TECHNICAL REPORTS SERIES No. 425

Country Nuclear Fuel Cycle Profiles

Second Edition

IAEA
International Atomic Energy Agency

COUNTRY NUCLEAR FUEL CYCLE PROFILES

Second Edition

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BANGLADESH
BELARUS
BELGIUM
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHILE
CHINA
COLOMBIA
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LATVIA
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SERBIA AND MONTENEGRO
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIETNAM
YEMEN
ZAMBIA
ZIMBABWE

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".

TECHNICAL REPORTS SERIES No. 425

COUNTRY NUCLEAR FUEL CYCLE PROFILES

SECOND EDITION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2005

Sales and Promotion Unit, Publishing Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna
Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
http://www.iaea.org/books

Printed by the IAEA in Austria
May 2005
STI/DOC/010/425

IAEA Library Cataloguing in Publication Data

Country nuclear fuel cycle profiles. — 2nd edn — Vienna : International Atomic Energy Agency, 2005.
p. ; 24 cm. — (Technical reports series, ISSN 0074–1914 ; no. 425)
STI/DOC/010/425
ISBN 92–0–114803–8
Includes bibliographical references.

1. Nuclear fuels. 2. Reactor fuel reprocessing. 3. Nuclear power plants. I. International Atomic Energy Agency. II. Series: Technical reports series (International Atomic Energy Agency) ; 425.

IAEAL 05–00401

FOREWORD

In recent years, activities related to the nuclear fuel cycle have expanded globally. In addition, the complexity of the nuclear fuel cycle market has increased with the emergence of new providers of fuel cycle services.

In this context a need was perceived for a compilation of country profiles on nuclear fuel cycle activities in a form which could be easily understood both by experts and by the public, and which should lead to a greater understanding of these activities worldwide. Furthermore, such information would improve the transparency of nuclear energy development in general.

The first edition was published in 2001, showing the status of the nuclear fuel cycle at the end of 1999. This second edition has been prepared on the basis of available documents and comments received from experts who participated in a consultants meeting held in 2002 and a technical committee meeting held in 2003. It also reflects the comments received in response to IAEA Circular Note 651.T1.41.Circ, which was sent to selected countries at the end of 2002. Essentially it shows the status of the nuclear fuel cycle at the end of 2002 and consists of two parts: the first part is a review of worldwide activities related to the nuclear fuel cycle; the second comprises the country profiles, reflecting each country's status with regard to fuel cycle activities. The second part also incorporates graphical representations of the flow of material in the nuclear fuel cycle of each country.

The scope of this publication is confined to commercial nuclear activities. Information on research reactors, fuel cycle facilities at the pilot plant stage and experimental facilities is thus not included in this report.

The IAEA wishes to express its gratitude to the chairperson, A. Grigoriev, and to the participants of the various meetings. The IAEA officers responsible for this publication were Y. Hosokawa and K. Kawabata of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

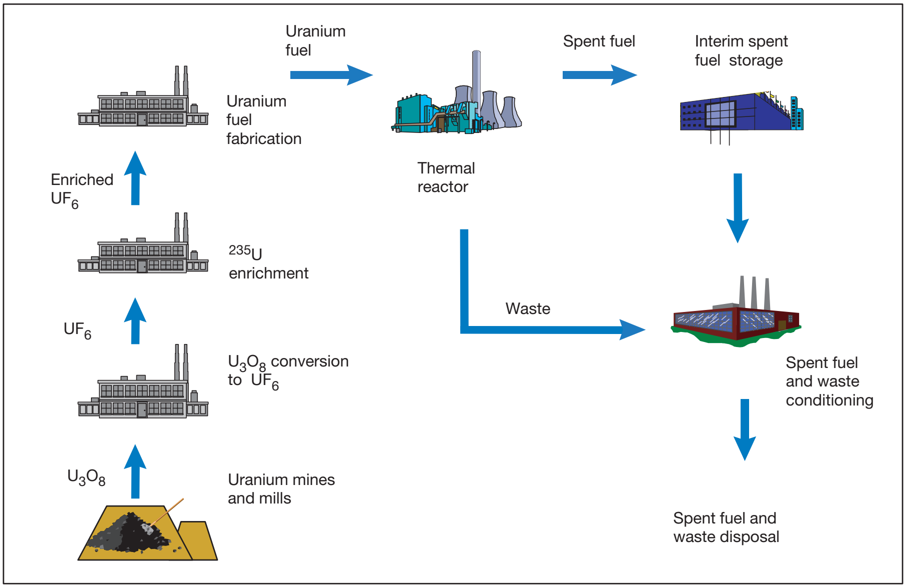
1.1. BACKGROUND

In recent years globalization of the nuclear fuel cycle has become evident. For example, Asia has not only emerged as a market for power reactors but also as a supplier of nuclear fuel and related fuel cycle components and services. Countries comprising the former Soviet Union and eastern European countries are now active participants in the nuclear fuel cycle market worldwide. The interactions of the nuclear fuel cycle market have become more complex with the emergence of new providers of fuel cycle services.

In this context, a need was perceived for a compilation of country profiles on nuclear fuel cycle activities in a form which can be easily understood both by experts and by the public, and which should lead to a greater understanding of these activities worldwide. Furthermore, such information would improve the transparency of nuclear energy development in general.

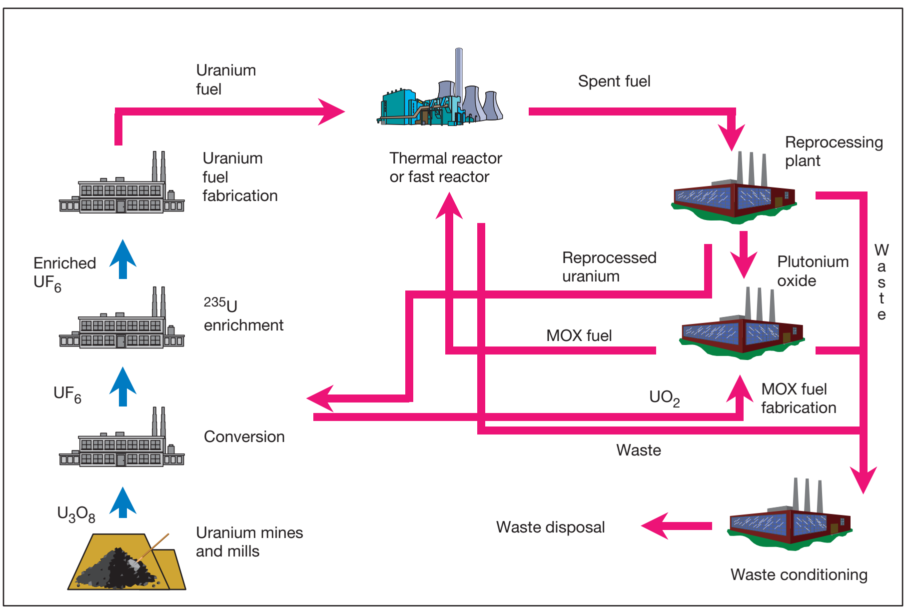
This second edition of the original publication published in 2001 updates data on the world's nuclear fuel cycle facilities and international relationships with respect to each component of the nuclear fuel cycle. Since 2001 the world's nuclear fuel cycle industry has been reshaped and competitive pressures have forced a realignment in the supply/demand balance. With respect to the mining and milling sector, mining activities in France, Portugal and Spain have ceased. In conversion, British Nuclear Fuels Ltd (BNFL) has announced that it will shut its Springfields plant in 2006 following the cessation of fuel production for its Magnox reactors. In the enrichment sector, USEC Inc. shut down its Portsmouth gaseous diffusion plant in the United States of America. Consolidation has given rise to three 'mega-suppliers' in the nuclear fuel fabrication sector which dominate the world market. There have been other developments in this period, such as capacity changes of many facilities and material flow changes.

There are two common types of nuclear fuel cycle. One is the 'open' fuel cycle (Fig. 1), in which the spent fuel is not reprocessed but kept in storage pending disposal as waste. The other is the 'closed' fuel cycle (Fig. 2), where the spent fuel is reprocessed and the residual uranium and plutonium are separated from the waste products. Both the uranium and the plutonium can be recycled into new fuel elements for use in thermal and fast reactors.



U_3O_8: yellowcake
UF_6: uranium hexafluoride

FIG. 1. Open fuel cycle.



U_3O_8: yellowcake
UF_6: uranium hexafluoride
MOX: mixed oxide fuel (uranium/plutonium)

FIG. 2. Closed fuel cycle.

1.2. SCOPE

This publication presents an overall review of worldwide nuclear fuel cycle activities, followed by country specific nuclear fuel cycle information. This information is presented in a concise form and focuses on the essential activities related to the nuclear fuel cycle in each country operating commercial nuclear power reactors or providing nuclear fuel cycle services. It also includes country specific diagrams which illustrate the main material flow in the nuclear fuel cycle. These illustrations are intended to help clarify understanding of both the essential nuclear fuel cycle activities in each country and international relationships.

1.3. STRUCTURE

Section 2 provides a review of worldwide nuclear fuel cycle activities, dealing with mining and milling, conversion, enrichment, fuel fabrication, heavy water production, spent fuel management, and the dismantling of facilities. Individual country profiles are then given in Section 3.

2. REVIEW OF WORLDWIDE NUCLEAR FUEL CYCLE ACTIVITIES

2.1. TRENDS

The world's nuclear fuel cycle industry has been reshaped in the past few years as it has responded to increased competition brought about by electricity market internationalization, liberalization and deregulation. In addition, the introduction of excess nuclear materials from military programmes has had an effect on the market. These competitive pressures have driven the industry to improve operations and forced a realignment in the supply–demand balance.

Reactor operating organizations have responded by shutting down uneconomical plants, reducing maintenance outage times, increasing plant operating levels and capacity factors, and consolidating ownership of facilities. These actions have reduced operating costs and increased the competitiveness of nuclear power generation.

In response to the increased competition among electricity producers, reactor operating organizations have sought lower prices for the necessary fuel cycle commodities and services and increased flexibilities in supply contracts. The fuel cycle industry has responded by shutting down uneconomical plants and consolidating ownership.

In the natural uranium market today, only three companies control nearly 50% of total primary production. With the low prices for natural uranium in the past several years it was inevitable that the smaller producers would exit the market and some mining operations would be closed.

The conversion industry is responding to the competitive pressures by shutting down plants as they become uneconomical. BNFL has announced that it will shut its Springfields plant in 2006 following the cessation of fuel production for its Magnox reactors. The UF_6 conversion plant shares facilities with the Magnox fuel production operations and UF_6 conversion will no longer be economical when the Magnox programme is stopped. Five suppliers will serve the world's conversion industry following the Springfields shutdown.

With only four main suppliers in the world enrichment market, further ownership consolidation is less likely than in other segments of the fuel cycle. Excess supply capacity is being addressed by the shutdown of old production facilities. For example, USEC Inc. recently shut down the Portsmouth gaseous diffusion plant in the USA.

The nuclear fuel fabrication market has undergone considerable changes in the past few years, going from a closed domestic market to an open international market. Oversupply has existed for many years in this market that was served by 16 suppliers delivering in excess of 25 fuel designs. This constituted a specialized service rather than the supply of a commodity on an industrial scale. The nuclear fuel fabrication segment has responded to the market pressure by shutting down facilities and consolidating ownership. Consolidation has given rise to 3 mega-suppliers which dominate the world market. Oversupply still exists and it is likely that additional facilities will be shut down in the near future to bring the supply–demand balance more into line.

In 1999, BNFL acquired the Westinghouse Electric Company and in the following year purchased ABB's nuclear business. The integration of these three companies has led to the rebranding of ABB's nuclear operations and BNFL's fuel activities as Westinghouse.

In 2001 the nuclear activities of Framatome and Siemens merged into a new company, Framatome ANP. This company has been integrated into the AREVA Group with Cogéma and other subsidiaries of CEA Industrie. This new group provides services in all segments of the nuclear industry.

2.2. MINING AND MILLING

Uranium is an element that is widely distributed within the earth's crust. Its principal use is as the primary fuel for nuclear power programmes. Naturally occurring uranium is composed of 99.3% ^{238}U and only 0.7% ^{235}U. ^{235}U is the fissile isotope of uranium, i.e. its atoms have a high probability of undergoing fission after capture of a slow neutron.

Commercial uranium mining activities have tended to exploit ores with grades ranging up to about 20% U. Uranium is extracted by three basic processes: underground mining, open pit mining and in situ leaching (ISL). Underground mining is used to exploit orebodies lying well below the earth's surface. This is a traditional process of mineral extraction, with shafts sunk into the earth in order to gain access to the uranium ore. Open pit mining is used on orebodies lying nearer to the surface. With both of these processes, the ore is transported to a processing facility (mill) in which the uranium is separated from the ore. In situ leaching is a process that does not require the removal of solid ore from the ground. Instead the uranium is extracted from the ore in situ by the use of a leaching solution. In addition to being mined as a primary ore, uranium is also recovered as a by-product from the mining of other minerals, such as gold, copper and phosphate.

Once the uranium ore has been extracted, it is processed in a mill where the uranium is leached from the ore using either an acid or an alkaline leaching solution. The uranium is recovered from this solution, or from ISL solutions, using an ion exchange or solvent extraction process. The usable mill product is a uranium oxide concentrate termed yellow cake. The yellow cake is usually heated to remove impurities, thus increasing the U_3O_8 concentration.

The U_3O_8 may be used in any nuclear power programme. It is, therefore, a commodity that is traded daily in the world nuclear fuel market. Users of U_3O_8 (i.e. nuclear utilities) generally seek out supply sources on the basis of price and supply security issues, but other factors such as supply diversification and government involvement in production operations can impact procurement decisions. A typical LWR (900 MW(e)) in current operation uses about 160 t U of natural uranium annually. At present, the main uranium producing countries are Australia, Canada, China, Kazakhstan, Namibia, Niger, the Russian Federation, South Africa, the USA and Uzbekistan.

2.3. CONVERSION

The term 'conversion' refers to the process of purifying the uranium concentrate and converting it to the chemical form required for the next stage of the fuel cycle. There are 3 such forms in common use: metal, oxide (UO_2) and uranium hexafluoride (UF_6).

Uranium hexafluoride is the predominant product at this stage of the nuclear fuel cycle since it is easily converted to a gas for the enrichment stage, as employed for PWRs, BWRs, AGRs, etc. Normally, the utility purchases U_3O_8 and supplies it to the converter. While awaiting conversion, the uranium concentrate is treated as a fungible commodity. In other words, a utility can consign its uranium to any conversion plant and the product can be sent to any enrichment plant (subject only to limitations which apply to material of certain origins and which are based on trade restrictions between countries). Six countries operate commercial scale U_3O_8 to UF_6 conversion facilities: Canada, China, France, the Russian Federation, the UK and the USA.

In Canada, Cameco operates the Port Hope facility (capacity 12 500 t U/a). In China, the China National Nuclear Corporation (CNNC) operates the Lanzhou plant (capacity 1500 t U/a). In France, Comurhex operates the Malvesi and Pierrelatte plants (total capacity 14 000 t U/a). In the Russian Federation, Minatom operates the Tomsk and Angarsk plants (total capacity 30 000 t U/a). In the UK, BNFL operates the Springfields Line 4 plant (capacity 6000 t U/a). In the USA, Converdyn operates the Metropolis plant (capacity 14 000 t U/a).

For the CANDU fuel cycle, which generally uses natural uranium oxide as the fuel, conversion to UF_6 is unnecessary. Uranium is purified and converted to UO_2 or UO_3 in Argentina, Canada (Blind River and Port Hope), China, India and Romania.

The Magnox fuel cycle uses natural uranium metal as fuel. Only the UK has such reactors in operation and only BNFL operates a large scale facility for the production of metal.

The introduction of reprocessed uranium (REPU) into the fuel cycle has led to plans for the construction of facilities dedicated to the production of UF_6 from REPU. These include the Comurhex's Pierrelatte 2 plant (France) and BNFL's Line 3 plant (UK).

2.4. ENRICHMENT

In the nuclear power industry, enrichment is the process of increasing the amount of ^{235}U contained in a unit quantity of uranium, the predominant isotope being ^{238}U. Two main technologies currently exist for the commercial enrichment of uranium. The older technology is gaseous diffusion. In gaseous diffusion, separation is achieved by virtue of the faster rate of diffusion of ^{235}U through a porous membrane relative to ^{238}U, the uranium being in the form of gaseous UF_6. This process is energy intensive and requires very large plants for economically viable operation.

The more recent technology is centrifuge enrichment, which relies on the application of extremely high rotational speeds to separate the lighter ^{235}U from the ^{238}U, again present in the form of gaseous UF_6. The separation is effected in cylinders. This technology can be developed in a modular way, allowing expansion of the facility according to demand.

Some countries have investigated other isotope separation technologies. Most of these involve separation by atomic and molecular laser excitation. None of the technologies has been commercialized and it is unlikely that commercialization will be achieved in the near future.

Enrichment is expressed in terms of separative work units (SWUs), which are a measure of the amount of work performed in separating the two isotopes. The number of SWUs required to produce fuel depends not only on the quantity and enrichment required, but also on the enrichment of the feed (usually 0.7%) and the tails assay, which is a measure of the amount of ^{235}U remaining with the depleted stream.

Six organizations operate commercial scale enrichment plants: CNNC, Eurodif, Minatom, Japan Nuclear Fuel Limited (JNFL), Urenco Ltd and USEC Inc. CNNC operates two centrifuge plants with a total capacity of 1.0 million SWU/a. Eurodif is a joint venture of Belgium, France, Italy and Spain and operates one diffusion plant at Tricastin, France (10.8 million SWU/a). Minatom, the Russian Federation's organization, operates centrifuge plants at Ekaterinburg, Krasnoyarsk, Tomsk and Angarsk with a total capacity of 15 million SWU/a. In Japan, JNFL has operated a plant with a capacity of 1.1 million SWU/a since 1992. Urenco Ltd is a joint venture of companies in Germany, the Netherlands and the UK and operates facilities at Gronau (Germany), Almelo (Netherlands) and Capenhurst (UK). All the facilities are centrifuge plants with a total capacity of 5.95 million SWU/a. USEC Inc., which was privatized in 1998, operates a diffusion plant at Paducah, Kentucky (11.3 million SWU/a).

In recent years the introduction of enriched uranium derived from materials excess to defence programmes in the Russian Federation and the USA has in effect resulted in the introduction of a significant new supply source (~5.5 million SWU/a).

Since REPU contains isotopes that are difficult to handle at a diffusion plant, the low inventory and modular design of a centrifuge enrichment plant is preferred for its enrichment.

A typical LWR (900 MW(e)) needs about twenty tonnes of heavy metal (HM) fuel annually. In cases where fuel is made from natural uranium it is enriched to about 4% ^{235}U from roughly 160 t U of UF_6 feed by the expenditure of about 100 000 SWU.

2.5. FUEL FABRICATION

The feed material for the manufacture and fabrication of fuel for reactors utilizing enriched uranium is UF_6 enriched to about 3–5% ^{235}U. UF_6 is converted to UO_2 powder which is formed into pellets, sintered to achieve the desired density and ground to the required dimensions. Fuel pellets are loaded into tubes of zirconium alloy or stainless steel, which are sealed at both ends. These fuel rods are spaced in fixed parallel arrays to form reactor fuel assemblies.

Mixed oxide (MOX) fuel consists of a mixture of plutonium and uranium oxide. Its fabrication requires the use of purpose-built facilities in order to handle plutonium radiotoxicity and to satisfy safeguards requirements. The use of MOX fuel in some European countries (Belgium, France, Germany and Switzerland) and its future use in Japan will require additional MOX fuel fabrication capacity. Plans to use MOX fuel in the USA and in the Russian Federation are limited to the disposal (by burning in commercial reactors) of plutonium formerly used in nuclear weapons.

