548116

[10] NAMIBIAN URANIUM INSTITUTE, Annual Review 2023, NUI, Swakopmund (2024).

[11] ROSATOM, Performance of the Mining Division in 2023, Rosatom, Moscow (2024).

[12] AUSTRALIAN DEPARTMENT OF INDUSTRY, SCIENCE AND RESOURCES, Resources and Energy Quarterly Historical Data, DISR (2024).

[13] KUN.UZ, "Navoiuran" ranks 6th globally in uranium production, Kun (11 Sep. 2024).

[14] U.S. DEPARTMENT OF COMMERCE, Understanding HS Codes and the Schedule B, U.S DOC. https://www.trade.gov/harmonized-system-hs-codes

[15] INTERNATIONAL ATOMIC ENERGY AGENCY DIRECTOR GENERAL, Verification and monitoring in the Islamic Republic of Iran in light of United Nations Security Council resolution 2231 (2015), IAEA, Vienna (2024).

[16] ROSATOM, Rosatom ships nuclear fuel mock-ups for testing the first unit of Akkuyu NPP in Turkey, Rosatom (2022).

[17] IUEC.RU, Supplies to shareholders, International Uranium Enrichment Centre (2024) (in Russian)

[18] ARMENIAN NUCLEAR POWER PLANT CJSC, Annual Financial Statements and Independent Auditor's Report for the Year Ended 31 December 2023, CJSC HAEK, Yerevan (2024).

[19] ARMENIAN NUCLEAR POWER PLANT CJSC, Armenia, Russia company sign supplement to contract for fuel supply to Armenian nuclear plant, CJSC HAEK (27 Jun. 2019).

[20] EURORADIO.FM, Belarus has signed contracts for the supply of fuel for Bel NPP for 14-15 years (2018) (in Russian).

[21] RACYJA.COM, Nuclear fuel for Bel NPP will arrive at the end of 2018 (2018) (in Polish).

[22] BELARUSIAN NUCLEAR POWER PLANT, Nuclear power plant fuel: Where it is inspected and how storage facilities prepare to receive it, Belarusian Nuclear Power Plant (9 Jun. 2020) (in Russian).

[23] TASS.RU, Repairs at the first power unit of the Belarusian NPP are scheduled for the fourth quarter of 2023, Tass (23 Feb. 2023) (in Russian).

[24] HRODNA.LIFE, How they produce, what they will take and how much nuclear fuel will operate on the first delivery to BeIAES, Hrodna Life (13 Sep. 2018) (in Belarusian)

[25] VAN BRUGEN, I., Nuclear plant at heart of rift between Putin and top Ally, Newsweek (31 Oct. 2023).

[26] LIST-ORG.COM, Reporting of the organization JSC "ROSENERGOATOM CONCERN", List-Org (Accessed 9 Jan. 2025) (in Russian)

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Funding of the IAEA LEU Bank, IAEA, https://www.iaea.org/topics/leubank/funding.

[28] ATOMIC ENERGY, Glossary to the nuclear code of the Russian Federation, Atomic Energy (2013) https://www.atomic-energy.ru/articles/2013/10/18/44529 (in Russian).

[29] KHLOPKOV, A., CHEKINA, V., Governing Uranium In Russia, Danish Institute for International Studies, Copenhagen (2014).

[30] ORANO, https://www.orano.group/en/unpacking-nuclear/recycled-uranium-an-energy-source-for-low-carbon-.

[31] FINEMARKET.RU, Russia's uranium reserves will last for 20-25 years, but now is the time to step up exploration of new deposits, Finemarket (21 Sep. 2021) (in Russian).

[32] NIKITIN, A., MURATOV, O., VAKHRUSHEVA, K., Depleted Uranium Hexafluoride (current situation, issues of safe handling and prospects), Bellona, (2021) (in Russian).

[33] NUCLEAR ENGINEERING INTERNATIONAL, Russia´s Angarsk ElectroChemical combine to start new enrichment project, Nuclear Engineering International (8 Dec. 2023).

[34] ROSATOM, JSC Angarsk Electrolysis Chemical Plant, https://aecc.tvel.ru/activity/.

[35] EURATOM SUPPLY AGENCY, ESA Annual Report 2023, ESA, Luxembourg (2024).

[36] FORUMNUCLEAIR.BE, Belgian electricity mix February 2022: limited need for fossil energy thanks to records of electricity produced via nuclear and renewable energies, Nucleair Forum (7 Mar. 2022) (in French)

[37] SYNATOM, Activity Report 2023, Synatom, Brussels (2024).