PHWR fuel fabrication uses natural or slightly enriched UO_2 as a feed material. Sintered fuel pellets are loaded into zirconium alloy tubes which are then sealed at both ends. These fuel rods are spaced and arranged in a cylindrical array to form a fuel bundle.

Current world uranium fuel fabrication capacity exceeds demand. Industry consolidation has proceeded rapidly in recent years as companies have merged and formed alliances in order to secure favourable positions in the highly competitive market for services in this segment of the nuclear fuel cycle. While adjustments to the supply and demand balance for fuel fabrication are likely to be made in the coming years in response to market forces, other factors will also affect the balance, including national policies and strategies for domestic supply capability.

In 2002, fuel for commercial nuclear reactors was fabricated in 18 countries. These countries have a total fabrication capacity of about 19 000 t U/a (fuel assemblies and elements).

Nuclear fuel requirements worldwide in 2002 were estimated to be around 10 000 t HM, which is equivalent to about 53% of the total fabrication capacity. Nevertheless, a number of countries are embarking on national programmes to set up domestic capabilities for reactor fuel fabrication. These include countries with established nuclear power programmes (e.g. Brazil, China, India, the Republic of Korea, Romania) and those planning to initiate nuclear programmes. The overcapacity is mostly attributable to LWR uranium fuel fabrication which has about twice the capacity required.

The technical challenge for the fabrication industry in the coming years will be the design of fuel assemblies capable of achieving higher burnup. This will require adaptations to fuel fabrication facilities.

2.6. HEAVY WATER PRODUCTION

Heavy water is required as a moderator and coolant for PHWRs. Heavy water represents about 10% of the operational cost of PHWRs. Several processes are available for the commercial production of heavy water, the most widely used being the Girdler–sulphide and ammonia–hydrogen processes. Heavy water can also be recovered by means of the electrolytic hydrogen process and from a laser based process. Both processes are still in the research phase and are not currently operating on a commercial scale. The main suppliers of heavy water are Argentina, China, India and Romania.

2.7. SPENT FUEL MANAGEMENT

In the early days of the nuclear power industry the accepted assumptions were that spent fuel would be reprocessed and that the recovered uranium and plutonium would be recycled. This situation arose as a consequence of the predicted growth of nuclear programmes and the scarcity of proven uranium resources. However, the scaling back in the construction of new reactors, the discovery of new uranium resources and the use of fissile materials from nuclear weapons programmes have reduced the pressure for recycling recovered uranium and plutonium. The reprocessing technology is available and proven and several countries have decided to implement it in their nuclear programmes.

Some countries or electric utilities have judged it to be more advantageous to implement the open fuel cycle, in which the spent fuel elements discharged from the reactor core are stored. After a period of interim storage, the fuel will be conditioned and disposed of directly in a deep geological repository. Both the open and closed approaches have their respective advantages and disadvantages.

Many countries with nuclear programmes are using the ‘deferral of a decision’ approach combined with interim storage, which provides the opportunity to monitor the storage continuously and to retrieve the spent fuel later for either direct disposal or reprocessing. Some countries use both approaches in their nuclear programmes.

Discharged fuel elements may be placed in dry storage after having resided in the spent fuel pool for a period of several years. The final destination of these spent fuel elements, or of the waste resulting from reprocessing, is a deep geological repository. In many countries, spent fuel is currently being stored in at reactor (AR) or away from reactor (AFR) facilities.

2.8. DISMANTLING OF NUCLEAR FUEL CYCLE FACILITIES

Dismantling and decommissioning of shut down facilities is an integral part of the world nuclear fuel cycle. The processes include the dismantling of physical plant structures, the isolation, treatment and disposal of the resulting waste products, and the restoration of the plant site for future use.

In the past several years some nuclear fuel cycle facilities have been permanently shut down. Some of these facilities have been fully dismantled and the sites have been restored to green field status. Other facilities are still undergoing dismantling. The technologies for these activities are well established and have already been applied to numerous facilities associated with the nuclear fuel cycle worldwide.

Examples of nuclear fuel cycle facility decommissioning successes exist in numerous countries in the world. Tables 1–3 provide capacity data on specific aspects of nuclear fuel cycle facilities (NFCFs).

TABLE 1. CAPACITY OF NUCLEAR FUEL CYCLE FACILITIES RELATED TO LWRs, AGRs AND FRs

Type of facility	Capacity (t HM/a)
Conversion to UF_6	78 452
Enrichment	45 125 (10^3 SWU/a)
Fuel fabrication	13 458
Reprocessing	4 920

Note: The number of LWRs (PWR, BWR, WWER, RBMK) and other reactors (AGR, FR) connected to the grid which use enriched fuel is 379.

TABLE 2. CAPACITY OF NUCLEAR FUEL CYCLE FACILITIES RELATED TO PHWRs AND GCRs

Type of facility	Capacity (t HM/a)
Conversion to UO_2 and U	5 260
Fuel fabrication	5 450

Note: The number of PHWRs and GCRs connected to the grid is 53.

TABLE 3. CAPACITY OF NATIONAL NUCLEAR FUEL CYCLE FACILITIES

Country	Facility				
	Mining and milling (t U/a)	Conversion to UF_6 (t U/a)	Enrichment (10^3 SWU/a)	Fuel fabrication (t HM/a)	Reprocessing (t HM/a)
Argentina	120	62	20	150	
Armenia					
Australia	9 438				
Belgium				435	
Brazil	340	40		280	
Bulgaria					
Canada	14 890	12 500		2 700	
China	840	1 500	1 000	400	
Czech Republic	650				
Finland					
France		14 350	10 800	1 585	1 700
Germany			1 800	650	
Hungary					
India	175			594	—
Japan			1 050	1 689	120
Kazakhstan	5 950				
Korea, Rep. of				800	

TABLE 3. CAPACITY OF NATIONAL NUCLEAR FUEL CYCLE FACILITIES (cont.)

Country	Facility				
	Mining and milling (t U/a)	Conversion to UF_6 (t U/a)	Enrichment (10^3 SWU/a)	Fuel fabrication (t HM/a)	Reprocessing (t HM/a)
Lithuania					
Mexico					
Mongolia					
Namibia	4 000				
Netherlands			2 500		
Niger	3 800				
Pakistan	30		5	20	
Portugal					
Romania	300			110	
Russian Federation	4 200	30 000	15 000	2 600	400
Slovakia					
Slovenia					
South Africa	1 272				
Spain				400	
Sweden				600	
Switzerland					
Ukraine	1 000				
UK		6 000	2 300	1 680	2 700
USA	1 150	14 000	11 300	3 450	
Uzbekistan	2 300				

Tables 4–8 illustrate international relationships with respect to each component of the nuclear fuel cycle by presenting supply and demand data for: uranium; conversion UF_6; enrichment; fuel fabrication; and fuel reprocessing. As shown in these tables, international relationships in nuclear fuel cycle services have become more complex in recent years.

TABLE 4. URANIUM (U_3O_8): SUPPLY/DEMAND

Country	Supplier					
	Australia	Canada	Former Soviet Union	USA	Domestic	Others
Argentina					×	×
Armenia			×			
Belgium	×	×		×		×
Brazil					×	
Bulgaria			×			
Canada	×			×	×	
China					×	
Czech Republic			×		×	
Finland	×	×	×	×		×
France	×	×	×	×		×
Germany	×	×	×	×		×
Hungary			×			
India					×	
Japan	×	×		×		×
Kazakhstan					×	
Korea, Rep. of	×	×	×	×		×
Lithuania			×			
Mexico		×				×
Netherlands						×
Pakistan		×				×
Romania					×	
Russian Federation					×	
Slovakia			×			
Slovenia		×	×	×		
South Africa					×	
Spain	×	×	×		×	×
Sweden	×	×	×			×
Switzerland	×	×	×			×
Ukraine			×		×	
UK	×	×	×	×		×
USA	×	×	×		×	×

TABLE 5. CONVERSION TO UF_6: SUPPLY/DEMAND

Customer	Supplier						
	Canada	France	Russian Federation	UK	USA	Domestic	Others
Argentina						×	
Armenia			×				
Belgium	×	×		×	×		
Brazil				×			
Bulgaria			×				
Canada							
China						×	
Czech Republic	×	×	×				
Finland	×	×	×	×			
France			×	×	×	×	
Germany	×	×	×	×	×		
Hungary			×				
India							×
Japan	×	×		×	×		
Kazakhstan							
Korea, Rep. of	×	×	×	×	×		
Lithuania			×				
Mexico	×	×					
Netherlands				×			
Pakistan							
Romania							
Russian Federation						×	
Slovakia			×				
Slovenia		×	×		×		
South Africa		×					
Spain	×	×	×	×	×		
Sweden	×	×	×	×	×		
Switzerland	×	×		×	×		
Ukraine			×				
UK	×	×	×			×	
USA	×	×	×	×		×	

TABLE 6. ENRICHMENT OF URANIUM: SUPPLY/DEMAND

Customer	Supplier					
	Eurodif	Minatom	Urenco Ltd	USEC Inc.	Domestic	Others
Argentina						
Armenia		×				
Belgium	×	×	×	×		
Brazil			×	×		
Bulgaria		×				
Canada						
China	×	×			×	
Czech Republic		×		×		
Finland		×	×			
France	×	×	×	×	×	
Germany	×	×	×	×	×	
Hungary		×				
India					×	×
Japan	×		×	×	×	
Kazakhstan		×				
Korea, Rep. of	×	×	×	×		
Lithuania		×				
Mexico				×		
Netherlands			×	×		
Pakistan						
Romania						
Russian Federation					×	
Slovakia		×				
Slovenia				×		
South Africa	×	×	×	×		
Spain	×	×	×	×		
Sweden	×	×	×	×		
Switzerland	×		×	×		
Ukraine		×				
UK		×	×	×	×	
USA	×	×	×		×	×

TABLE 7. FUEL FABRICATION: SUPPLY/DEMAND (FINISHED FUEL ASSEMBLIES)[a]

Customer	Supplier								
	Belgium	France	Germany	Russian Federation	Spain	Sweden	UK	USA	Domestic
Argentina									×
Armenia				×					
Belgium		×			×				×
Brazil									×
Bulgaria				×					
Canada									×
China		×		×					×
Czech Republic				×				×	
Finland		×			×	×	×		
France			×			×			×
Germany		×			×	×		×	×
Hungary				×					
India									×
Japan									×
Kazakhstan									
Korea, Rep. of									×
Lithuania				×					
Mexico								×	
Netherlands			×				×		
Pakistan									×
Romania									×
Russian Federation									×
Slovakia				×					
Slovenia								×	
South Africa		×							
Spain	×		×			×	×	×	×
Sweden		×			×				×
Switzerland		×				×	×	×	
Ukraine				×					
UK			×						×
USA						×			×

[a] This table also includes MOX fuel.

TABLE 8. REPROCESSING OF FUEL: SUPPLY/DEMAND (OXIDE AND METAL)

Customer	Supplier			
	France	Russian Federation	UK	Domestic
Belgium	×			
France				×
Germany	×		×	
Hungary		×		
India				×
Italy			×	
Japan	×		×	×
Netherlands	×		×	
Russian Federation				×
Spain			×	
Sweden			×	
Switzerland	×		×	
Ukraine		×		
UK				×

Tables 9–12 provide data on commercial nuclear fuel cycle facilities for UF_6 conversion, for enrichment, fuel fabrication and fuel reprocessing.

TABLE 9. COMMERCIAL UF_6 CONVERSION FACILITIES

Country	Facility name (or location)	Operating organization	Capacity (t U/a)	Start of operation
Canada	Port Hope	Cameco	12 500	1984
China	Lanzhou	CNNC	1 500	1963
France	Pierrelatte 2	Comurhex	350	1976
	Pierrelatte 1	Comurhex	14 000	1961
Russian Federation	Angarsk	Minatom	20 000	1954
	Tomsk	Minatom	10 000	1953
UK	Springfields Line 4	BNFL (Westinghouse)	6 000	1974/94
USA	Metropolis	Converdyn	14 000	1959

TABLE 10. COMMERCIAL ENRICHMENT FACILITIES

Country	Facility name (or location)	Operating organization	Capacity (10^3 SWU/a)	Enrichment process	Start of operation
China	Lanzhou	CNNC	500	Centrifuge	2002
	Shaanxi	CNNC	500	Centrifuge	1999
France	Tricastin (George Besse)	Eurodif	10 800	Gaseous diffusion	1979
Germany	Gronau	Urenco Ltd	1 800	Centrifuge	1985
Japan	Rokkasho-Mura 1	JNFL	600	Centrifuge	1992
	Rokkasho-Mura 2	JNFL	450	Centrifuge	1997
Netherlands	Almelo	Urenco Ltd	1 850	Centrifuge	1973
Russian Federation	Angarsk	Minatom	1 000	Centrifuge	1954
	Ekaterinburg	Minatom	7 000	Centrifuge	1949
	Krasnoyarsk	Minatom	3 000	Centrifuge	1964
	Tomsk	Minatom	4 000	Centrifuge (reprocessed U)	1953
UK	Capenhurst	Urenco Ltd	2 300	Centrifuge	1976
USA	Paducah	USEC Inc.	11 300	Gaseous diffusion	1954

TABLE 11. COMMERCIAL FUEL FABRICATION FACILITIES

Country	Facility name (or location)	Operating organization	Fuel type	Capacity (t HM/a)	Start of operation
		LWR			
Belgium	Dessel	Framatome ANP	LWR	400	1961
Brazil	Resende	Industrias Nucleares do Brasil S.A. (INB)	LWR	280	1982
China	Yibin	CNNC	LWR	200	1990
France	Romans	Framatome ANP	LWR	1 400	1979
Germany	Lingen	Framatome ANP	LWR	650	1979
India	Hyderabad	NFC	BWR	24	1974

TABLE 11. COMMERCIAL FUEL FABRICATION FACILITIES (cont.)

Country	Facility name (or location)	Operating organization	Fuel type	Capacity (t HM/a)	Start of operation
Japan	Tokai-Mura	MNF	PWR	440	1972
	Kumatori-machi	NFI	PWR	284	1972
	Tokai-Mura	NFI	BWR	200	1980
	Kurihama	GNF-J	BWR	750	1970
Kazakhstan	UST-Kamenogorsk	Ulba Metallurgical Company	WWER, RBMK (powder, pellets)	2 000	1949
Korea, Rep. of	Yuseong	Korea Nuclear Fuel Company Ltd (KNFC)	PWR	400	1989
Russian Federation	Elektrostal	JSC TVEL	LWR (WWER, PWR, RBMK)	1 520	1946
	Novosibirsk	JSC TVEL	LWR (WWER)	1 000	1949
Spain	Juzbado	ENUSA	LWR	400	1985
Sweden	Västerås	Westinghouse	LWR	600	1971
USA	Columbia	Westinghouse	PWR	1 250	1986
	Lynchburg	Framatome ANP	PWR	400	1982
	Richland	Framatome ANP	LWR	700	1970
	Wilmington	GNF	BWR	1 100	1982
		PHWR			
Argentina	Ezeiza	CNEA	PHWR	150	1982
Canada	Toronto	GE Canada Inc.	Pellets	1 300	1967
	Peterborough	GE Canada Inc.	PHWR	1 200	1956
	Port Hope	Zircastec Precision Industries Inc.	PHWR	1 500	1964
China	Baotou	CNNC	PHWR	200	2002
India	Hyderabad	NFC	PHWR	570	1974
Korea, Rep. of	Yuseong	KNFC	PHWR	400	1998
Pakistan	Chashma	PAEC	PHWR	20	1986

TABLE 11. COMMERCIAL FUEL FABRICATION FACILITIES (cont.)

Country	Facility name (or location)	Operating organization	Fuel type	Capacity (t HM/a)	Start of operation
Romania	FCN Pitesti	National nuclear power company	PHWR	110	1992
		Others			
UK	Springfields	Westinghouse	Magnox (GCR)	1 300	1960
	Springfields	Westinghouse	UO_2 AGR	260	1996
		FBR			
Russian Federation	Elektrostal	JSC TVEL	FBR	50	1946
		MOX fuel			
Belgium	Dessel	Belgonucléaire	LWR	35	1973
France	Cadarache	Cogéma	LWR	40	1961
	Marcoule-Melox	Cogéma	LWR	145	1995
UK	Sellafield SMP	BNFL (Westinghouse)	LWR	120	2001
Japan	Tokai-Mura	JNC	ATR	10	1972
			FBR	5	1988

TABLE 12. COMMERCIAL FUEL REPROCESSING FACILITIES

Country	Company	Facility name (or location)	Year of commissioning	Capacity (t HM/a)	Fuel type
France	Cogéma	UP2-UP3/La Hague	1976, 1989	1 700	LWR
India	DAE	Prefre-1, Tarapur	1977	—	PHWR
		Prefre-2, Kalpakkam	1996	—	PHWR
Japan	JNC	Tokai-Mura	1977	120	LWR, ATR
UK	BNFL	Thorp/Sellafield	1994	1 200	LWR, AGR
		B205 Magnox	1964	1 500	Magnox GCR
Russian Federation	Minatom	RT-1 Tcheliabinsk-65 Mayak	1977	400	WWER FR. Propulsion reactor

3. COUNTRY NUCLEAR FUEL CYCLE PROFILES

3.1. ARGENTINA

Nucleoeléctrica Argentina S.A. operates two nuclear power plants: Atucha 1, a pressure vessel type 357 MW(e) PHWR imported from Germany, and Embalse, a CANDU 648 MW(e) PHWR imported from Canada. The nuclear units account for less than 10% of the electricity generating capacity of the country and provided 7.5% of the electricity supply in 2002.

The new Government may decide on the completion of Atucha 2, a pressure vessel type 745 MW(e) PHWR of Siemens design. Construction of Atucha 2 is 85% complete (Fig. 3).

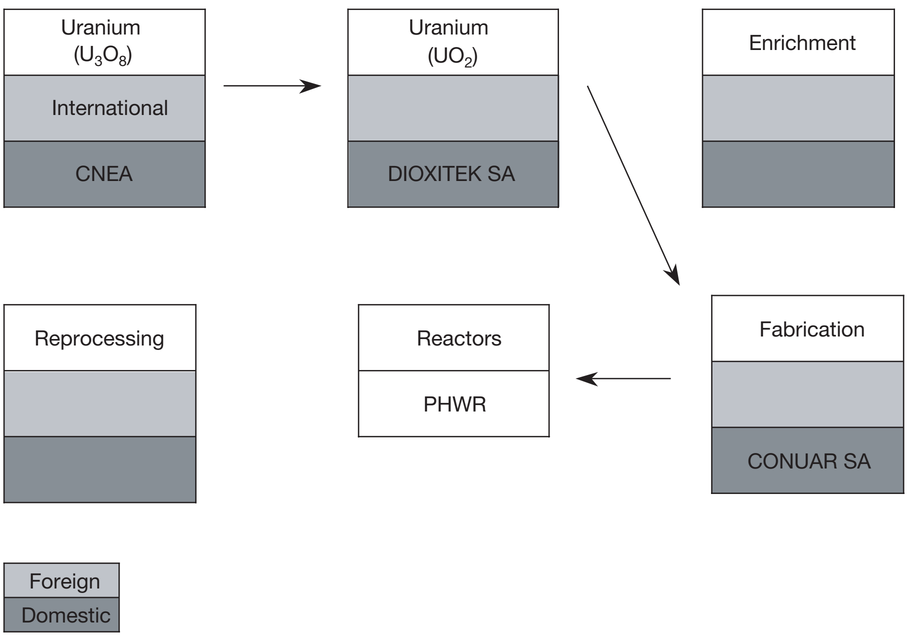


FIG. 3. Material flow in the nuclear fuel cycle: Argentina.

Nuclear fuel cycle policy[1]

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

For economic reasons, which favour the import of material bought on the spot market, the Sierra Pintada mine and milling centre at San Rafael, Mendoza was in operation at a low rate of production. The plant is not being started up at present due to changes in the dollar–peso exchange rate. The mine has reserves of 5000 t U and a yellow cake production capacity of 120 t HM/a. A call for international bids is under way for the exploration and exploitation of a new site in Chubut Province, with a reserve potential of at least 4000 t U.

Conversion

The Córdoba mill complex, which has a capacity of 150 t HM/a, is used for purifying yellow cake and for converting it to UO_2. This plant is expected to be moved in the near future for environmental reasons, but the decision is being discussed with the parties involved. The use of REPU as raw material for slightly enriched uranium fuel is under development. DIOXITEK S.A. operates this plant. The Pilcaniyeu conversion plant of the Comisión Nacional de Energía Atómica (CNEA), located near Bariloche in Rio Negro Province, has a capacity of 62 t HM/a (UO_2 to UF_6).

Enrichment

CNEA's gaseous diffusion pilot plant at Pileaniyeu has a capacity of 20 t SWU/a. The technology of this plant is in the process of being changed by the introduction of new types of axial compressors, a new generation of membranes, and a new gaseous diffusion stage concept called SIGMA. These developments may allow the plant to operate competitively at a low level of production of slightly enriched uranium material.

---

[1] Filled circle represents current policy.

Fabrication

A fuel fabrication plant with a capacity of 150 t HM/a for PHWR Atucha 1 type fuel assemblies and CANDU 600 fuel bundles is in operation at Ezeiza, fifty kilometres from Buenos Aires. A new fuel that fits both types of reactor and termed CARA is under development. The objectives of introducing the new fuel are to reduce the system's fuel costs by 30%, improve the performance of old CANDU reactors and improve safety. The operating organization of this plant is CONUAR S.A. The zirconium alloy tubes are produced by FAE S.A. in a plant next to CONUAR S.A. Atucha 1, originally designed to use natural uranium, is presently operating with a full slightly enriched uranium core at an 0.85% of enrichment.

Spent fuel management

The Atucha 1 nuclear power plant has 2 pools for the underwater storage of its spent fuel. The Embalse nuclear power plant has a pool with a spent fuel storage capacity of ten years and vertical dry silos. Atucha has started the evaluation of dry silo as a long term storage option, as the vertical silo there is currently in use at Embalse.

Heavy water production

The Arroyito heavy water production facility located in Neuquén Province is in operation and has a capacity of 200 t/a. This plant is operated by ENSI S.A.

3.2. ARMENIA

Armenia has one nuclear power plant at Metsamor, which consists of two power units with WWER-440/270 type reactors. Unit l started operation in 1976 and unit 2 in 1980. In 1989, after the country's destructive earthquake of late 1988, the plant was shut down even though it was undamaged. After the dissolution of the Soviet Union, Armenia lacked energy sources owing to the severe economic crisis and, in April 1993, the Government took the decision to restart unit 2. Unit 2 was put back into operation in November 1995, after 6.5 years of outage. In 2002 the plant produced 2.29 TW·h of electricity, equivalent to 40.5% of all electricity generated in Armenia (Fig. 4).

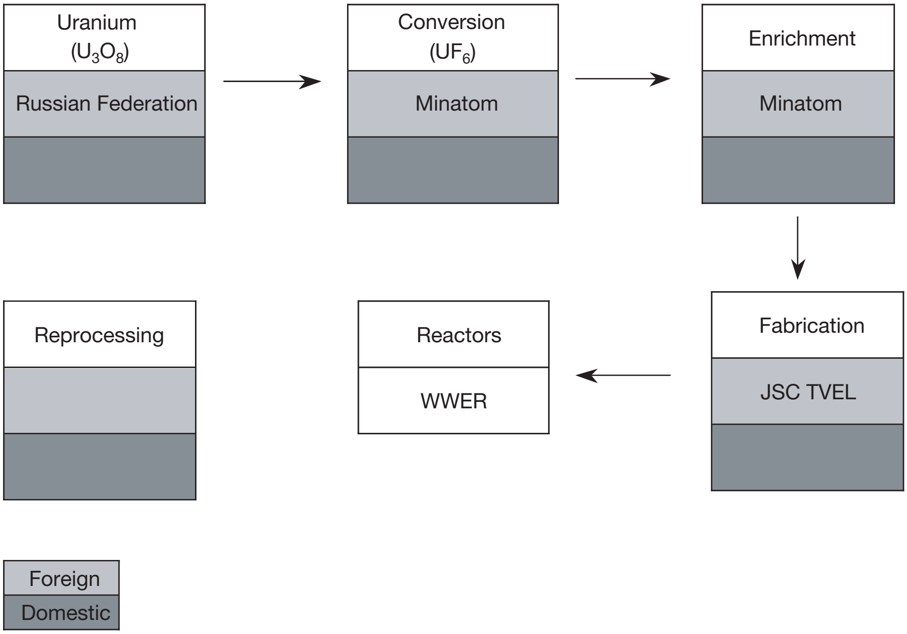


FIG. 4. Material flow in the nuclear fuel cycle: Armenia. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

None

Conversion

None

Enrichment

None

Fabrication

There is no domestic fuel fabrication. Fuel is flown in from the Russian Federation.

Spent fuel management

Up to 1989 spent fuel was routinely sent back to the Mayak facility (RT-1) in the Russian Federation for reprocessing without high level waste needing to be returned. At present, spent fuel is stored in the storage pool at the Armenian nuclear power plant. A dry storage facility for spent fuel has already been constructed at Metsamor and is in operation.

3.3. AUSTRALIA

Australia is a major uranium supplier to the world's nuclear power programme. It has no nuclear power plants.

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

Uranium oxide is produced at 3 commercial mining/milling operations, Ranger, Olympic Dam and Beverley. Ranger consists of an open cut mining operation and a concentration plant. The plant has a production capability of 4660 t U/a. Olympic Dam, with a capacity of 3930 t U/a, consists of an underground mining operation and a metallurgical complex. The metallurgical complex includes a grinding/concentration circuit, a hydrometallurgical plant, a copper smelter, a copper refinery and a recovery circuit for precious metals. Beverley (based on ISL technology) has a production capability of 848 t U/a.

Conversion

None

Enrichment

Pilot scale research into the enrichment of uranium by the use of lasers has been conducted in Australia since the early 1990s. This research has not yet been commercialized.

Fabrication

None

Spent fuel management

None

3.4. BELGIUM

Seven PWRs are in operation. With a total capacity of 5761 MW(e), nuclear power accounted for about 60% of total electricity production in 2002. Belgium now ranks second behind France in terms of the percentage share of electricity produced by the nuclear power sector among OECD countries. In 2002 the Belgian Parliament voted to phase out nuclear electricity production after expiration of the current operating licences (Fig. 5).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

None

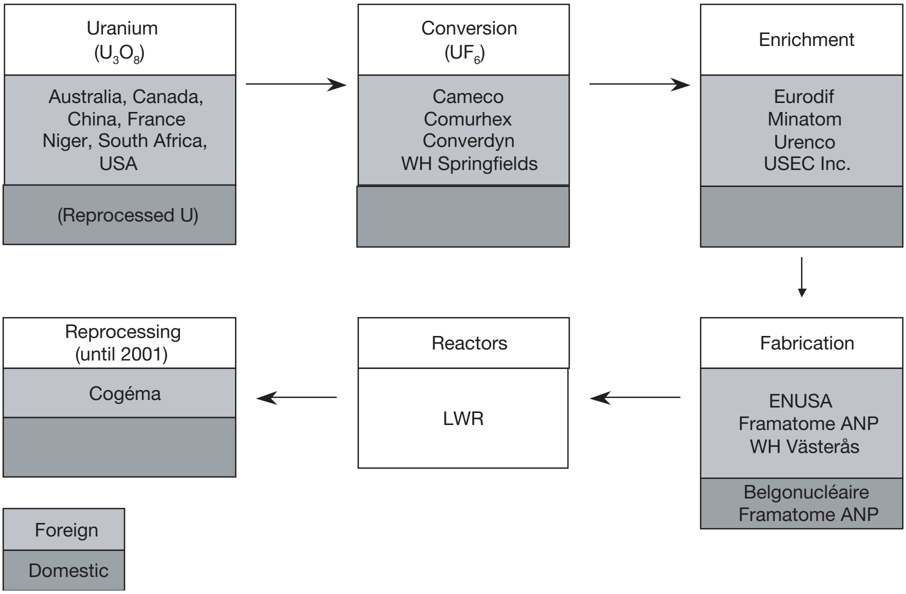


FIG. 5. Material flow in the nuclear fuel cycle: Belgium. Foreign organizations: Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), Minatom (Russian Federation), SPC (USA), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK), WH Västerås (Sweden). One of the Framatome ANP fabrication plants is located at Dessel in Belgium.

Conversion

None

Enrichment

None

Fabrication

Framatome ANP operates a 400 t U/a PWR and BWR fuel plant at Dessel. Belgonucleaire operates a 35 t HM/a MOX plant at Dessel.

Spent fuel management

The Mol reprocessing plant (Eurochemic), which had a capacity of 350 kg U/d, was shut down in 1975. Belgian fuels have been reprocessed at La Hague (Cogéma) in France. Wet storage is in operation at the Tihange nuclear power plant and dry storage at the Doel nuclear power plant.

3.5. BRAZIL

Brazil has two operating nuclear power plants: Angra 1, a 657 MW(e) Westinghouse PWR and Angra 2, a 1350 MW(e) Siemens KWU PWR. Both units are owned and operated by ELETRONUCLEAR. Angra 1 started operation in March 1982 (commercial operation since December 1984) and Angra 2 started commercial operation in February 2001. In 2002 the two plants produced about 4% of the country's electricity supply, of which more than 88% comes from hydroelectric plants (Fig. 6).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

The Poços de Caldas CIPC mining and ore processing plant was closed in 1997. The Lagoa Real area Caetité unit started operation in 2000 with an initial capacity of 340 t U/a.

Conversion

As part of the Brazilian Navy's nuclear propulsion programme, a UF_6 pilot plant with a nominal production capacity of 40 t U/a is under construction at the Navy Research Institute (CTMSP) at Iperó, 100 km from São Paulo. There are no plans to install a commercial plant in the near future.

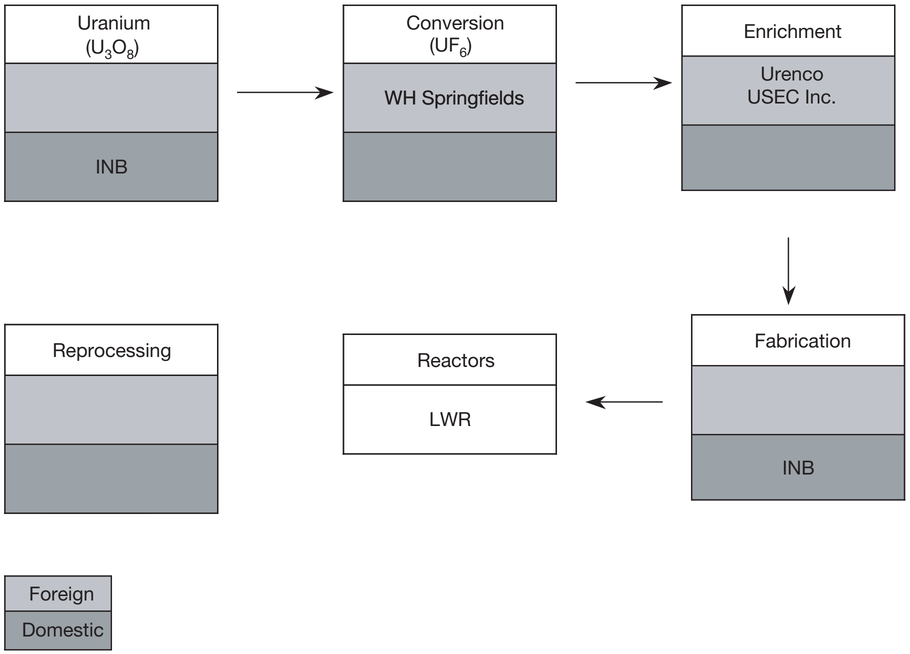


FIG. 6. Material flow in the nuclear fuel cycle: Brazil. Foreign organizations: Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK).

Enrichment

As part of its nuclear propulsion programme the Brazilian Navy has installed a demonstration enrichment centrifuge pilot plant at Iperó. Recently the Brazilian Government decided to start the industrial implementation of the ultracentrifuge process developed by the CTMSP in the Resende industrial plant in the State of Rio de Janeiro. The complete set of units is intended to be operating in 8 years to meet the needs of Angra 1 and partially those of Angra 2 and 3 (~300 t SWU/a). A future increase in this capacity will depend on technical evaluation and resource availability.

Fabrication

The two unit fuel fabrication plant of INB is located at Resende, Rio de Janeiro State, and has a production capacity of 280 t U/a. The fuel fabrication plant has been refurbished and produces the fuel rods and fuel elements for Brazilian nuclear reactors at its unit I. Unit II, which is responsible for pellet fabrication, has been operating since June 1999 with a capacity of 120 tonnes of UO_2 pellets/a. The UO_2 powder production line, which uses the ammonium uranyl carbonate process and pellet fabrication has been in operation at Unit II since September 1999, with an overall production capacity of 140 t U/a. The fuel assemblies for Angra 1 are manufactured by INB using both Westinghouse and Siemens technology. The fuel assemblies for Angra 2 are manufactured using Siemens technology and the first core of this plant has already been manufactured by INB. The fuel fabrication plant also produces other fuel element components such as top and bottom nozzles, grids and end plugs.

Spent fuel management

The storage of spent fuel will be undertaken at the site on a long term basis.

3.6. BULGARIA

Bulgaria had six nuclear power reactors in operation at the Kozloduy nuclear power plant, comprising four WWER-440/230 units and two WWER-1000 units with a total generating capacity of 3.76 GW(e). Nuclear generation accounts for 47.4% of the country's total electricity production. The first two WWER-440/230 reactors (units 1 and 2) were shut down at the end of 2002 in accordance with a government decision. Four reactors, with a total capacity of 2.88 GW(e), are in operation at present. At the moment a 'deferred decision' for the back end of the nuclear fuel cycle is in force in Bulgaria (Fig. 7).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

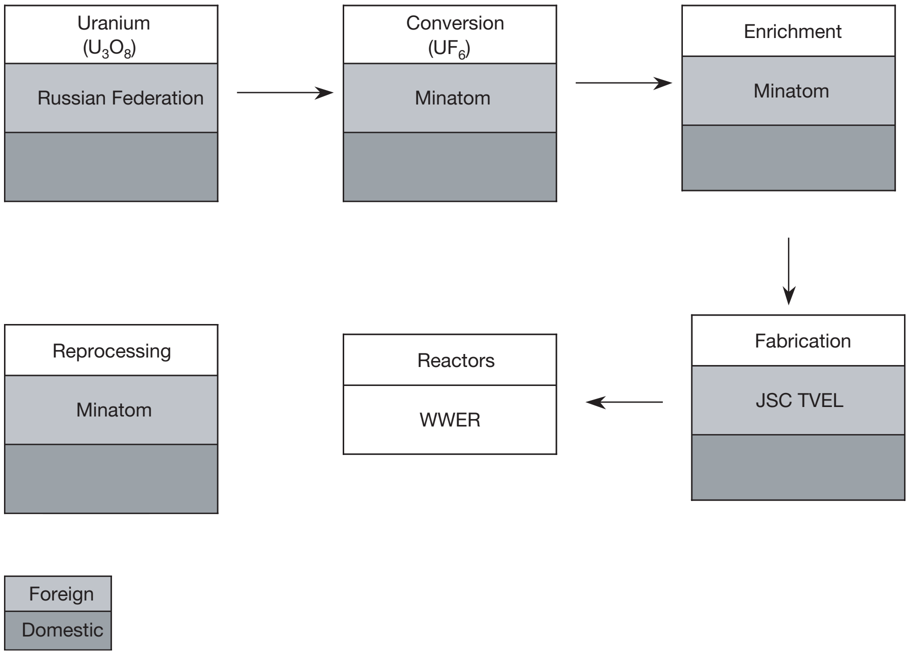


FIG. 7. Material flow in the nuclear fuel cycle: Bulgaria. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

Mining and milling

All production ended in 1994 following the Government's decision to close the uranium production industry.

Conversion

None

Enrichment

None

Fabrication

There is no domestic fuel fabrication. Fuel is flown in by Minatom, Russian Federation.

Spent fuel management

Up to 1989, spent fuel from WWER-440/230 units was routinely sent back to the Mayak facility (RT-1) in the Russian Federation for reprocessing without high level waste needing to be returned. At present, the wet AFR spent fuel storage facility (capacity 600 t HM) at the Kozloduy nuclear power plant is in operation. After cooling in the AR spent fuel storage pools, the spent fuel is transferred to the AFR spent fuel storage facility for further safe storage. To ensure the normal operation of the plant, every year some of the spent fuel assemblies are shipped to the Russian Federation for reprocessing. An interim dry spent fuel storage facility will be built on the site of the Kozloduy nuclear power plant.

3.7. CANADA

Canada operates five nuclear power plants comprising 22 PHWR (CANDU) reactors with a total net capacity of 15 GW(e). Fourteen reactors are currently in operation and eight are awaiting repair. Nuclear power generation accounted for 12.3% of the country's total electricity production in 2002.

Canada is the world's leading producer and exporter of uranium, with an output of some 11 607 t U in 2002, representing 32% of total world production (Fig. 8).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

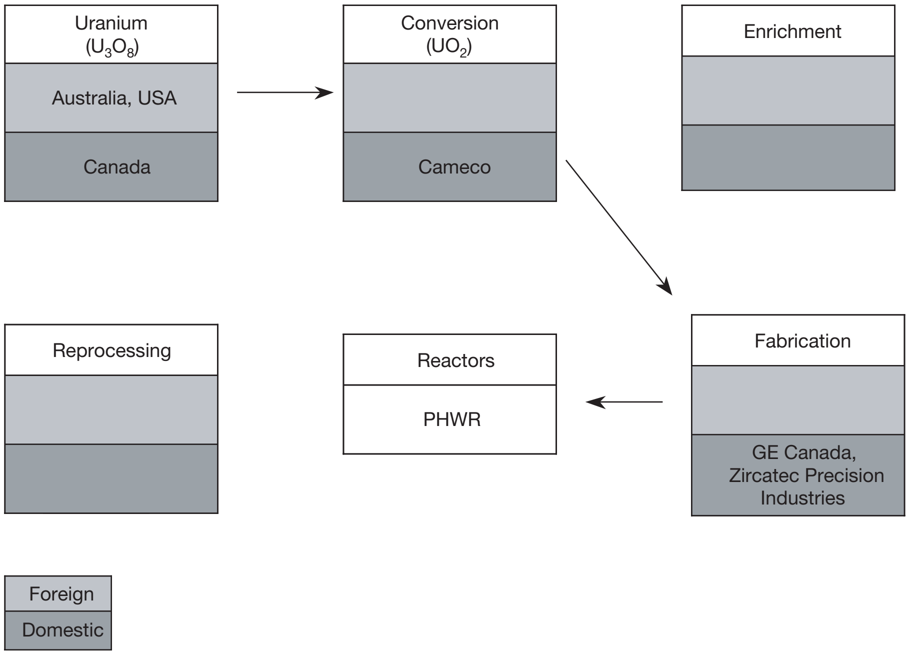


FIG. 8. Material flow in the nuclear fuel cycle: Canada.