[38] ENGIE, Activity Report and Annual Consolidated Financial Statements 2023, ENGIE, Paris (2024).

[39] ELECTRABEL SA, NUCLEARSUB BV, Fuel Supply Agreement, Electrabel – Nuclearsub (2023).

[40] NEWS.BG, The government wants to diversify its nuclear fuel supply, News (13 Jul. 2022).

[41] KOZLODUY NPP EAD, Annual Separate Management Report, Non-Financial Statement, Independent Auditors' Report, Separate Annual Financial Statements, 31 December 2023, Bulgarian Energy Holding EAD, Kozloduy (2024).

[42] KRASSEN, N., Bulgarian government must urgently find non-Russian nuclear fuel, Euractiv (10 Nov. 2022) (in Bulgarian).

[43] GOVERNMENT OF THE CZECH REPUBLIC, National Energy and Climate Plan of the Czech Republic, Prague (2019)

[44] PLATTS NUCLEAR FUEL, CEZ boosts Dukovany fresh fuel storage capacity to around five years' worth, S&P Global Commodity Insights (6 Oct. 2023).

[45] CEZ GROUP, 2023 Annual Report, CEZ a. s., Prague (2024).

[46] FINNISH RADIATION AND NUCLEAR SAFETY AUTHORITY (STUK), Implementing nuclear non-proliferation in Finland - Regulatory control, international cooperation and the Comprehensive Nuclear-Test-Ban Treaty - Annual report 2023, STUK, Vantaa (2024).

[47] FORTUM, Kestävän kehityksen raportin pääkohdat (2023) (in Finnish).

[48] FRENCH NATIONAL AGENCY FOR RADIOACTIVE WASTE MANAGEMENT, Inventaire national des matières et déchets radiocatifs - Les Essentiels 2024, ANDRA, Paris (2024).

[49] ORANO, Nuclear: an asset for France´s energy independence, Orano (5 Sep. 2023).

[50] ELECTRICITÉ DE FRANCE, Consolidated Financial Statements at 31 December 2023, EDF, Paris (2024).

[51] VGBE ENERGY, ‘Operating experience with nuclear power plants 2023’, Energy Journal 5 (2024) 63-69.

[52] RWE, Powering towards a green tomorrow. Annual Report 2023, RWE Aktiengesellschaft, Essen (2024).

[53] POWER TECHNOLOGY, Hungary receives nuclear fuel shipment by air from Russia, (2022).

[54] EUROPEAN UNION, Extra-EU trade since 2000 by mode of transport (2024) https://ec.europa.eu/eurostat/databrowser/view/DS-058213__custom_10803740/default/table?lang=en.

[55] WEINHARDT, A., It was announced: the Paks operating time extension may cost 1.5 billion euros, the nuclear fuel stock will be increased to 3 years, Portfolio (5 Dec. 2023).

[56] MVM ZRT., Consolidated Financial Statements of MVM Energetika Private Limited Company and its subsidiaries for the year ending December 31, 2023, MVM Group, Budapest (2024).

[57] GOVERNMENT GAZETTE OF THE KINGDOM OF THE NETHERLANDS, Notification Nuclear Energy Act Final Decision NV EPZ Fuel diversification in Borssele Nuclear Power Plant, Ministry of Economic Affairs (2011) (in Dutch).

[58] AUTORITEIT NUCLEAIRE VEILIGHEID EN STRALINGSBESCHERMING (ANVS), Revisievergunning voor de kernenergiecentrale Borssele van EPZ, ANVS (2016).

[59] ZEH JaaRBERICHT 2023, ZEH, Middelburg (2024).

[60] S.N. NUCLEARELECTRICA S.A., Annual Report 2023, Nuclearelectrica S.A., Bucharest (2024).

[61] ROMANIA MINISTRY OF ENERGY, Two essential decisions for the Romanian civil nuclear program were adopted, Ministry of Energy (2022).

[62] ENERGIA.SK, They say we have reserves in the state material reserves, Energia (19 Jan. 2016) (in Slovak).

[63] SLOVENSKÉ ELEKTRÁRNE, A.S., Annual Report 2023, Slovenské elektrárne, a.s., Bratislava (2024).

[64] ENERGIA.SK, Power plants bought nuclear fuel for 116 million euros last year, Energia (15 Jun. 2016) (in Slovak).