Mining and milling

Three uranium mining and ore processing plants are in operation in Saskatchewan: Key Lake/McArthur River (7200 t U/a), Rabbit Lake (4615 t U/a), and McClean Lake (3075 t U/a). Two more are planned. Cluff Lake (1900 t U/a) was closed in 2002.

Conversion

Cameco Corporation operates the Blind River plant in Ontario (capacity 18 000 t U/a as UO_3) and the Port Hope plant, also in Ontario (capacity 12 500 t U/a as UF_6 and 2800 t U/a as UO_2).

Enrichment

None

Fabrication

GE Canada operates a fabrication plant for PHWR fuel assembly at Peterborough, Ontario (capacity 1200 t U/a) and a pellet fabrication plant in Toronto (capacity 1300 t U/a).

Zircatec Precision Industries, located in Port Hope, Ontario, operates a plant for PHWR fuel assembly which has a capacity of 1500 t U/a.

Spent fuel management

Spent nuclear fuel is stored on-site in pools or dry silos. With respect to the long term management of this spent fuel, Atomic Energy of Canada Ltd (AECL) has developed a deep geological disposal concept. Although an environmental review panel concluded that this concept was technically safe, a waste management organization has been set up and will submit its recommendation to the Government within three years.

Heavy water production

The BHWP-B facility was shut down in 1997.

3.8. CHINA

Six PWRs and one PHWR, with a total capacity of 5400 MW(e), are in operation. Three PWRs and one PHWR, with a total capacity of 3300 MW(e), are under construction. In 2002, nuclear electricity generation represented 1.5% of the total electricity generated (Fig. 9).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

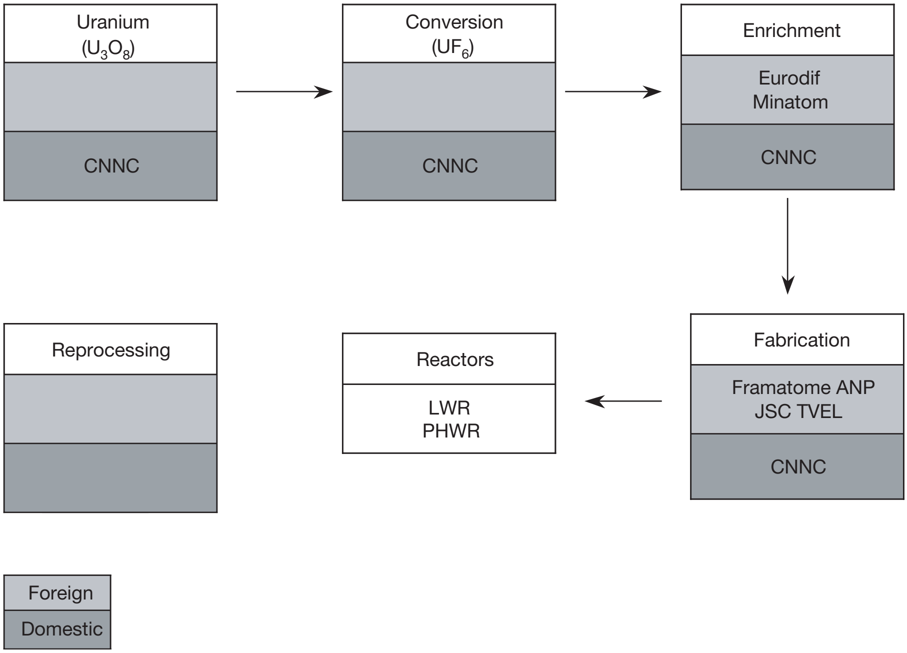


FIG. 9. Material flow in the nuclear fuel cycle: China. Foreign organizations: Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), JSC TVEL (Russian Federation), Minatom (Russian Federation).

Mining and milling

In 2002, the Fuzhou centre (capacity 300 t U/a) processed 220 t U in the form of chemical concentrate. The Chongyi centre (capacity 120 t U/a) produced 100 t U using heap leaching. The Yining centre (capacity 200 t U/a), using ISL, supplied 180 t U. The Lantian centre (capacity 100 t U/a) produced 90 t U using both surface and underground heap leaching. The Benxi centre (capacity 120 t U/a) produced 75 t U, also using surface and underground heap leaching. A total of 665 t U was produced at these facilities.

Conversion

The UF_6 conversion facility near Lanzhou (capacity 1500 t U/a) has been in operation since 1963.

Enrichment

China has 2 enrichment plants: the Lanzhou gaseous centrifuge uranium enrichment plant, and the Shaanxi uranium enrichment plant, both of which use the centrifugal process. The total separative capacity is 1000 t SWU/a.

Fabrication

The Yibin fabrication plant in Sichuan province has been producing fuel for the Qinshan nuclear power plant since 1984 and currently has a capacity of 200 t HM/a. Under a contract with Framatome ANP to transfer fuel fabrication technology to China, the Yibin fabrication plant has been modernized with the goal of providing fuel to all Chinese PWRs.The Baotou fabrication plant, with a CANDU fuel production line, is operating and has a throughput of 200 t U/a.

Spent fuel management

All spent fuel is currently stored at the nuclear power plants. A civil reprocessing pilot plant with a capacity of 100 kg HM/d is under construction in Lanzhou and is scheduled to be commissioned some time in the near future. A centralized wet storage facility with a capacity of 550 t HM is under construction in the Lanzhou nuclear fuel complex.

3.9. CZECH REPUBLIC

Four WWER-440/213 power reactors are in operation at Dukovany (total capacity 1648 MW(e)) and provided about 24.5% of the country's electricity supply in 2002. The first reactor started operation in 1985. Two more WWER-1000/320 reactors are located at the Temelin site. The total capacity of the Temelin nuclear power plant is 1864 MW(e) and it is expected that both nuclear power plants will soon meet about 45% of the national electricity demand (Fig. 10).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

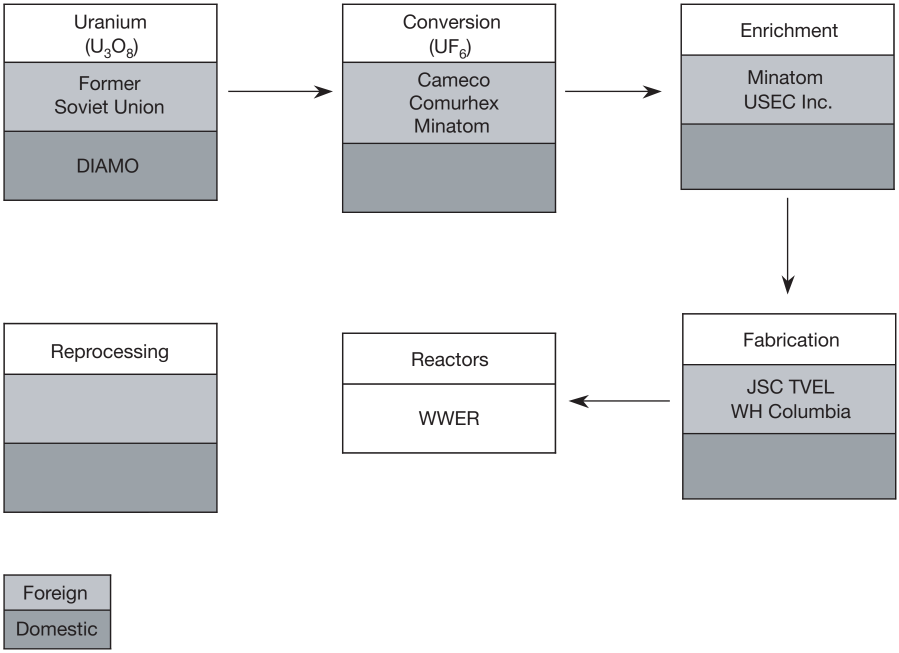


FIG. 10. Material flow in the nuclear fuel cycle: Czech Republic. Foreign organizations: Cameco (Canada), Comurhex (France), JSC TVEL (Russian Federation), Minatom (Russian Federation), USEC Inc. (USA), WH Columbia (USA).

Mining and milling

The State owned company DIAMO is the only organization operating uranium mining and milling facilities in the Czech Republic. Only one underground mine remains in operation at the Rozna site and the milling facility (capacity 400 t U/a) produced 350 t U in 2002. All other mines have been closed and remediation work is being carried out. Therefore about 110 t U/a is produced as the by-product of technologies used for the remediation of chemical mining sites (capacity 250 t U/a) near the city of Straz pod Ralskem.

Conversion

None

Enrichment

None

Fabrication

The supplier from the Russian Federation provides fresh nuclear fuel for the Dukovany nuclear power plant. For the Temelin nuclear power plant it has been decided to rely on supplies from the USA (Westinghouse).

Spent fuel management

Until 1989 spent fuel was routinely sent back to the Mayak Facility (RT-1) in the former Soviet Union for reprocessing. The high level waste generated was not returned to the former Czechoslovakia.

Until 1992 the spent fuel assemblies from the Dukovany nuclear power plant were transported (after a 3 year cooling period) to the wet interim storage facility at Jaskovske Bohunice in Slovakia. These transports were stopped after the split of Czechoslovakia. In 1991 it was decided to build an interim spent fuel storage facility at the site of the Dukovany nuclear power plant. The interim spent fuel storage facility at Dukovany, which uses dual transport and storage CASTOR 440/84 casks, was commissioned in January 1997. The Dukovany facility has a planned capacity of 60 casks (60 t HM).

Due to the limited storage capacity of the Dukovany facility it has been decided to build a new spent fuel storage facility at the same site. The new facility, with a capacity of 1340 t HM in 133 modified CASTOR 440/84 M casks, will be connected to the existing Dukovany facility. The facility should be put into operation in 2006.

3.10. FINLAND

In 2002 Finland's four nuclear power plants, which have a combined capacity of 2.66 GW(e), provided 21.4 TW·h of electricity, equivalent to 26% of total electricity output. Fortum Power and Heat Oy (Fortum) operates two PWR reactors in Olkiluoto. In 2001 the Finnish Parliament ratified the Government's decision-in-principle on building a fifth nuclear power unit in Finland, considering that the construction is "in the overall interest of society".

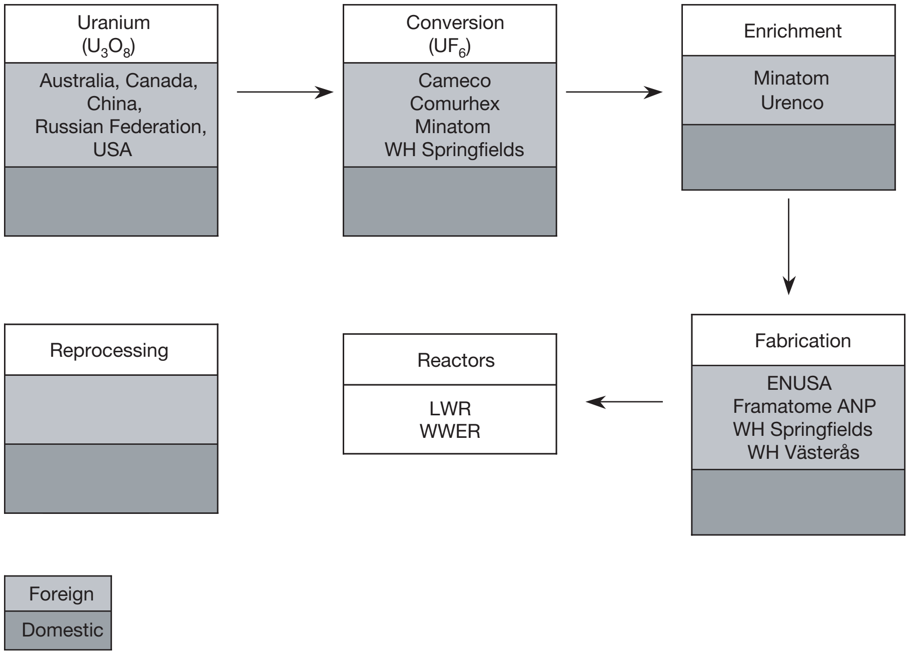


FIG. 11. Material flow in the nuclear fuel cycle: Finland. Foreign organizations: Cameco (Canada), Comurhex (France), ENUSA (Spain), Framatome ANP (France), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), WH Springfields (UK), WH Västerås (Sweden).

TVO, the responsible applicant organization, planned to start construction in 2005 and operation in 2009 (Fig. 11).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

Finland produced 30 t U between 1958 and 1961. Currently no mines are in operation.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

The last return shipment of spent fuel from Loviisa to the Russian Federation took place at the end of 1996. An interim spent fuel storage facility with a capacity of 490 t HM is in operation at the Loviisa nuclear power plant. At the Olkiluoto nuclear power plant a wet storage facility for spent fuel, termed the TVO-KPA store, has a capacity of 1200 t HM.

A project for the final disposal of spent fuel was started in the early 1980s. In 2001 Parliament ratified the decision-in-principle of the Government on construction of a final disposal facility at Olkiluoto. Construction of the encapsulation and disposal facility is scheduled to start around 2010, with operation scheduled to commence in 2020.

3.11. FRANCE

France started nuclear electricity generation in 1959 with GCR reactors, which are now shut down. In 1973 the French Government decided to rely heavily on PWRs for electricity generation and the country currently has 58 PWR units, totalling 61.5 GW(e) of capacity, which produced 415.5 TW·h in 2002 (78% of total electricity production). No reactors are currently under construction in France, pending a decision being taken on a possible order for an EPR (advanced reactor design). The State currently holds, either totally or partially, the capital of the main French companies involved in the nuclear industry.

The fuel cycle policy is based on a closed cycle with reprocessing of PWR spent fuel and the recycling of plutonium and REPU in PWRs. The nuclear fuel market is fully open and France imports nuclear products and services from abroad. Its nuclear fuel industry has available capacities for hire

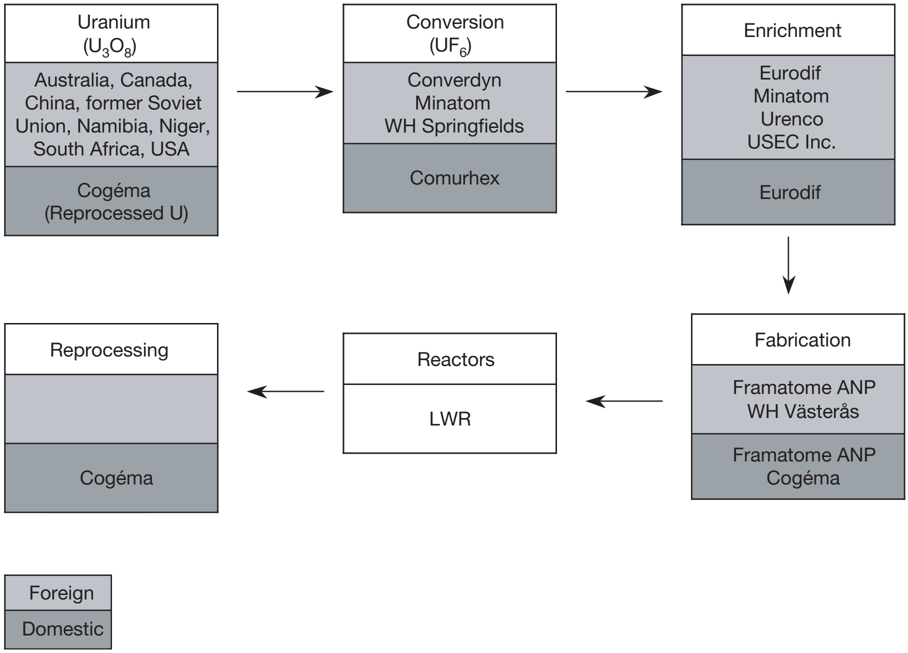


FIG. 12. Material flow in the nuclear fuel cycle: France. Foreign organizations: Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (Germany), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK),USEC Inc. (USA), WH Springfields (UK), WH Västerås (Sweden).

(conversion, enrichment, fuel fabrication and reprocessing) to foreign utilities (Fig. 12).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

Cogéma operates mines in Niger through the activities of SOMAÏR and COMINAK, and in Canada and the USA through Cogéma Resources. It also has financial interests in Australian mines and in mines in central Asia. French mines are exhausted.

Conversion

Comurhex operates two plants (total capacity 14 000 t U/a): Malvesi (yellow cake to UF_4) and Pierrelatte (UF_4 to UF_6). Cogéma and Comurhex also operate plants for the conversion of REPU and for defluorination of depleted uranium.

Enrichment

Eurodif performs enrichment at its gaseous diffusion plant located in Pierrelatte (capacity 10 800 t SWU/a). Cogéma is studying the installation of centrifuges at Pierrelatte.

Fuel fabrication

Framatome ANP fabricates UO_2 fuel at its Romans plant from enriched natural or REPU (capacity 1400 t HM/a). It also operates a plant in Belgium. MOX fuels are fabricated by Cogéma at Cadarache and by Melox at Marcoule. These plants have a total capacity of 185 t HM/a. France also has capacities for hire in zirconium metallurgy and in cladding fabrication through the activities of Cesus and Zircotube.

Spent fuel management

All GCR fuel (18 000 t) was reprocessed at the Cogéma UP1 plant located at Marcoule. This plant is now undergoing decommissioning. French PWR fuel is sent to the La Hague pools for cooling before undergoing reprocessing at the Cogéma UP2 plant. Foreign fuel is reprocessed at Cogéma's UP3 plant located at La Hague. Recovered uranium and plutonium are reused in the fuel fabrication plants. Wastes are conditioned and stored before transfer to the Agence nationale pour la gestion des déchets radioactifs (Andra) or to foreign customers. Total LWR spent fuel reprocessing exceeded 18 300 t HM by the end of 2002.

Waste disposal

Low level wastes are transported to the Andra site at Soulaines (capacity 1 million t). Conditioned intermediate and high level wastes are stored at production sites pending creation of a disposal site by Andra in accordance with the Nuclear Waste Act of 30 December 1991.

3.12. GABON

All mining and milling activities in Gabon have ceased.

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

Gabon's total production of uranium up to the end of 1996 amounted to 26 109 t. The Mounana production centre operated from 1988 until 1997, and the Mikolongou production centre operated from 1991 until 1999, after which all mine production ceased.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

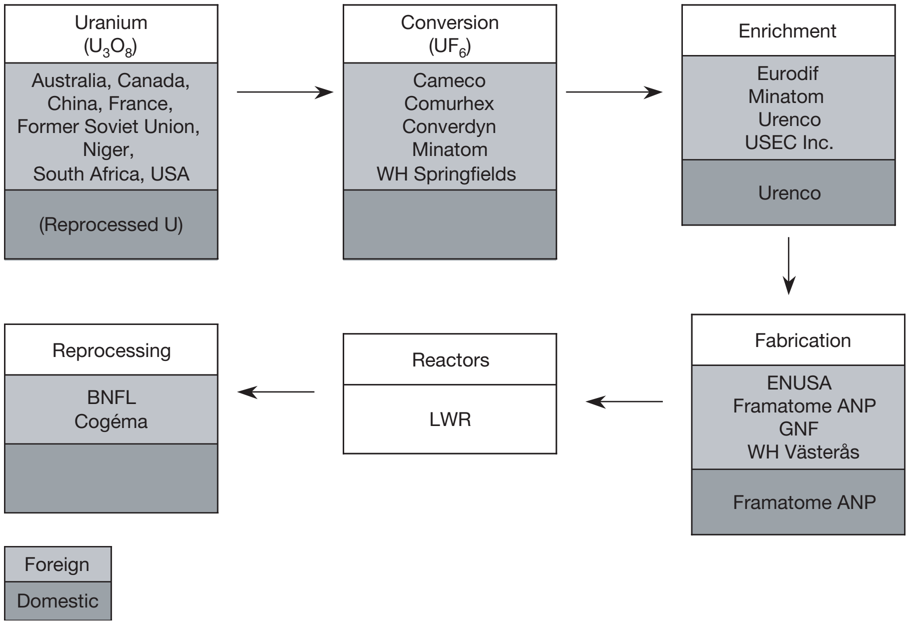


FIG. 13. Material flow in the nuclear fuel cycle: Germany. Foreign organizations: BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), GNF (USA), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK), WH Västerås (Sweden).