[65] FONTECH.STARTITUP.SK, Slovakia will buy more nuclear fuel, the state wants to prepare for unforeseen situations, Fontech Startitup (24 Aug. 2022).

[66] NUKLEARNA ELEKTRARNA KRŠKO, Annual Report NPP 2023, NEK, Krško (2024).

[67] AGENCIA ESTATAL BOLETÍN OFICIAL DEL ESTADO, Orden ITC/2821/2005, de 7 de septiembre, por la que se modifican las cantidades a que se refiere el artículo 3.c) del Real Decreto 1464/1999, de 17 de septiembre, sobre actividades de la primera parte del ciclo del combustible nuclear (2005).

[68] IBERDROLA, S.A., Annual financial information Iberdrola, S.A. and subsidiaries - 2023, Iberdrola, S.A., Bilbao (2024).

[69] ENDESA S.A., Annual Financial Report Legal Documentation 2023, ENDESA, S.A. and Subsidiaries. ENDESA, S.A., Madrid (2024).

[70] NATURGY, Annual Consolidated Financial Report 2023, Naturgy Energy Group S.A., Barcelona (2024).

[71] SVENSK KÄRNBRÄNSLEHANTERING AKTIEBOLAG (SKB), SKB Annual Report 1995, SKB, Stockholm (1996).

[72] VATTENFALL AB, Working for Fossil Freedom. Annual and Sustainability Report 2023. Vattenfall AB, Stockholm (2024).

[73] OKG AB, Annual Report for OKG. Fiscal year 23-01-01 – 23-12-31, OKG AB (2024).

[74] FORUM NUCLÉAIRE SUISSE, Swiss stocks of nuclear material broad in 2023, Forum Nucléaire Suisse (25 Mar. 2024) (in French).

[75] AXPO HOLDING AG, Financial Report 2022/23 - 1 October 2022 to 30 September 2023. Axpo Holding AG, Baden (2023).

[76] KERNKRAFTWERK GÖSGEN, Annual Report 2023 - Kernkraftwerk Gösgen-Däniken AG, Däniken (2024).

[77] INTERFAX UKRAINE, Energoatom's reserves are designed for 1.5 years, but the non-payment crisis threatens new supplies and the export of spent nuclear fuel, Interfax Ukraine (16 Apr. 2020) (in Ukrainian).

[78] DELO, "Energoatom" told how much nuclear fuel reserves will be enough for Ukrainian nuclear power plants, Delo (2 May 2022) (in Ukrainian).

[79] STATE ENTERPRISE "NATIONAL ATOMIC ENERGY GENERATING COMPANY" ENERGOATOM, Financial statements in accordance with IFRS for the year ended December, 31 2023, NAEC Energoatom, Kyiv (2024) (in Ukrainian).

[80] JACOBS UK LTD AND AFRY SOLUTIONS UK LTD., 2022 UK Radioactive Material Inventory, UK NDA, Moor Row (2023).

[81] UK NUCLEAR DECOMMISSIONING AUTHORITY, Nuclear Decommissioning Authority Strategy effective from March 2021, UK Nuclear Decommissioning Authority (2021).

[82] EDF ENERGY HOLDINGS LIMITED, Annual Report and Financial Statements - 31 December 2023, EDF Energy, Barnwood (2024).

[83] EXPRESS.CO.UK, Putin's nuclear grip on UK sparks panic as EDF scrambles to block Russian uranium, Express (24 May 2022).

[84] EDF ENERGY, Sustainability datasheet, EDF Energy Customers Ltd., London, (2023).

[85] LE FIGARO.COM, ORANO CHIMIE-ENRICHISSEMENT S.A.S, Orano Chimie-Enrichissement, Comptes Sociaux - Exercice clos le 31 décembre 2023 Orano Chimie-Enrichissement, Paris (2024) (in French).

[86] LE FIGARO.COM, ORANO MINING S.A.S, Orano Mining, Comptes Sociaux - Exercice clos le 31 décembre 2021 - 2023 Orano Mining, Paris (2024) (in French).

[87] LE FIGARO.COM, FRAMATOME SAS ETATS FINANCIERS au 31 décembre 2023 Annexe aux comptes sociaux (2024) (in French).

[88] ADVANCED NUCLEAR FUELS GMBH, Lingen (Ems), Annual financial statements for the financial year from 01.01.2023 to 31.12.2023, Advanced Nuclear Fuels GmbH, Lingen (2024).

[89] URENCO DEUTSCHLAND GMBH, Urenco Deutschland GmbH - Annual financial statements for the financial year from 1 January to 31 December 2023 plus independent auditor's report, Gronau (2024).