3.13. GERMANY

With the exception of repositories for final disposal and national interim storage facilities (the latter facilities based on Section 5 of the German Atomic Energy Act), which are the responsibility of the Federal Government, all nuclear fuel cycle facilities are private enterprises.

In 2002, 13 PWRs and 6 BWRs were in operation; their total capacity amounting to about 22.2 GW(e). Nuclear power generation accounts for 30% of the country's total electricity production (Fig. 13).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

No mining or milling has been undertaken in Germany since the closure of the SDAG Wismut operation in the former German Democratic Republic in 1991.

Conversion

None

Enrichment

In Urenco's Gronau uranium enrichment plant, natural uranium or uranium recovered from reprocessing in the form of UF_6 is enriched by centrifuge separation. The plant started operation with a capacity of 400 t SWU/a in 1985 and this has since been expanded to 1800 t SWU/a.

Fabrication

Framatome ANP operates a fabrication plant (capacity 650 t U/a) for LWR fuel at Lingen.

Spent fuel management

All domestic reprocessing activities have ceased; utilities contract out the reprocessing of spent fuel to the UK and France.

Amendments to the Atomic Act in Germany, which became law in 1994, permit utilities to dispose of spent fuel in a geological repository in lieu of reprocessing it (direct disposal). In 2001, a new atomic law was passed forbidding the transport of spent fuel to reprocessing plants after mid 2005.

Spent fuel not shipped abroad for reprocessing is being stored at central interim storage facilities (ZAB Greifswald (560 t HM), BZD-Ahaus (3960 t HM), BLG-Gorleben (3800 t HM)) or at local interim storage facilities (in the nuclear power plants). High level waste from reprocessing is returned to Germany and is also stored at the BLG facility. Uranium and plutonium recovered in foreign reprocessing plants are recycled as uranium fuel and MOX fuel.

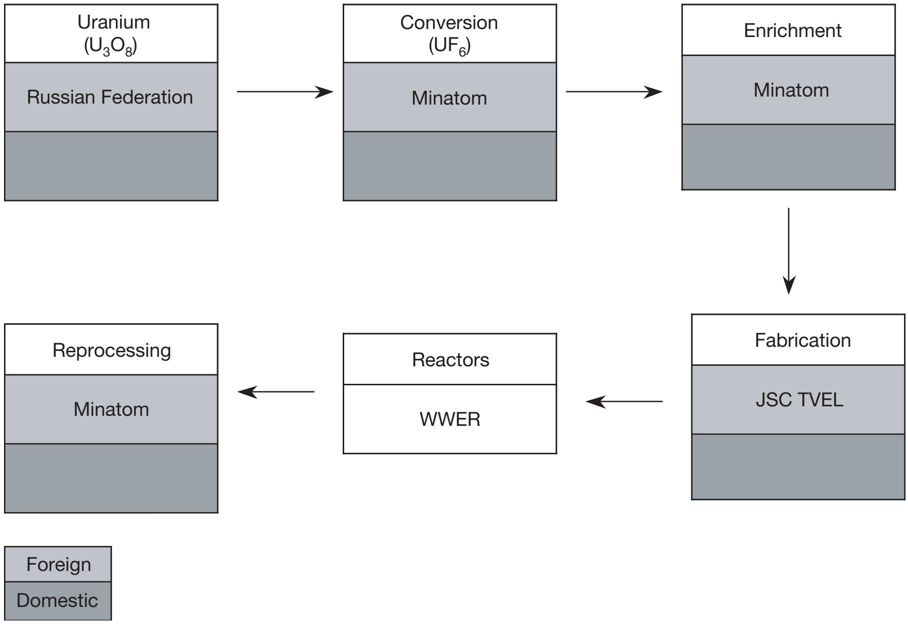


FIG. 14. Material flow in the nuclear fuel cycle: Hungary. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

3.14. HUNGARY

Four WWER-440/213 reactors are in operation at the Paks nuclear power plant with a total capacity of 1866 MW(e). The first reactor started operation in 1983. Nuclear generation accounted for 37% of the country's total electricity production in 2002 (Fig. 14).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

Prior to its closure, the Mecsekuran Lic/Cserkut mining and ore processing facility produced up to 500 t U/a, or half the requirements of the Paks nuclear power plant. The mine was closed in 1997 and production at the milling facility was phased out in 1999.

Conversion

None

Enrichment

None

Fabrication

There is no domestic fuel fabrication. At present, nuclear fuel is flown in from the Russian Federation. Westinghouse has developed advanced fuel designs for the Paks nuclear power plant in conjunction with TVO (Finland).

Spent fuel management

Between 1989 and 1998 spent fuel was sent back to the Mayak facility (RT-1) in the Russian Federation without U, Pu or high level waste from reprocessing needing to be returned. At the Paks nuclear power plant, the AFR dry storage facility (modular vault dry storage) is in operation. The capacity of the first phase (11 vaults) is 4950 fuel assemblies (574 t HM).

3.15. INDIA

India's first nuclear reactor started operation in 1969. Two BWRs and twelve PHWRs were in operation in 2002, with a total capacity of 2720 MW(e). Nuclear power accounted for about 4% of total power generation. In addition, eight reactors having a total capacity of 3960 MW(e) are under construction, scheduled to be commissioned between 2004 and 2008. India has plans to build more PHWR, FBR and thorium based reactors. It has completed the design and technology development of a 500 MW(e) FBR and construction of the prototype began recently. India is one of the few countries to have developed expertise in all areas of the nuclear fuel cycle and allied fields covering mineral exploration, mining, heavy water production, fuel fabrication, fuel reprocessing and the management of nuclear waste at the back end of the cycle. These nuclear programmes are undertaken by governmental bodies (Fig. 15).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

Four underground uranium mines (Jaduguda, Bhatin, Narwapahar and Turamdih) are in operation in the Singhbhum district of Jharkhand State. Uranium ore produced from these mines is processed in the mill located at Jaduguda. The end product from Jaduguda is yellow cake.

Conversion

The Nuclear Fuel Complex (NFC)-Hyderabad conversion plant (conversion to UO_2) is in operation and processes yellow cake and converts the same to uranium oxide for use in PHWRs. It also processes imported enriched UF_6 and converts the same to uranium oxide for use in BWRs.

Fabrication

The NFC continues to support the nuclear power programme and supplies all the fuel bundles required by India's operating PHWR reactors. It has also supplied fuel bundles fabricated from enriched UF_6 to BWRs. In order to meet the future needs of the Indian nuclear power programme, NFC has been expanding its manufacturing capabilities with regard to nuclear fuels and zirconium alloy, with 1 zirconium sponge facility and 2 zirconium alloy tubing facilities.

The Bhabha Atomic Research Centre (BARC) has manufactured twelve MOX fuel assemblies for irradiation in BWRs. Two of these assemblies are undergoing post-irradiation examination. BARC also fabricates mixed carbide sub-assemblies for the Fast Breeder Test Reactor and MOX test fuel assemblies for PHWR and PFBR.

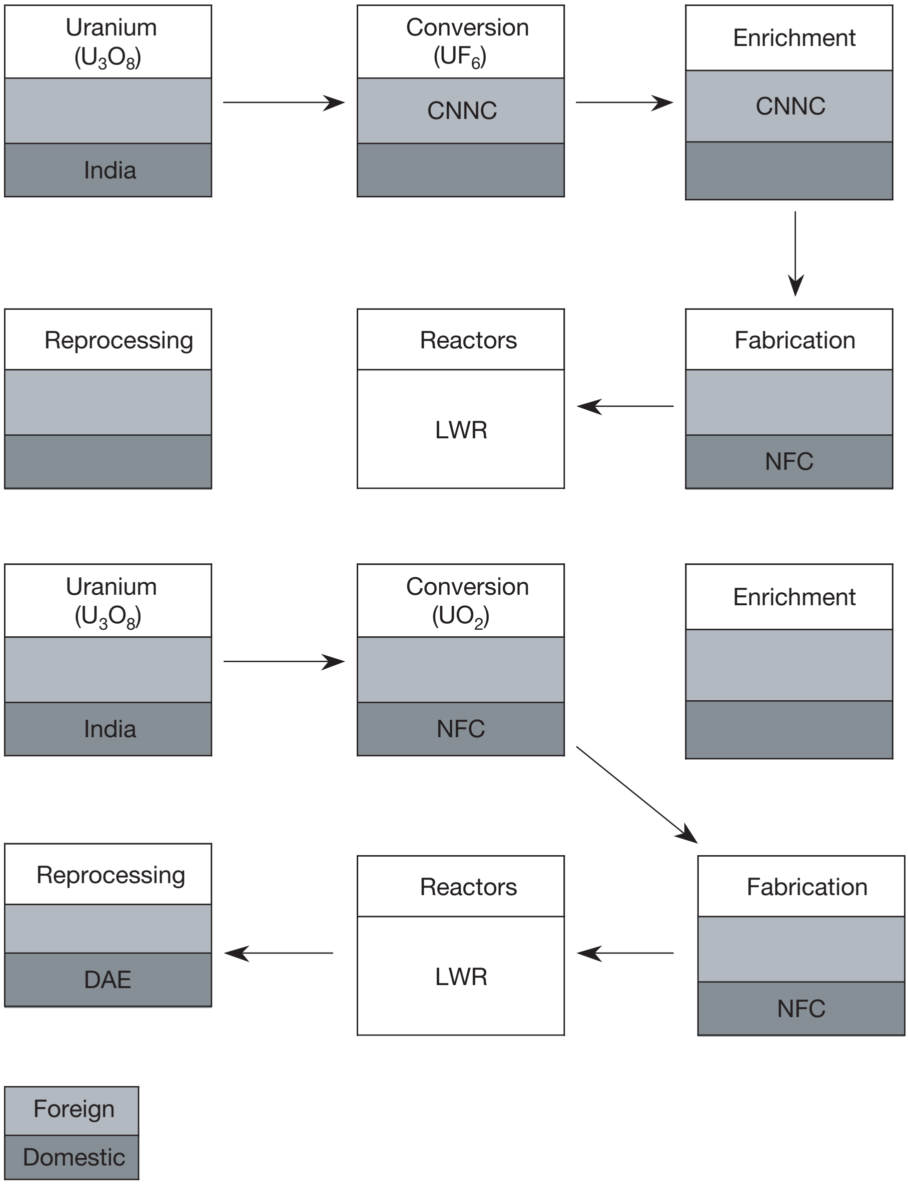


FIG. 15. Material flow in the nuclear fuel cycle: India. Foreign organization: CNNC (China).

Spent fuel management

In the 1960s, India developed technology for reprocessing natural uranium oxide fuel from its heavy water reactors. A plant for reprocessing spent fuel from its PHWRs was put into service at Tarapur in 1977. Another plant was commissioned at Kalpakkam in 1996.

Heavy water production

Seven heavy water production facilities are in operation at Baroda, Hazira, Kota, Manuguru, Talcher, Thal-Vaishet and Tuticorin. All the plants are working at their intended capacities.

3.16. JAPAN

Nuclear power generation began in Japan in 1963. Since then, ten successive electricity companies have constructed LWRs. The Japan Nuclear Cycle Development Institute (JNC) has developed the advanced thermal reactor (ATR), which is a heavy water moderated, light water cooled reactor (HWLWR), and the fast breeder reactor (FBR). As of the end of 2002, 23 PWRs, 29 BWRs and the ATR were in operation, with a total generating capacity of about 46 GW(e). Nuclear electricity accounted for 34.6% of the total electricity generated in 2002. Research and development of nuclear fuel cycle technology has mainly been done by the JNC, although some commercial facilities are operated or have been constructed by the private sector (Fig. 16).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

Domestic uranium exploration ended in 1988. Since then, JNC has concentrated its efforts on overseas exploration in thirteen countries (Australia, Canada, Niger, the USA, Zimbabwe, etc.). However, following the

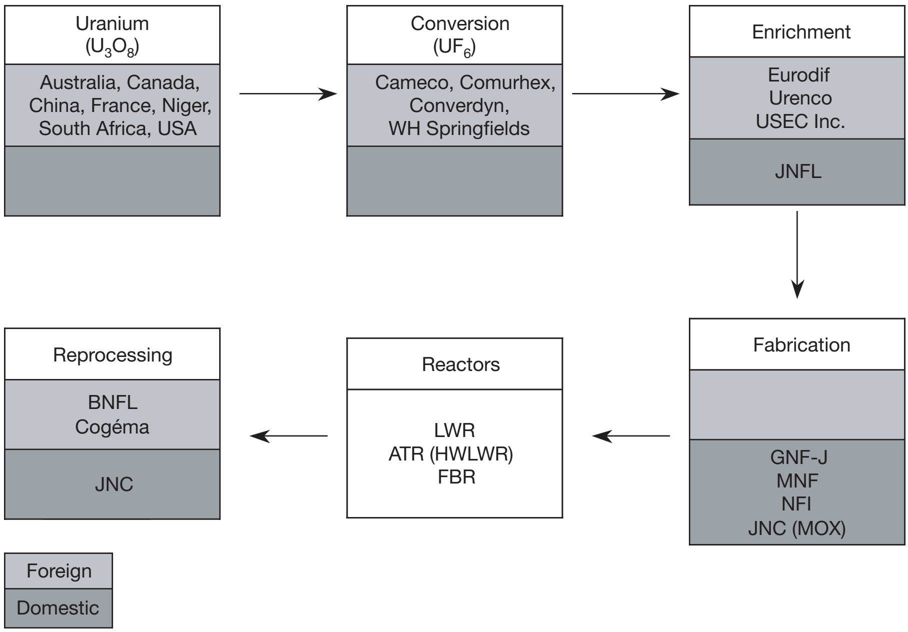


FIG. 16. Material flow in the nuclear fuel cycle: Japan. Foreign organizations: BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Italy, Spain), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK).

Government reform of JNC they withdrew from exploration activities by September 2002. The JNC has transferred most of their rights and interests to private companies, as well as to foreign companies. The annual requirement for natural uranium for LWRs amounted to about 7840 t U in fiscal year 2002.

Conversion

There is no commercial conversion facility in Japan, but a private company operates a commercial reconversion facility with a capacity of 475 t U/a. Japan depends on other countries (Canada, France, the UK and the USA) to meet all its conversion requirements.

Enrichment

Domestic development of uranium enrichment technology using the centrifuge method started in 1959. Until recently there were two enrichment facilities. One was a demonstration plant with a capacity of 100 t SWU/a (200 t SWU/a until November 1999), located at Ningyo-toge and operated by JNC since 1988. Its operation ended in March 2001. The other is a commercial plant with a capacity of 1050 t SWU/a located at Rokkasho-mura and operated by JNFL since 1992. Expansion of the capacity of this commercial plant to 1500 t SWU/a is planned. The requirement for enrichment amounted to about 5900 t SWU in fiscal year 2002, over 80% of which was supplied by other countries.

Fabrication

Most of the nuclear fuel for LWRs is fabricated in Japan. There are four facilities for LWR fuel fabrication, having a total capacity of 1674 t U/a. These are operated by private companies. In addition, JNC has 2 MOX fuel fabrication facilities, a 10 t MOX/a line for the HWLWRs and a 5 t MOX/a line for the FBR. Cumulative MOX fuel production reached about 167 t as of the end of 2002. There are 3 zirconium alloy tubing facilities in Japan. JNFL plans to construct a MOX fuel fabrication facility with a capacity of 130 t HM/a.

Spent fuel management

Up to the end of 2002 there were no spent fuel storage facilities at AFR sites in Japan. The JNC's Tokai reprocessing plant has been in operation and its cumulative production of reprocessed fuels had reached about 1009 t U by the end of 2002. There are also contracts for reprocessing with France and the UK. Under these contracts about 5600 t U of spent fuel from LWRs were shipped to both countries, ending in September 1998. Aside from the Tokai reprocessing plant, a domestic reprocessing plant with a capacity of 800 t U/a is under construction by JNFL at Rokkasho-mura. At the end of 2002 there was a low level waste disposal centre with a current capacity of 80 000 m^3 and a high level vitrified waste storage centre with a current capacity of 1440 canisters at Rokkasho-mura.

3.17. KAZAKHSTAN

The BN-350, a 70 MW(e) fast neutron liquid metal cooled reactor, which had been the only nuclear unit in operation in Kazakhstan (at Aktau), was shut down in 1999. The reactor had started operation in 1973. Prior to its closure, nuclear generation had accounted for 0.6% of the country's total electricity production. Plans to construct a new nuclear power plant are currently being evaluated.

Nuclear fuel cycle policy

- ○ Open nuclear fuel cycle
- ○ Closed nuclear fuel cycle
- ○ No decision yet
- ● Not applicable

Mining and milling

The entire current uranium production capability is associated with seven production centres (Centralnoye, Stepnoye, No. 6, Akdala, KATKO, Inkai and KazSubton), which have an aggregate production capacity of 5950 t U/a.

Conversion

None

Enrichment

None

Fabrication

The UST-Kamenogorsk fuel fabrication plant (powder and pellets) is in operation and has a capacity of 2000 t HM/a, supplying both WWER and RBMK reactors. The manufactured pellets are exported to the Russian Federation.

Spent fuel management

Formerly, spent fuel was routinely sent back to the Mayak facility (RT-1) in the Russian Federation for reprocessing without high level waste needing to be returned. At present, spent fuel is stored in the AR pool.

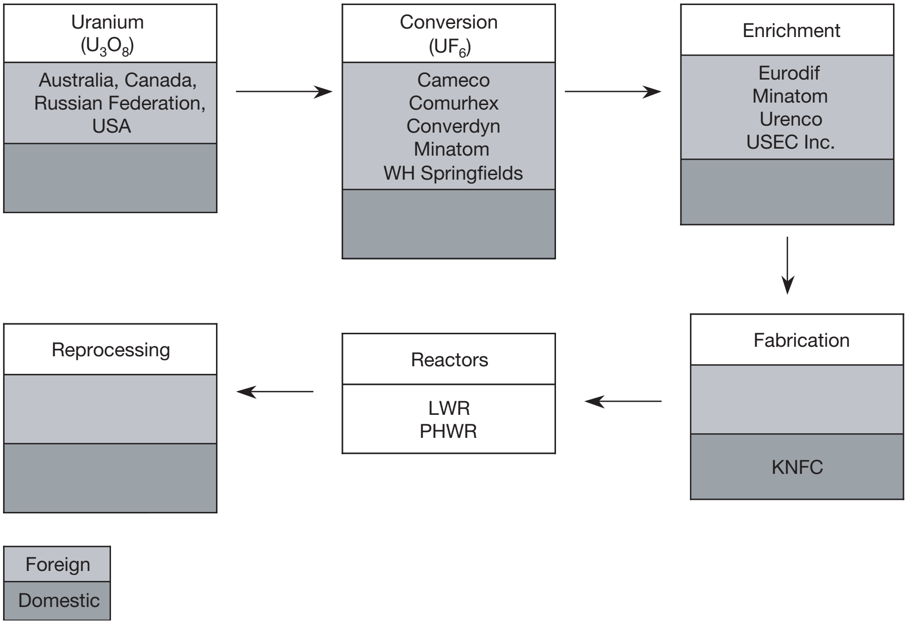


FIG. 17. Material flow in the nuclear fuel cycle: Republic of Korea. Foreign organizations: Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Italy, Spain), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK).

3.18. REPUBLIC OF KOREA

With the startup of a PWR (Yonggwang 6) in 2002, a total of 14 PWRs and 4 PHWRs are now in commercial operation in the Republic of Korea, with a generating capacity of 15 716 MW(e). Nuclear power accounted for 38.9% of total electricity production in 2002. (Fig. 17).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

Since the early 1980s, the Korea Electric Power Corporation has invested in uranium exploration/development programmes in Canada and the USA. Some exploration programmes ended in 1999 with the sale of equity stakes in the Cigar Lake and Dawn Lake mines, while others at the Henday Lake and Crow Butte mines have been suspended temporarily.

Conversion

The Korea Atomic Energy Research Institute (KAERI) has a pilot plant for converting yellow cake to UO_2. This plant will be decommissioned in a few years.

Fabrication

The KNFC, which is the country's sole nuclear fuel fabricator, was established in 1982 and began producing nuclear fuel for LWRs on a commercial basis in 1989. The KNFC has been using the ammonium uranyl carbonate reconversion process (capacity 200 t U/a) since 1990 and the dry reconversion process (capacity 200 t U/a) since 1998, as well as converting enriched uranium from UF_6 to UO_2. The total production capacity is 400 t U/a of fuel for all types of PWR. The KNFC built a PHWR (CANDU) fuel fabrication plant in 1998 with a capacity of 400 t U/a.

Spent fuel management

Spent fuels are stored at each AR storage facility. The Atomic Energy Commission, which is the nation's top policy making body in the field of nuclear energy, decided to build an AFR interim storage facility and designated KAERI as the national radioactive waste management organization in 1984. In 1999, however, the task of radioactive waste management was transferred to the Nuclear Environment Technology Institute (NETEC), which was established as a special division of Korea Hydro and Nuclear Power Ltd. The NETEC is now preparing to select a candidate site for the AFR storage facility and is also investigating technical aspects of the interim storage facility, which is to be constructed by 2016.

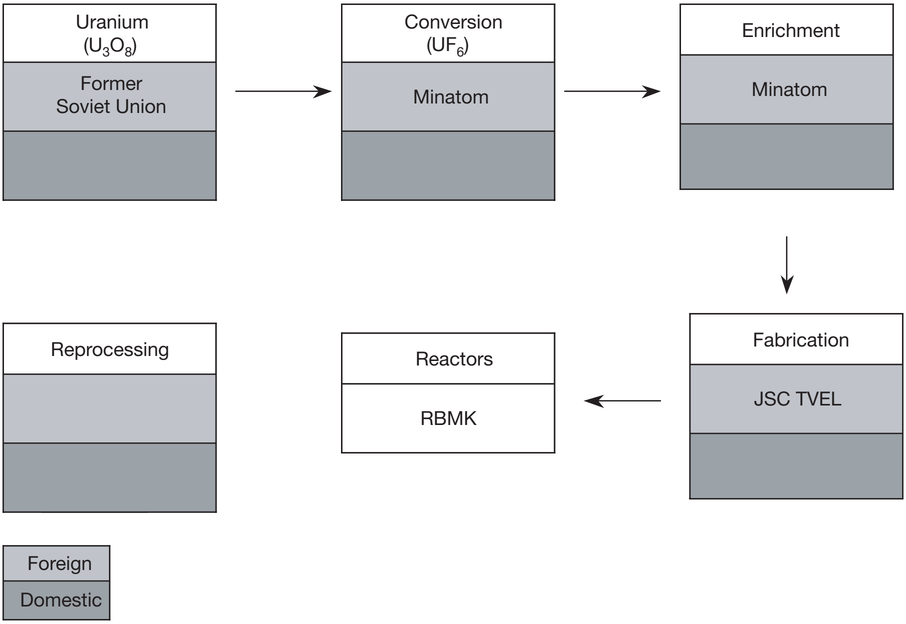


FIG. 18. Material flow in the nuclear fuel cycle: Lithuania. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

3.19. LITHUANIA

The two 1300 MW(e) LWGR (RBMK) power reactors at the Ignalina nuclear power plant accounted for 80.1% of all electricity generated in Lithuania in 2002. The first reactor started operation in 1983, the second in 1987. In 2002, electricity exports to Belarus, Estonia, Latvia, Poland and the Russian Federation amounted to 6.8 TW·h (Fig. 18).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

None

Conversion

None

Enrichment

None

Fabrication

There is no domestic fuel fabrication; fuel is flown in from the Russian Federation.

Spent fuel management

Spent fuel storage was commissioned in 1999. Twenty Castor casks and forty Constor casks manufactured by GNB in Germany have been delivered to the Ignalina nuclear power plant site. The spent nuclear fuel can be stored in these casks for 50 years. Previously, all spent nuclear fuel had been stored in the pools constructed next to the reactors. There are plans to build a new interim spent fuel storage facility on the Ignalina nuclear power plant site, which will start operation in 2009.

3.20. MEXICO

The two BWRs at the Laguna Verde facility, which have a combined capacity of 1308 MW(e), generated 5% of domestic electricity production (9.6 TW·h) in 2002 (Fig. 19).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

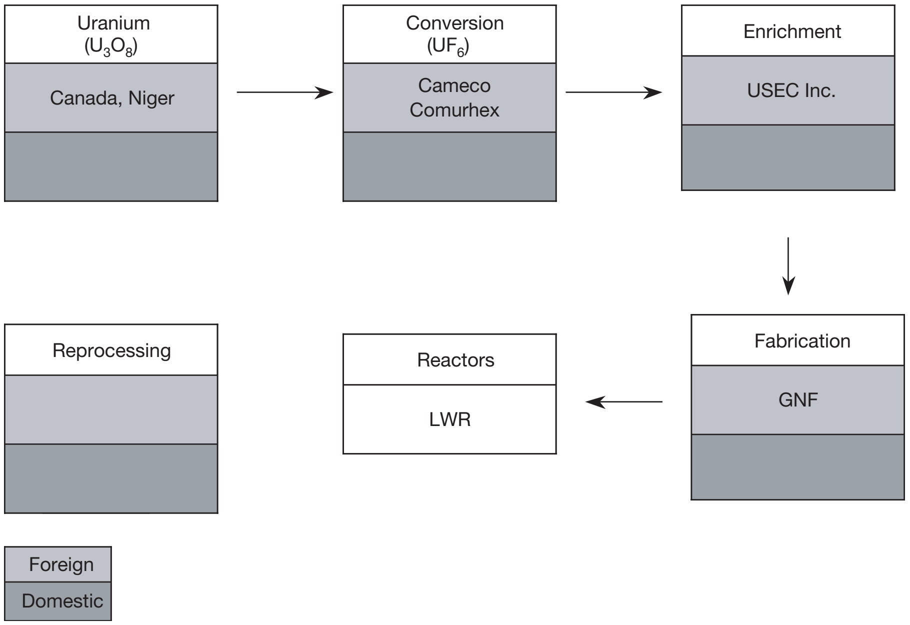


FIG. 19. Material flow in the nuclear fuel cycle: Mexico. Foreign organizations: Cameco (Canada), Comurhex (France), GNF (USA), USEC Inc. (USA).

Mining and milling

The Mining Development Commission operated a plant at Villa Aldama, Chihuahua from 1969 to 1971. The facility recovered molybdenum and by-product uranium from ores mined in the Sierra de Gomez, Domitilia and other localities. A total of 49 t U was produced. At present, there are no plans to resume uranium production.

Conversion

None

Enrichment

Uranium enrichment is not undertaken domestically, requirements being met by USEC Inc., USA.

Fabrication

Fuel fabrication requirements are met by GNF, USA. A fuel fabrication facility (capacity 5 t HM/a) of the Centro Nuclear de México BWR was in operation from 1980 to 1996 when it was shut down for economic reasons.

Spent fuel management

Spent fuel is stored at the reactor site.

3.21. MONGOLIA

Nuclear fuel cycle policy

- ○ Open nuclear fuel cycle
- ○ Closed nuclear fuel cycle
- ○ No decision yet
- ● Not applicable

Mining and milling

Uranium production started in 1989 and was terminated in 1995. During that period, 499 587 t of ore were mined and transported to the Russian Federation for processing.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.22. NAMIBIA

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

The only uranium producer in Namibia is Rössing Uranium Ltd. The operation has a nominal production capacity of 4000 t U/a. Rössing Uranium Ltd is a mixed enterprise with private and government shareholders.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.23. NETHERLANDS

In 2002, the Netherlands' only reactor, the 449 MW(e) PWR at Borssele, provided 3.6 TW·h of electricity, equivalent to 4% of domestic electricity output. Two successive governments ordered the Borssele nuclear power plant to shut down by December 2003, earlier than had originally been foreseen. However, the Government that came into office at the beginning of August 2002 has agreed to postpone closure of this plant, as it said "taking into account the Kyoto obligations, it would not be sensible to close Borssele prematurely".

The new Cabinet will consult with the owner of the plant to seek an agreement on continuing its operation, taking into account its economic and technical lifetime (Fig. 20).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

None

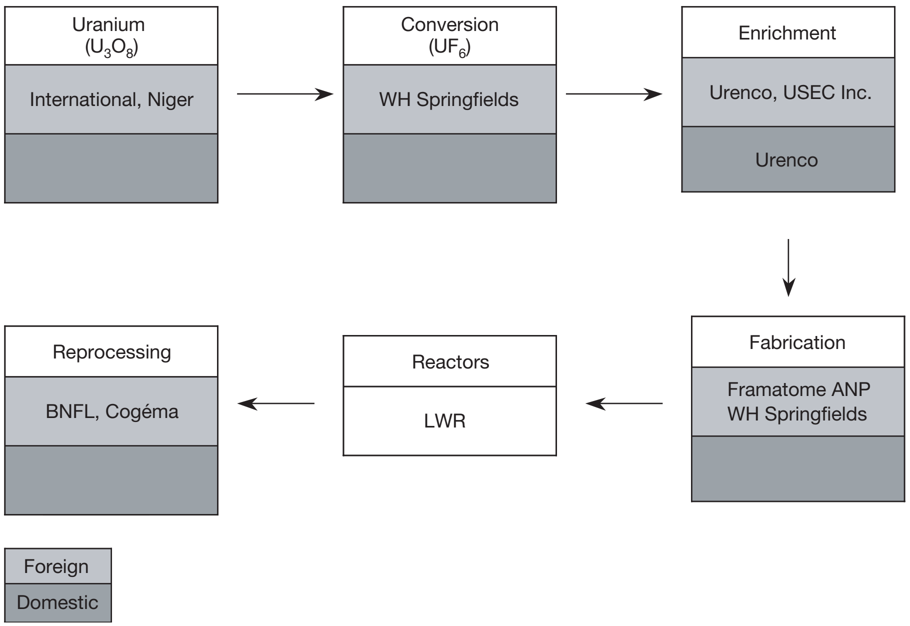


FIG. 20. Material flow in the nuclear fuel cycle: Netherlands. Foreign organizations: Cogéma (France), Framatome ANP (Germany), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK).

Conversion

None

Enrichment

Uranium enrichment is carried out by Urenco Nederland B.V., which is located in Almelo. Urenco Nederland is owned by the multinational company Urenco Ltd, which is located in Marlow (UK) and which has three shareholders holding equal shares: Ultra Centrifuge Nederland (UCN) in the Netherlands, Uranit (Germany) and BNFL. The Government of the Netherlands owns 99% of the shares in UCN.

The current capacity of Urenco Nederland is 1850 t SWU/a. However, in 1999 the company obtained a licence to expand its capacity to 2500 t SWU/a, for which a fifth enrichment plant has been built at the Almelo site. In early 2003 a new nuclear licence was issued to increase capacity to 2800 t SWU/a. Urenco uses advanced gas ultracentrifuge technology for the enrichment of uranium.

Fabrication

None

Spent fuel management

Spent fuel is being reprocessed at the BNFL reprocessing facility in the UK and at the Cogéma reprocessing facility in France.

3.24. NIGER

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

In Niger, uranium is produced by two companies, Société des Mines de l'Aïr (SOMAÏR) and Compagnie Minière d'Akouta (COMINAK), which have mined uraniferous sandstone deposits since 1970 and 1978, respectively. SOMAIR has a production capability of 1500 t U/a from open pit operations, while COMINAK's production capability of 2300 t U/a derives from underground mining. Current production is about 3000 t U/a. The Government owns 33% of the production, while other governments and a private foreign mining company own the remainder.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.25. PAKISTAN

Pakistan has two operating nuclear power plants: KANUPP, a CANDU 137 MW(e) PHWR and CHASNUPP 1, a 325 MW(e) PWR. Both units are owned and operated by the Pakistan Atomic Energy Commission. In 2002 the two plants produced about 2.5% of the country's electricity supply (Fig. 21).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle

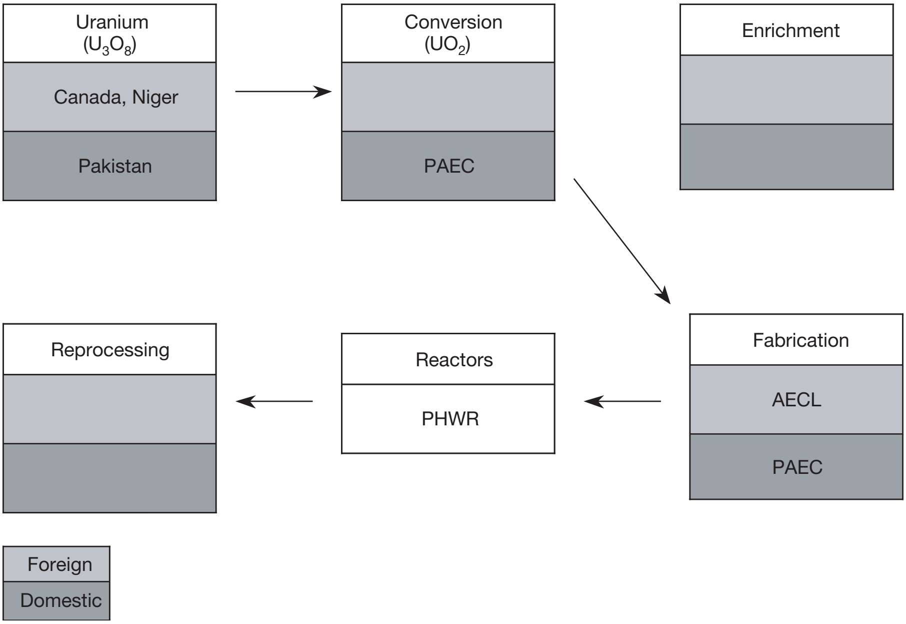


FIG. 21. Material flow in the nuclear fuel cycle: Pakistan. Foreign organization: AECL (Canada).

● No decision yet
○ Not applicable

Mining and milling

Two plants are operative: the Dera Ghazi Khan pilot plant which has a capacity of 30 t U/a, and the Issa Khel/Kubul Kel pilot plant which has a capacity of 1 t U/a. Both plants use ISL technology.

Conversion

The Islamabad conversion plant converts yellow cake to UO_2.

Enrichment

The Kahuta uranium centrifuge enrichment plant is in operation and has a capacity of 5 t SWU/a.

Fabrication

The Chashma fuel fabrication facility (capacity 20 t HM/a), operated by the Pakistan Atomic Energy Commission (PAEC) to produce PHWR fuel, has been in operation since 1986.

Spent fuel management

Spent fuel is stored at the reactor sites.

3.26. PORTUGAL

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

At present there are no uranium mining and milling activities in Portugal. Production of uranium concentrate in the Urgeiriça production mill stopped in March 2001 and there are no intentions of restarting production.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.27. ROMANIA

Romania has operated the Cernavoda nuclear power plant (unit 1, CANDU), which has a total capacity of 706.5 MW(e), since 1996. Nuclear power generation accounted for about 10% of Romania's total electricity production in 2002. Unit two of the Cernavoda nuclear power plant is under construction and three other units are in conservation. Unit 2 is expected to begin operation in 2007 and the last three units after 2010. Front end nuclear fuel cycle industrial facilities have been developed to supply nuclear fuel and heavy water for domestic purposes (Fig. 22).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

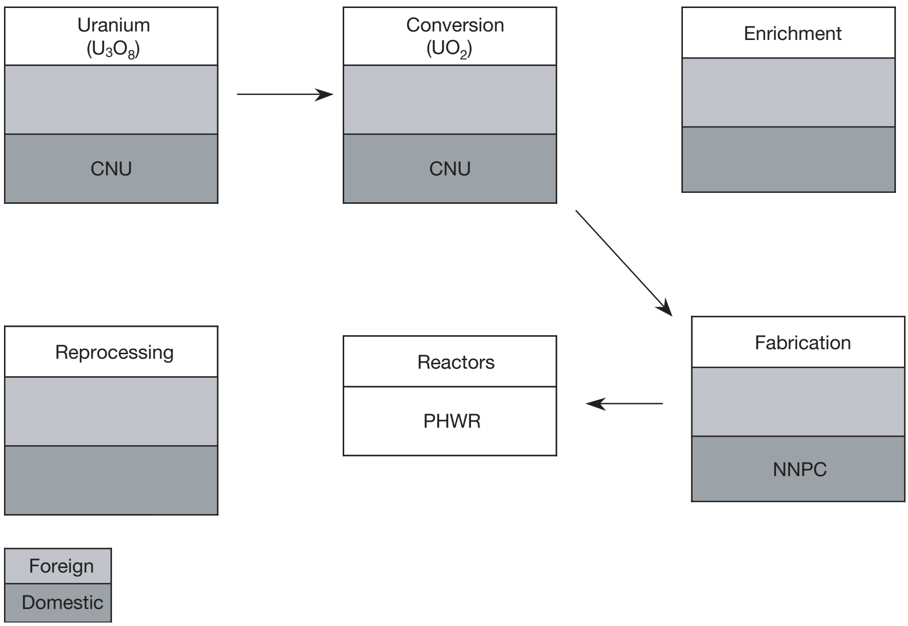


FIG. 22. Material flow in the nuclear fuel cycle: Romania.

Mining

Uranium mining activities started in Romania in 1952. Uranium exploration, exploitation and processing are State run activities. The representative of the State in the management of the uranium industry is the National Uranium Company (CNU) which operated 3 uranium mining branches at Bihor (E.M. Bihor), Banat (E.M. Banat) and Suceava (E.M. Crucea).

E.M. Banat is being fully and E.M. Bihor partially closed down. E.M. Crucea is in full operation and E.M. Bihor is in partial operation, with a production capacity of 100 t U/a. The uranium production capacity is tailored to meet the requirements of the national nuclear power programme.

Milling and conversion

Uranium ores are processed by the Feldioara plant, which is operated by CNU. The Feldioara processing plant has 2 modules:

(a) An 'R' type module for uranium milling and concentration (nominal capacity 300 t U (U_3O_8)/a);
(b) An 'E' type module for uranium refining and conversion to nuclear grade UO_2 (nominal capacity 300 t U (UO_2)/a).

Both modules are in operation but their production capacity has been reduced to about 100 t U (U_3O_8)/a for the R plant and on request (by the Pitesti Fuel Fabrication Plant (FCN Pitesti)) for the E plant. The Feldioara processing plant has been qualified by AECL as a CANDU UO_2 fuel supplier.