[90] URANGESELLSCHAFT GMBH, Exempting consolidated financial statements for the financial year from 01.01.2023 to 31.12.2023, ORANO SA, Châtillon (2024).

[91] GRUPO ENUSA, Memoria Annual 2023, ENUSA Industrias Avanzadas, S.A., S.M.E, Madrid (2024) (in Spanish).

[92] WESTINGHOUSE ELECTRIC SWEDEN AB, Annual Report for Westinghouse Electric Swede AB. Fiscal year 23-01-01 – 23-12-31, Västerås (2024).

[93] WORLD NUCLEAR ASSOCIATION, World Uranium Mining Production, WNA (2024).

[94] CLARITY PROJECT.INFO, State enterprise "Eastern mining and enrichment plant", Clarity Project (2024).

[95] SE "SHIDGZK" VOSTGOK, Financial statements for 2023, SE "ShidGZK" VostGOK, Zhovti Vody (2024).

[96] URENCO LIMITED, Urenco Annual report and accounts 2023, Stoke Poges (2024).

[97] URENCO UK LIMITED, Annual Report and Financial Statements for the year ended 31 December 2023, Capenhurst (2024).

[98] GOV.UK (COMPANIES HOUSE), Uranium Asset Management Limited - Annual Report and financial statements for the year ended 31 December 2023, Uranium Asset Management Limited, Salwick (2024).

[99] GOV.UK (COMPANIES HOUSE), Springfields Fuels Limited - Annual Report and financial statements for the year ended 31 December 2023, Springfields Fuels Limited, Salwick (2024).

[100] YELLOW CAKE PLC, Yellow Cake plc - Quarterly Operating Update, Yellow Cake plc, London (2024).

[101] BRUCE POWER, 2023 Bruce Power Annual Review and Energy Report, Tiverton (2024).

[102] NEW BRUNSWICK POWER CORPORATION, Annual Report 2023/24 - New Brunswick Power Corporation, Énergie NB Power, Fredericton (2024).

[103] ÉNERGIE NB POWER, CANDU 6 fuel, Énergie NB (2025)

[104] ONTARIO POWER GENERATION INC., Management's discussion and analysis - December 31, 2023, OPG INC., Toronto (2024).

[105] ONTARIO POWER GENERATION, Nuclear Fuel Costs, OPG (2021).

[106] HABITATMX.COM, Laguna Verde, el monopolio de recarga para General Electric, HabitatMx (1 Dic. 2021).

[107] COMISIÓN FEDERAL DE ELECTRICIDAD MEXICO, Información Financiera Trimestral - Q4 2023, CFE Mexico (2024).

[108] U.S. ENERGY INFORMATION ADMINISTRATION, 2023 Uranium Marketing Annual Report, US Department of Energy, Washington DC (2024).

[109] U.S. GOVERNMENT ACCOUNTABILITY OFFICE, NNSA Should Clarify Long-Term Uranium Enrichment Mission Needs and Improve Technology Cost Estimates (2018).

[110] SOUTH CAROLINA PUBLIC SERVICES COMMISSION, Direct testimony of Tom A. Brookmire on behalf of Dominion Energy South Carolina, Inc. (2021).

[111] BWX TECHNOLOGIES, INC., BWXT Nuclear Energy Canada Awarded CA$168 Million Contract Extension for OPG Nuclear Fuel Manufacturing, BWX Technologies (12 Mar. 2018).

[112] DENISON MINES, Corporate Update - March 2024, Denison Mines, Toronto (2024).

[113] SPROTT PHYSICAL URANIUM TRUST, Investor Presentation – December 31, 2023, SPUT, Toronto (2024).

[114] URANIUM ROYALTY CORP., Condensed interim consolidated financial statements for the three and nine months ended January 31, 2024, URC, Vancouver (2024).

[115] WESTINGHOUSE ELECTRIC COMPANY LLC, Watt New Aggregator LP Consolidated Financial Statements as at December 31, 2023 and 2022, Watt New Aggregator LP, Grand Cayman (2024).

[116] LOUISIANA ENERGY SERVICES LLC, Consolidated Financial Statements as of and for the Years Ended 31 December 2023 and 2022, Louisiana Energy Services, Delaware (2024).

[117] CENTRUS ENERGY CORP., Annual report pursuant to section 13 or 15(d) of the securities exchange act of 1934. For the fiscal year ended December 31, 2023, Centrus Energy Corp., Bethesda (2024).