Enrichment

None

Fabrication

The National Nuclear Power Company operates FCN Pitesti. The present capacity of FCN Pitesti (110 t U/a) will be increased in accordance with the requirements of the Cernavoda nuclear power plant. FCN Pitesti has been qualified by AECL as a CANDU fuel supplier.

Spent fuel management

To date, spent fuel resulting from the operation of unit 1 of the Cernavoda nuclear power plant has been stored on-site in the water filled pool near the reactor. An interim dry storage silo on the site became operational in 2003 and ensures storage for at least fifty years.

Heavy water production

The Romanian Nuclear Activities Authority operates the ROMAG heavy water plant (design capacity 360 t/a). Using the Girdler–sulphide process ROMAG is the largest source of heavy water in Europe.

3.28. RUSSIAN FEDERATION

The Russian Federation has 14 WWERs, 15 LWGRs (RBMKs and EGPs) and 1 FBR in operation, which have a total capacity of about 22.24 GW(e). The first WWER reactor started operation in 1964. Nuclear generation accounted for around 15% of the country's total electricity production in 2002. In 2001, a WWER-1000 started operation at the Volgodnskaj nuclear power plant. Three power reactors are under construction. The Russian Federation has capabilities in all segments of the nuclear fuel cycle. The excess capacities are offered to foreign utilities on a commercial basis. Some of the nuclear fuel cycle facilities are State owned (Minatom). The others are managed by joint stock companies (JSC TVEL, Rosenergoatom, Atomstroi, etc.) in which controlling interests are retained by the State (Fig. 23).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

The Priargunsky Mining–Chemical Production Association has a capacity of 3500 t U/a using open pit, underground and ISL extraction methods. In 2002

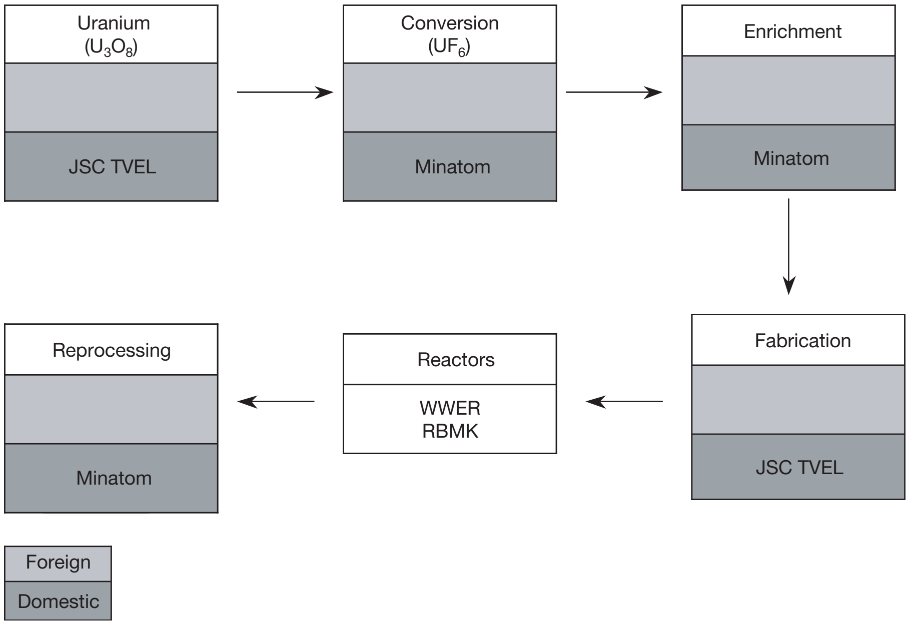


FIG. 23. Material flow in the nuclear fuel cycle: Russian Federation. Fuel pellets for WWER-1000 reactors are produced in Kazakhstan. WWER-1000 spent fuels take the direct storage option; WWER-440 spent fuels are reprocessed. Reprocessed uranium recovered from WWER-440 spent fuel is used in RBMK reactors.

the Dalur facility started operation, with a capacity of 700 t U/a, using the ISL extraction method.

Conversion

Minatom operates the Angarsk and Tomsk conversion plants (conversion to UF_6), which have a total capacity of 30 000 t U/a. The excess capacities are offered to foreign utilities on a commercial basis.

Enrichment

The first civil uranium enrichment plant in the Russian Federation started operation in 1964 at Ekaterinburg. Three more plants came into operation later at Tomsk, Angarsk and Krasnoyarsk. At present, Minatom operates all four plants which have a total capacity of 15 000 t SWU/a. The excess capacities are offered to foreign utilities on a commercial basis.

Fabrication

Nuclear fuel fabrication is carried out by JSC TVFL at 2 plants, Electrostal and Novosibirsk. Electrostal produces fuel elements, assemblies, powder and pellets for WWER-440, WWER-1000, BN-600, RMBK and PWR reactors. The Novosibirsk plant manufactures fuel elements and assemblies for WWER-1000 reactors. In the production of fuel assemblies for RBMK and WWER-1000 reactors a quantity of fuel pellets is supplied from the Ust Kamenogorsk plant (Kazakhstan). Zirconium production for nuclear fuel takes place at the Glazov plant (Ugmurtia, Russian Federation). The total fuel fabrication capacity (fuel assemblies for different reactor types) of JSC TVEL is about 2600 t HM/a. The excess capacities are offered to foreign utilities on a commercial basis.

Spent fuel management

The reprocessing option is the one followed for dealing with spent reactor fuel, with the exception of that originating from RBMKs, the spent fuel of which is to be disposed of. At present, Minatom operates the RT-1 plant in Chelyabinsk for reprocessing fuel from WWER-440 reactors, fast reactors and the propulsion reactors of icebreakers and submarines. The plant's capacity for WWER-440 fuel is 400 t HM/a. The construction of a second reprocessing plant (RT-2) at Krasnoyarsk, which has a first line design capacity of 800 t HM/a, has been postponed indefinitely. Reprocessed uranium is used for RBMK fuel production. Plutonium obtained at RT-1 is temporarily stored on-site in dioxide form. Minatom operates several wet AFR fuel storage facilities at RT-1 and RT-2 and at several nuclear power plants, which have a total capacity of about 16 000 t HM.

3.29. SLOVAKIA

Four WWER nuclear reactors are in operation at the Bohunice nuclear power plant and 2 at the Mochovce nuclear power plant. Their total capacity is 2.6 GW(e).

The heavy water moderated, gas cooled reactor at Jaslovske Bohunice started operation in 1972, but after an accident in 1977 its operation was stopped. The first WWER reactor started operation in 1978.

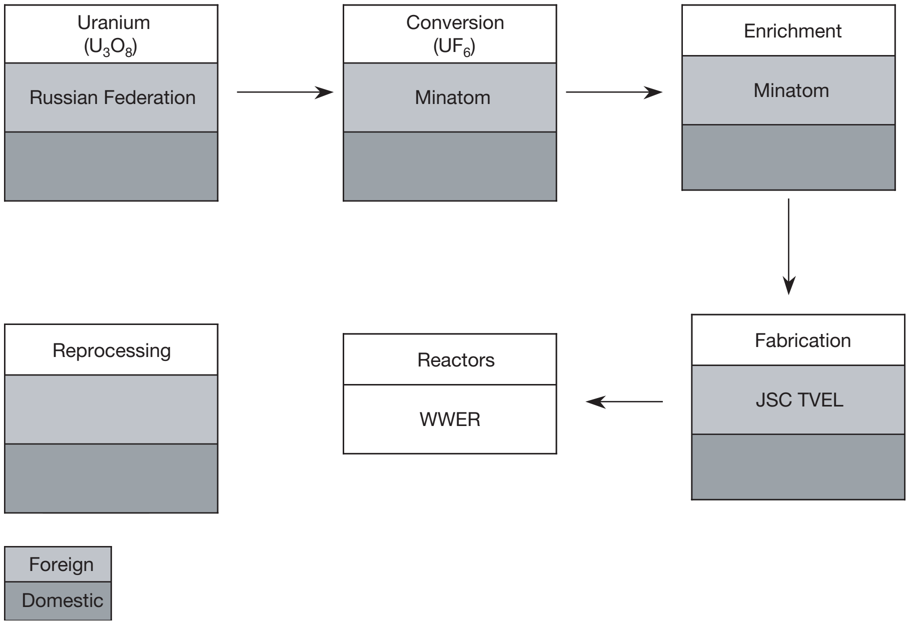


FIG. 24. Material flow in the nuclear fuel cycle: Slovakia. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

Nuclear generation accounted for 65% of the country's total electricity production in 2002. The plan to construct 2 new WWER reactors at the Mochovce nuclear power plant is currently under evaluation (Fig. 24).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

In the 1960s and 1970s small quantities of uranium were mined in eastern Slovakia.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

Until 1987 some spent fuel was returned to the Russian Federation. The AFR storage facility at Jaslovske Bohunice started operation in 1987. Its total storage capacity is 1693 t HM.

3.30. SLOVENIA

Slovenia has one 676 MW(e) PWR unit (imported from the USA) in operation. Nuclear power generation accounted for 39.8% of the country's total electricity production in 2002 (Fig. 25).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

Between 1982 and 1990, 362 t of uranium were produced at the Zirovski VRH mine and processing plant. This plant is now being decommissioned.

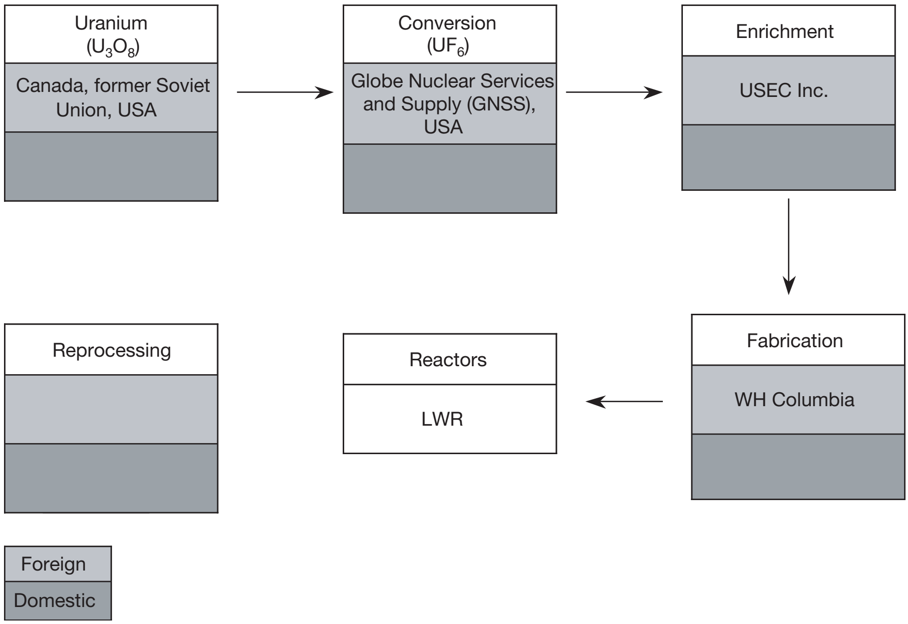


FIG. 25. Material flow in the nuclear fuel cycle: Slovenia. Foreign organizations: Converdyn (USA), USEC Inc. (USA), WH Columbia (USA).

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

A spent fuel storage pool (capacity 690 t HM) is in operation at the plant site.

3.31. SOUTH AFRICA

In 2002, two PWRs with a total capacity of 1842 MW(e) were in operation at the Koeberg nuclear power plant in the Western Cape. This power plant started operation in 1984. Total electricity generated from Koeberg in 2002 amounted to 12 588 TW·h. Nuclear power generation accounted for 6.3% of the country's total electricity production in 2002. No nuclear power units are currently under construction.

The State electricity utility ESKOM is considering a pebble bed modular reactor programme which would involve the construction of 110 MW high temperature reactors. A 'know-how' agreement has been signed with HTR GmbH (an ABB–Siemens joint venture) in this regard (Fig. 26).

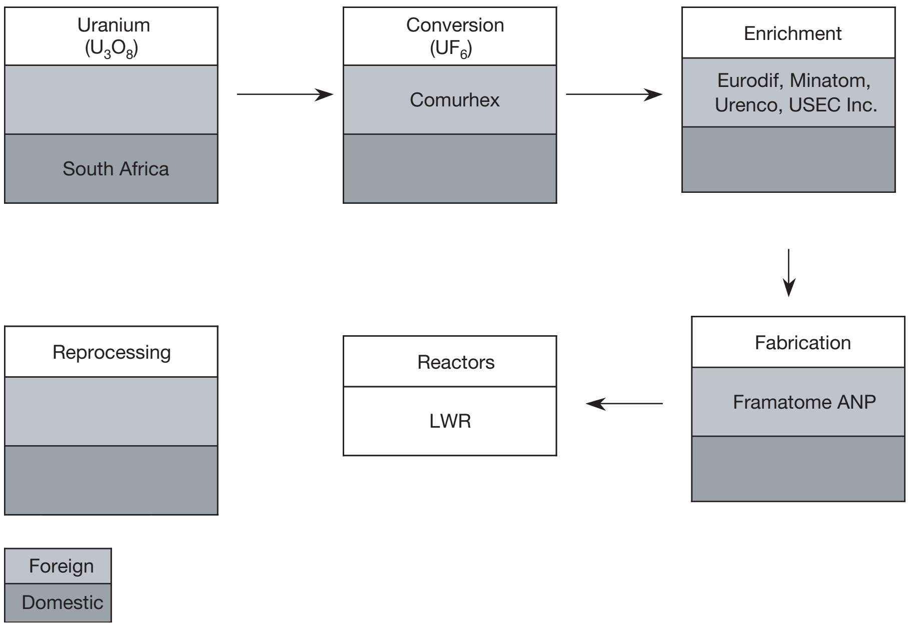


FIG. 26. Material flow in the nuclear fuel cycle: South Africa. Foreign organizations: Comurhex (France), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

Only one mine (Vaal River Operations) produced uranium as a by-product of gold mining in 2002. Total production for 2002 was 1000 t.

Conversion

The Valindaba plant, which converted uranium to UF_6 and which had a design capacity of 1400 t U/a, was permanently shut down in 1998.

Enrichment

The Valindaba Y plant (design capacity 10 t SWU/a) and the Valindaba Z Plant (design capacity 300 t SWU/a) were closed in 1990 and 1995, respectively. Decommissioning and decontamination operations at these plants are in progress.

Fabrication

The Beva fuel fabrication plant at Pelindaba, which had a design capacity of 100 t HM/a, was shut down in 1996.

Spent fuel management

ESKOM has increased the storage capacity of its spent fuel storage pool at the Koeberg nuclear power plant to make provision for all spent fuel to be stored in-pool for the lifetime of the reactor. Low and intermediate level wastes are compacted into drums and concrete containers, which are stacked in trenches at the Vaalputs national repository site.

3.32. SPAIN

Spain has nine nuclear power plants in operation at seven sites. At the end of 2002 the capacity of the plants totalled 7.9 GW(e). In 2002 their electricity production amounted to 60.28 TW·h, equivalent to 26% of national electricity production. The country currently has no plans to add further nuclear generating capacity (Fig. 27).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

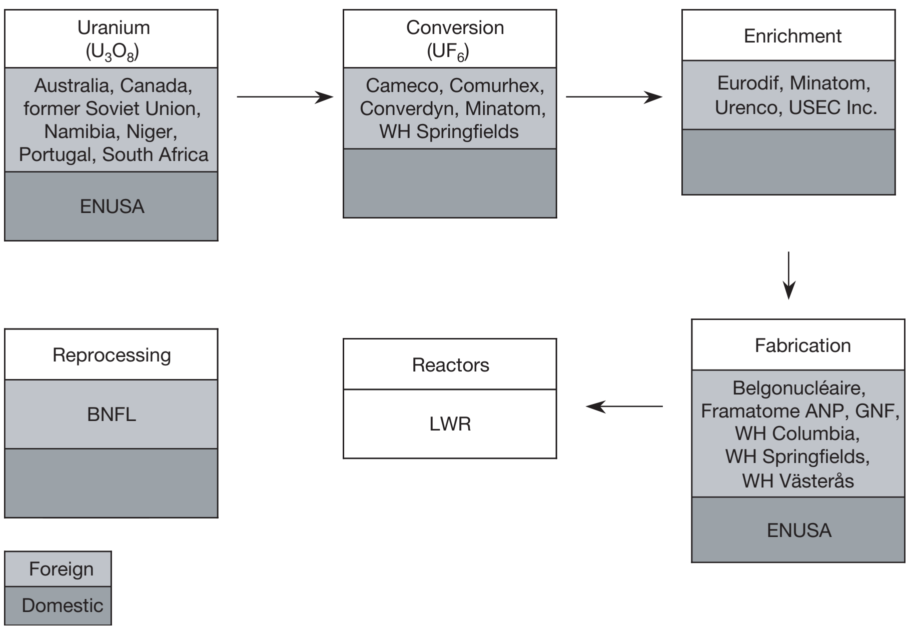


FIG. 27. Material flow in the nuclear fuel cycle: Spain. Foreign organizations: Belgonucléaire (Belgium), Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (Germany), GNF (USA), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Columbia (USA), WH Springfields (UK), WH Västerås (Sweden).

Mining and milling

ENUSA Industrias Avanzadas, S.A. provides products and services related to the front end of the nuclear fuel cycle. ENUSA had been exploiting an open pit uranium mine at Saelices el Chico (Salamanca). Owing to the low market price of uranium, the mine cannot be exploited economically and mining activities were stopped at the end of 2000.

At the mine site ENUSA has the Quercus plant which began producing uranium concentrates in 1993. In 2001 and 2002 the plant worked at a low production level treating mine water. At the end of 2002 ENUSA terminated the plant's production activities.

Conversion

There is no domestic conversion. In 2002 ENUSA managed and supplied 1325 t U in conversion services to Spanish nuclear power plants.

Enrichment

There is no domestic enrichment. In 2002 ENUSA managed and supplied 799 t SWU in enrichment services to Spanish nuclear power plants.

Fabrication

ENUSA operates a fuel fabrication facility for BWR, PWR and WWER reactors at Juzbado (Salamanca). The design capacity of this facility is 400 t U/a of fuel elements.

Spent fuel management

The Fifth Radioactive Waste Plan governs the policy regarding spent fuel management. The spent fuel is stored in each nuclear power plant pool. In addition, a temporary storage facility was started up at the Trillo nuclear power plant in 2002 which houses spent fuel from the plant in dual purpose casks.

After 2010 it is envisaged that a centralized temporary storage facility will exist. No decision will be taken prior to 2010 with respect to the final disposal of spent fuel. Until then it will be necessary to undertake two lines of research, one that considers a deep geological repository and the other that is oriented towards partitioning and transmutation.