[118] U.S. DEPARTMENT OF ENERGY, Tritium and Enriched Uranium Management Plan Through 2060 – Report to Congress (2015).

[119] WORLD NUCLEAR NEWS, First contracts awarded for US strategic uranium reserve, WNN (16 Dec. 2022).

[120] S&P GLOBAL, US DOE awards $14 million to US uranium converter for reserve program, S&P Global (5 Jan. 2023).

[121] NUCLEOELÉCTRICA ARGENTINA S.A., Statements of Financial Position 2023, NASA, Buenos Aires (2024).

[122] DIOXITEK S.A., Annual Report and Financial Statements as of December 31, 2022, Fiscal Year No. 27, Dioxitek SA, Buenos Aires (2023).

[123] ELECTRONUCLEAR S.A., Explanatory notes to the financial statements for the year ended December 31, 2023, Electronuclear S.A., Rio de Janeiro (2024).

[124] INDUSTRIAS NUCLEARES DO BRASIL, Management Report 2023, INB, Rio de Janeiro (2024).

[125] THE BUSINESS STANDARD.NET, Bangladesh to receive nuclear fuel for Rooppur plant in September, TBS (24 Jun. 2024).

[126] CCTV.COM, China proposes for the first time the strategy of establishing a natural uranium reserve to promote the development of nuclear power, CCTV (14 Apr. 2007) (in Chinese).

[127] MIN-YOUNG, J., China to push for uranium stockpiling, Energy & Environmental News (18 Apr. 2007) (in Corean).

[128] CHINA NUCLEAR POWER GRID, With so many nuclear power plants build, where does uranium come from?, China Nuclear Power Grid (2022) (in Chinese).

[129] POWER.IN-EN.COM, Zhu Ji, deputy to the National People's Congress and chairman of Sichuan Honghua Industrial Co., Ltd.: the establishment of my country's low-enriched uranium reserve system is imminent, Power In-En (2021).

[130] CHINA NATIONAL NUCLEAR POWER CO. LTD, China National Nuclear Power Co., Ltd. 2023 Annual Report, CNNP, Beijing (2024) (in Chinese).

[131] CHINA GENERAL NUCLEAR POWER GROUP, Professionalism Achieves a Bright Future - 2023 Annual Report, CGN Power Co., Ltd., Shenzhen (2024).

[132] NUCLEAR POWER CORPORATION OF INDIA LIMITED, Standalone Audited Financial Results for the Quarter and Year Ended 31 March 2024, NPCIL, Mumbai (2024).

[133] URANIUM CORPORATION OF INDIA LIMITED, Annual Report 2023-24, UCIL, Jadugora (2025).

[134] NIKKEI.COM, Government to stockpile uranium for nuclear power plant orders, Nikkei (16 Jan. 2011) (in Japanese).

[135] JUDGIT.NET, Subsidy for enriched uranium stockpiling Project, Judgit.

[136] CENTRAL RESEARCH INSTITUTE OF ELECTRIC POWER INDUSTRY, Potential effects of nuclear fuel stockpiling - Estimation results using 2016 data, Tokyo (2018).

[137] JAPANESE NATIONAL REGULATORY AUTHORITY, Results of safeguards activities in Japan in 2023 (2024) (in Japanese).

[138] NIKKEI.COM, TEPCO to reduce uranium fuel inventories, Nikkei (18 May 2015) (in Japanese).

[139] KOREA HYDRO & NUCLEAR POWER CO., LTD., Consolidated Financial Statements as of December 31, 2023, KHNP, Gyeongju (2024).

[140] KEPCO NUCLEAR FUEL CO., LTD., Summary Financial Statements (1st quarter of 2024), KNF, Daejon (2024).

[141] DIGITAL TIMES.CO.KR, Uranium prices soar... Is the unit price of nuclear power plant going up?, Digital Times (24 Mar. 2022) (in Korean).

[142] SE-YOUNG, J., Is there any problem with Korean uranium supply? Participate in the US HALEU supply chain or establish a self-sufficiency base, Electric Newspaper (2 Jan. 2023) (in Korean).

[143] HEE-MIN, A., Uranium $100 Era... Hanwha Solutions "Sufficient Stockpiles" Hankooki Daily (23 Jan. 2024) (in Korean).

[144] TAIWAN POWER COMPANY, 2018 Sustainability Report (2018) (in Chinese).