3.33. SWEDEN

In 2002, Sweden's eleven nuclear power reactor units, which have a combined installed capacity of 9.8 GW(e), provided 65.6 TW·h of electricity, equivalent to approximately 43% of the country's total output. In February 1998 the Swedish Government announced its intention to withdraw the operating licence of Barsebeck-1, effective as of 1 July 1998, in line with new legislation covering the decommissioning of nuclear power plants. However, the Governmental motion at that time failed. Operation of Barsebeck-1 ceased in November 1999 (Fig. 28).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

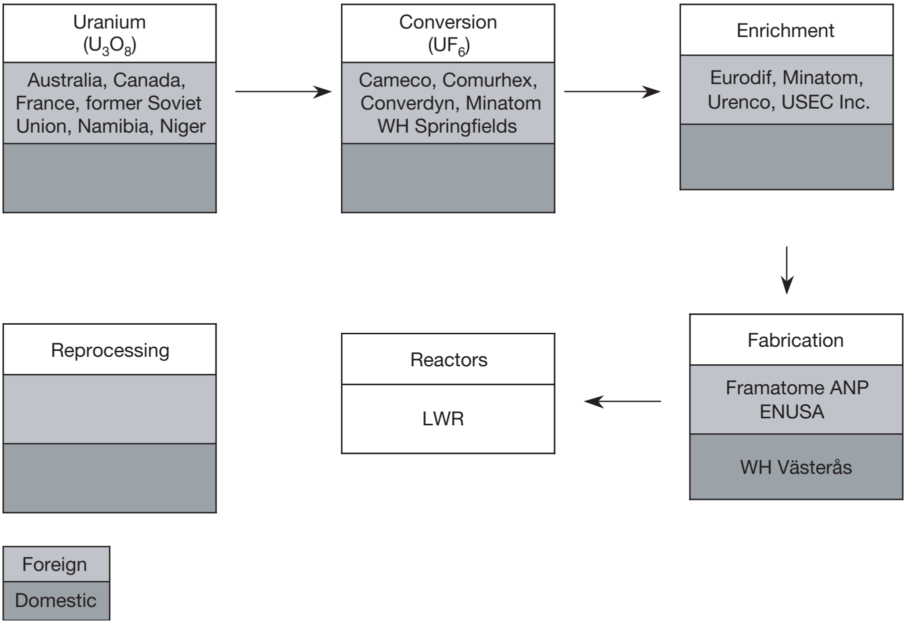


FIG. 28. Material flow in the nuclear fuel cycle: Sweden. Foreign organizations: Cameco (Canada), Comurhex (France), Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Springfields (UK).

Mining and milling

None

Conversion

None

Enrichment

None

Fabrication

The Westinghouse Atom fuel fabrication plant at Västerås produces PWR and BWR fuels and has a capacity of 600 t U/a.

Spent fuel management

Prior to the decision to phase out nuclear power in Sweden, contracts were established to reprocess some of Sweden's spent nuclear fuel in the UK and approximately 140 t HM were shipped to BNFL in the late 1970s. Since then, Sweden has opted for the direct disposal of spent nuclear fuel. Currently, all spent fuels are transported to the CLAB facility (wet storage, with a capacity of 8000 t HM) to be stored until final disposal. This management is financed by a surcharge levied on nuclear energy production.

3.34. SWITZERLAND

Three PWRs and two BWRs are in operation with a total capacity of 3.2 GW(e), accounting for about 40% of the country's electricity generation (Fig. 29).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

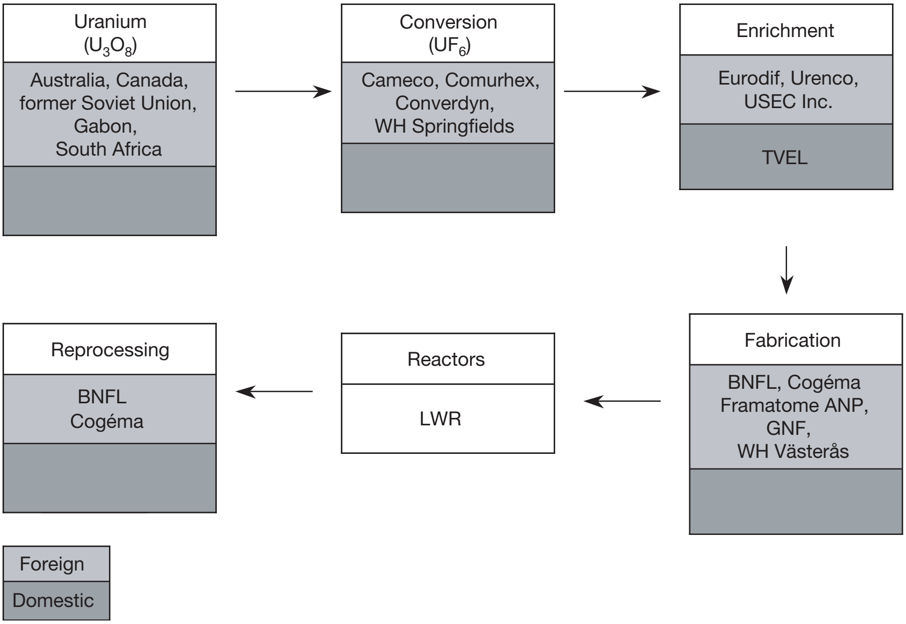


FIG. 29. Material flow in the nuclear fuel cycle: Switzerland. Foreign organizations: Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Italy, Spain), Framatome ANP (France), GNF (USA), Urenco Ltd (Germany, Netherlands, UK), USEC Inc. (USA), WH Columbia (USA), WH Springfields (UK), WH Västerås (Sweden).

Mining and milling

None

Conversion

None

Enrichment

None

Fabrication

There is no domestic fabrication; MOX fuels for LWRs are imported from the UK and France.

Spent fuel management

Swiss utilities follow a dual track approach to spent fuel management. Spent fuels are reprocessed at the BNFL reprocessing plant in the UK and at the Cogéma reprocessing plant in France. Spent fuel which is not sent for reprocessing is stored at the reactor site and in the dry spent fuel interim storage facilities at Würenlingen (ZWILAG) for later disposal.

3.35. UKRAINE

Thirteen WWER (two WWER-440 and eleven WWER-1000) power reactors are in operation and have a total capacity of 11.835 GW(e). The first reactor, an RBMK-1000, started operation on 26 September 1977 at the Chernobyl nuclear power plant. Nuclear generation accounted for about 45% of the country's total electricity production in 2002. There are plans to construct new fuel cycle facilities, with the exception of enrichment plants, by 2010 (Fig. 30).

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
● No decision yet
○ Not applicable

Mining and milling

Uranium production in Ukraine started in 1959 using underground mining. The Zheltiye Vody hydrometallurgical plant was brought into production in the same year. Its nominal production capacity is 1000 t U/a. It is planned to increase the uranium supply capability from 50% to 100%.

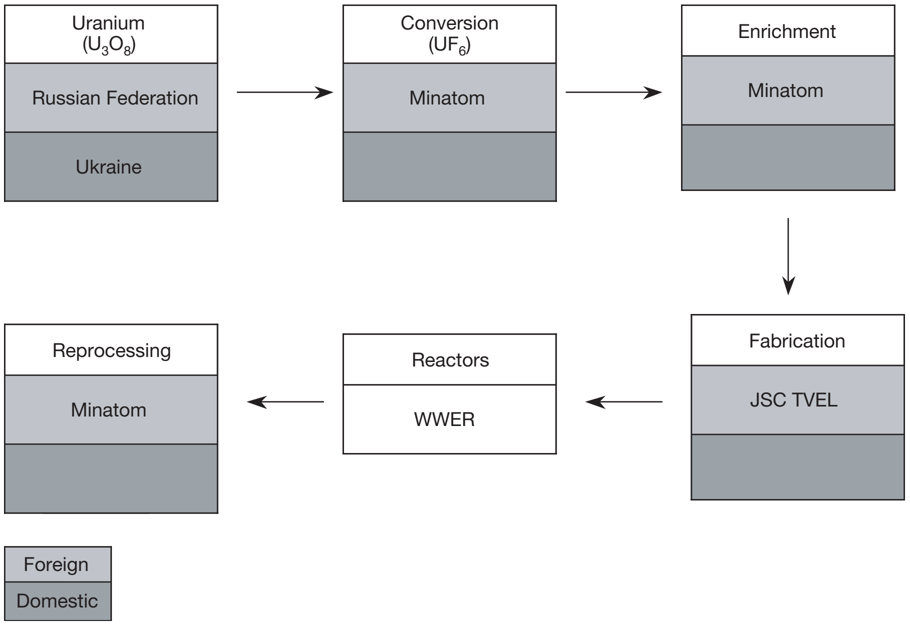


FIG. 30. Material flow in the nuclear fuel cycle: Ukraine. Foreign organizations: JSC TVEL (Russian Federation), Minatom (Russian Federation).

Conversion

None

Enrichment

None

Fabrication

There is no domestic fabrication. At present fuel is flown in from the Russian Federation. A joint venture for the fabrication of fuel for WWER-1000 reactors exists with the Russian Federation and Kazakhstan.

Spent fuel management

From the beginning of the nuclear programme until the present day, spent fuel from WWER reactors has routinely been returned to the RT-1 reprocessing plant and to the central storage facility at the Krasnoyarsk mining and chemical plant in the Russian Federation. After spent fuel reprocessing, radioactive wastes are to be taken back.

Spent RBMK fuel is stored in AR storage pools and at the wet AFR spent fuel storage facility (SFSF-1) on the Chernobyl nuclear power plant site. The total capacity of the wet SFSF-1 is approximately 2500 t HM. Construction of a dry version, SFSF-2, is under way in the area of the Chernobyl nuclear power plant. A dry AFR storage facility is being commissioned at the Zaporozhe nuclear power plant, which in its initial stage will have a capacity of approximately 160 t HM.

3.36. UNITED KINGDOM

Sixteen Magnox plants, fourteen AGRs and one PWR were in operation in 2002 with a total capacity of 12 GW(e). Around 22% of the UK's electricity was generated by nuclear power. A complete fuel cycle is provided by BNFL, both for the home market and for export (Fig. 31).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
● Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

No mining or milling of uranium ore takes place in the UK.

Conversion

Westinghouse operates a conversion facility at its Springfields plant near Preston, where uranium ore concentrate is converted to UF_6 for customers. The uranium ore concentrate to UF_6 conversion line has a capacity of 6000 t U/a.

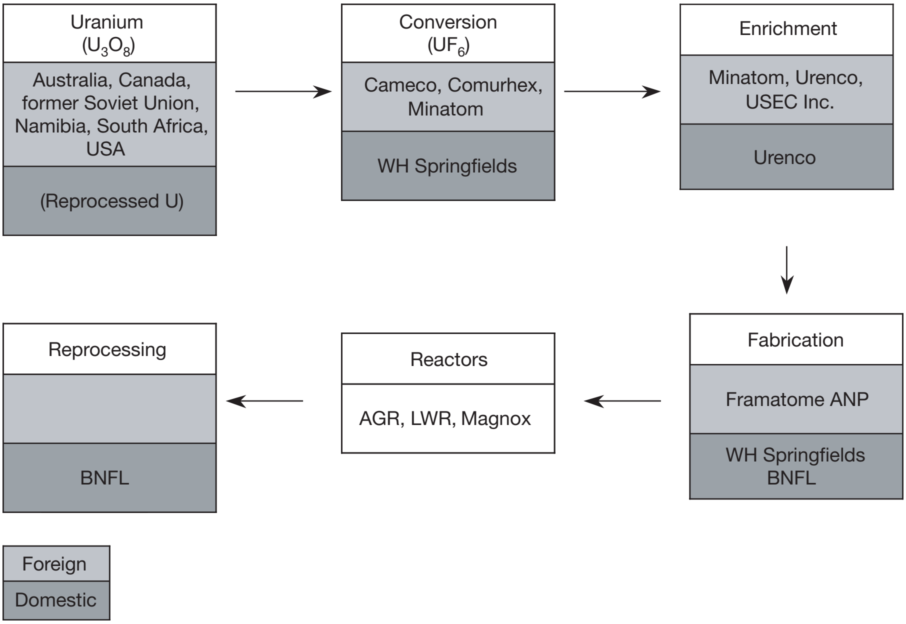


FIG. 31. Material flow in the nuclear fuel cycle: UK. Foreign organizations: Cameco (Canada), Comurhex (France), Framatome ANP (Germany), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK) USEC Inc. (USA).

A conversion line for uranium ore concentrate to UF_4, an intermediate stage in Magnox fuel production, has a capacity of 10 000 t U/a.

Enrichment

Urenco operates a commercial centrifugal enrichment plant at Capenhurst. This plant has a capacity of 2300 t SWU/a.

Fabrication

Westinghouse Springfields fabricates a number of different types of fuel. Current production capacities are Magnox (1300 t U/a), AGR (260 t U/a).

The UKAEA fabrication plant for material test reactor fuel is currently in operation at Dounreay to discharge historical contracts for the manufacture of fuel elements. Once these historical contracts have been discharged the fabrication plant will be shut down pending decommissioning.

BNFL operates a small scale MOX fuel demonstration facility at Sellafield that has a capacity of 8 t HM/a. This facility will only be used for development purposes in the future. The commercial scale MOX plant commenced Pu commissioning at the end of 2001 and has a capacity of 120 t HM/a. Quantities of UO_2 powder are exported to foreign fabricators.

Spent fuel management

BNFL operates a Magnox fuel reprocessing plant at Sellafield, which has an operational capacity of 1500 t HM/a. The thermal oxide reprocessing plant is also operated at Sellafield and has an operational capacity of 1200 t HM/a

BNFL operates spent fuel storage pools at Sellafield for both AGR and LWR fuels. The pools have a total capacity of 8000 t HM. A spent fuel dry storage facility (capacity 700 t HM) is in operation at the Wylfa nuclear power plant.

3.37. UNITED STATES OF AMERICA

Nuclear power reactors in operation in the USA in 2002 comprised 69 PWRs and 34 BWRs, their total capacity amounting to 98.1 GW(e). It is estimated that they accounted for 20% of the country's electricity generation in 2002. No new reactors are planned in the near term.

Both domestic and foreign suppliers provide the US nuclear power plant operating organizations with all types of fuel cycle services (Fig. 32).

Nuclear fuel cycle policy

● Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
○ Not applicable

Mining and milling

In 2002, two uranium in situ leach plants were operational in the USA. The total production capacity was 1150 t U/a.

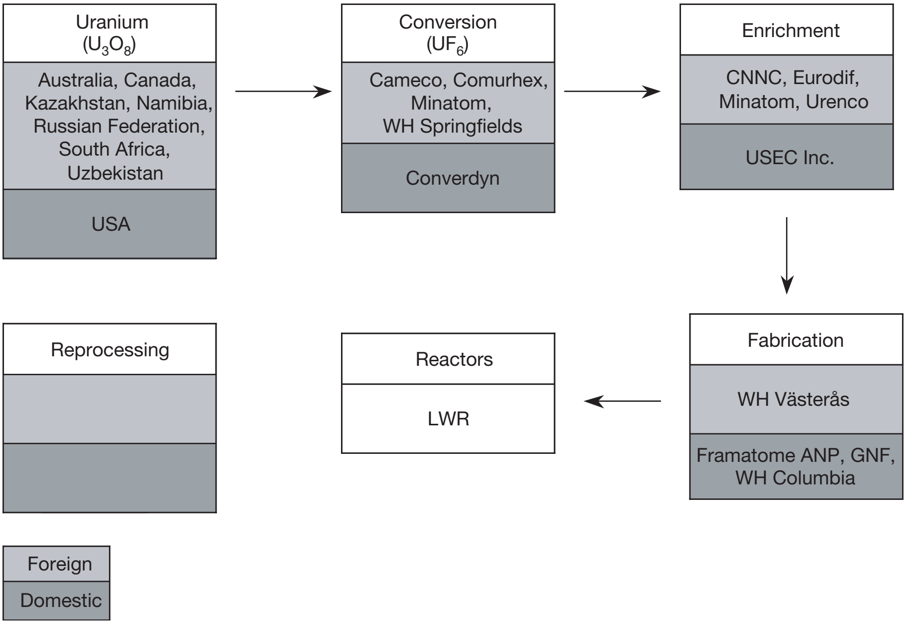


FIG. 32. Material flow in the nuclear fuel cycle: USA. Foreign organizations: Cameco (Canada), CNNC (China), Comurhex (France), Eurodif (Belgium, France, Italy, Spain), Minatom (Russian Federation), Urenco Ltd (Germany, Netherlands, UK), WH Springfields (UK), WH Västerås (Sweden).

Conversion

Converdyn operates the only commercial UF_6 conversion plant in the USA. The plant is located in Metropolis, Illinois, and has a capacity of 14 000 t U/a.

Enrichment

USEC Inc. operates a uranium enrichment plant at Paducah, Kentucky, with a capacity of 11 300 t SWU/a.

Fabrication

Four LWR fuel fabrication plants were in operation in 2002: Global Nuclear Fuels (Wilmington, North Carolina, 1100 t U/a (BWR)), Westinghouse Nuclear Fuel (Columbia, South Carolina, 1250 t U/a (PWR)), Framatome ANP (Lynchburg, Virginia, 400 t U/a (PWR)), Framatome ANP (Richland, Washington, 700 t U/a (PWR and BWR)), for a total of 3450 t U/a (LWR).

Spent fuel management

An estimated 47 100 t HM from commercial spent fuel was in inventory at the end of 2002 at both wet and dry storage facilities.

No commercial reprocessing plants are in operation. US nuclear power plant operating organizations employ the open fuel cycle.

3.38. UZBEKISTAN

Uranium production in Uzbekistan started in 1952. Production by the Navoi mining and metallurgical complex has been ongoing at the Navoi mill since 1964. Although uranium has been produced using both conventional and ISL mining technology, only ISL has been in use since 1994 when all conventional mining ceased.

Nuclear fuel cycle policy

○ Open nuclear fuel cycle
○ Closed nuclear fuel cycle
○ No decision yet
● Not applicable

Mining and milling

Total production of uranium in Uzbekistan up to 2002 was 99 562 t. In 2002 ISL production was organized into three mining districts or divisions, the northern, southern and mining division number 5. Each division includes one or more ISL mining facilities. The total capacity of the three divisions is about 2300 t U/a. Uranium concentrates are processed in the hydrometallurgical plant in Navoi (capacity 3000 t U/a).

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

BIBLIOGRAPHY

INTERNATIONAL ATOMIC ENERGY AGENCY, The Nuclear Fuel Cycle Information System (An International Directory of Nuclear Fuel Cycle Facilities), IAEA-TECDOC-408, IAEA, Vienna (1987).

—Power Reactor Information System (PRIS): Reference and On-line Access Manual, IAEA-TECDOC-507, IAEA, Vienna (1989).

—Country Nuclear Power Profiles — 2002 Edition, IAEA, Vienna (2003).

—Country Nuclear Power Profiles — 2003 Edition, IAEA, Vienna (2004).

INTERNATIONAL ATOMIC ENERGY AGENCY, OECD NUCLEAR ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD, Paris (2004).

JAPAN ATOMIC INDUSTRY FORUM, Nuclear Power Plants in The World 2002, JAIF, Tokyo (2003).

—Nuclear Power Plants in The World 2003, JAIF, Tokyo (2004).

CONTRIBUTORS TO DRAFTING AND REVIEW

Araujo da Silva, R.	Indústrias Nucleares do Brasil S.A., Brazil
Dunn, M.	British Nuclear Fuels Ltd, United Kingdom
Deroubaix, D.	Cogéma, France
Florido, P.C.	Comisión Nacional de Energía Atómica, Argentina
Grigoriev, A.	Joint Stock Company TVEL, Russian Federation
Hatter, J.	British Nuclear Fuels Ltd, United Kingdom
Hosokawa, Y.	International Atomic Energy Agency
Kawabata, K.	International Atomic Energy Agency
Koyama, K.	Japan Nuclear Fuel Cycle Development Institute, Japan
Shukla, D.S.	Bhabha Atomic Research Centre, India
Smith, M.J.	NAC International, United States of America
Yoo, J.H.	Korea Atomic Energy Research Institute, Republic of Korea
Zhang, Fubao	China Atomic Energy Authority, China

This second edition of the IAEA's Country Nuclear Fuel Cycle Profiles describes the status of the nuclear fuel cycle at the end of 2002, reviewing worldwide activities in this area and surveying fuel cycle activities in a number of countries. It also incorporates graphical representations of material flow in the nuclear fuel cycle of each country.

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA
ISBN 92–0–114803–8
ISSN 0074–1914