[145] TAIPOWER.COM, Current status of nuclear IV fuel, Taiwan Power Company (18 Nov. 2024) (in Chinese)

[146] TAIWAN MINISTRY OF ECONOMIC AFFAIRS, The fourth nuclear fuel is transported to Taipower: follow the resolution of the Legislative Yuan's third reading and it has nothing to do with restarting the referendum. The fuel has expired and must be shipped back to the original factory, Taiwan Ministry Of Economic Affairs (29 Mar. 2021) (in Chinese).

[147] FOCUS TAIWAN, Nuclear fuel rods in No. 4 plant to be removed within 3 years, Focus Taiwan (13 Mar. 2017).

[148] LEGISLATIVE YUAN, REPUBLIC OF CHINA (TAIWAN), 2019 Annual Operating Budget Evaluation Report of Taiwan Electric Power Co., Ltd. (2019) (in Chinese).

[149] ENERGY TREND, Taiwan's Government Faces Increasing Costs of Dismantling No. 4 Nuclear Power Plant and Selling Its Fuel Rods, Energy Trend (13 Jul. 2018).

ANNEX: CONTENTS OF THE SUPPLEMENTARY ELECTRONIC FILES

Supplementary electronic excel file with tables of uranic inventories by country and region.

LIST OF ABBREVIATIONS

AECC	Angarsk Electrolysis Chemical Complex
AEOI	Atomic Energy Organization of Iran
AEP	Atomenergoprom
AGR	Advanced gas cooled reactor
ANDRA	National Agency for Radioactive Waste Management (Japan)
BWR	Boiling water reactor
CANDU	CANada Deuterium Uranium
CFE	Comisión Federal de Electricidad
CNEIC	China Nuclear Energy Industry Corporation
DAE	Department of Atomic Energy
DBOT	Down Blending Offering for Tritium
EDF	Électricité de France
EIA	Energy Information Administration
ENEC	Emirates Nuclear Energy Corporation
ERU	Enriched reprocessed uranium
ESA	Euratom Supply Agency
EU	European Union
EUP	Enriched uranium product
FBR	Fast breeder reactor
FIFO	First-in-first-out
HALEU	High assay low enriched uranium
HEU	Highly enriched uranium
INB	Industrias Nucleares do Brasil
IUEC	International Uranium Enrichment Centre
JIT	Just-in-time

KEPCO	Korea Electric Power Corporation
KHNP	Korea Hydro & Nuclear Power
KNF	KEPCO Nuclear Fuel
LES	Louisiana Energy Services
LEU	Low enriched uranium
LWGR	Light water graphite reactor
LWR	Light water reactor
MOX	Mixed oxide
NatU	Natural uranium
NASA	Nucleoeléctrica Argentina SA
NEA	Nuclear Energy Agency
NEK	Nuklearna elektrarna Krško
NFP	Nuclear fuel plant
NPCIL	Nuclear Power Corporation of India Ltd.
NRA	Nuclear Regulatory Authority (Japan)
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
PAEC	Pakistan Atomic Energy Commission
PHWR	Pressurized heavy water reactor
PRIS	Power Reactor Information System
PWR	Pressurized water reactor
RepU	Reprocessed uranium
SE	Slovenské Elektrárne
SWe	Separative work equivalent
SIU	Slightly irradiated uranium
SPUT	Sprott Physical Uranium Trust
STUK	Finnish Radiation and Nuclear Safety Authority

SWU	Separative work unit
TENEX	Techsnabexport
TVA	Tennessee Valley Authority
UAM	Uranium Asset Management
US DOE	United States Department of Energy
VVER	water-water energetic reactor
WIP	Work in progress
WNA	World Nuclear Association

URANIUM WEIGHT CONVERSION FACTORS

Expressed form:	**Commonly reported as:**	**Conversion factor to kgU:**
Natural uranium concentrates	lbs U_3O_8	x 2.61285
Natural uranium concentrates	kg U_3O_8	x 0.848001
Natural uranium hexafluoride	kgUF_6 as feed material	x 0.676181
Enriched uranium hexafluoride	kgUF_6 as enriched uranium	x 0.676181
Enriched uranium dioxide	kgUO_2 as enriched uranium	x 0.881498
Fabricated fuel (LWR)	kg fabricated fuel	x 0.65 or x 0.7 (approx.)
Fabricated fuel (VVER 1000/1200)	kg fabricated fuel	x 0.65 (approx.)
Fabricated fuel (VVER 440)	kg fabricated fuel	x 0.55 (approx.)

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