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Country Nuclear Fuel Cycle Profiles

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2001

COUNTRY NUCLEAR FUEL CYCLE PROFILES

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GERMANY	NIGER	
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GREECE	NORWAY	
	PAKISTAN	

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FOREWORD

In recent years, activities related to the nuclear fuel cycle have become widely spread around the world. 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.

This publication was prepared on the basis of available documents and comments received from experts who participated in three Consultants Meetings held between 1997 and 1999 and an Advisory Group Meeting held in 2000. It also reflects the comments received in response to the IAEA Circular Note T1.41.Circ which was sent to selected countries at the beginning of 2000. Essentially, it represents the status of the nuclear fuel cycle at the end of 1999 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 nuclear fuel cycle activities. The second part incorporates graphical representation of material flow in the nuclear fuel cycle of each country. This report does not describe the irradiation of nuclear fuel.

The IAEA wishes to express its gratitude to the chairpersons, A. Grigoriev and M. Smith, and to the participants of the various meetings.

The officers at the IAEA responsible for this publication were Y. Orita, N. Ojima and K. Kawabata from the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

In recent years, activities related to the nuclear fuel cycle have become widely spread and globalization has become obvious in this field. For example, Asia has not only emerged as a market for power reactors but also as a market for nuclear fuel and related nuclear fuel cycle components and services. Countries comprising the former Soviet Union (FSU) 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 nuclear fuel cycle services. For example, in the field of fuel fabrication, the market has become more open, reflecting global liberalization of trade and electricity generation. In 1999, fuel for commercial nuclear reactors was fabricated in 17 countries. The relation between nuclear fuel supply and demand has become more complex as a result of the liberalization of the market and the development of nuclear power programmes in Asian and eastern European countries.

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.

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 eventual disposal as waste. The other is the ‘closed’ fuel cycle (Fig. 2), where the spent fuel is reprocessed and the uranium and plutonium separated from the fission products. Both the uranium and the plutonium can be recycled into new fuel elements. For example, plutonium can be recycled in thermal and fast reactors (FRs). It is also possible solely to recycle the uranium and to store the plutonium, or vice versa.

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 nuclear fuel cycle components in each country operating commercial nuclear power reactors or relates to nuclear fuel services having some activity relevant to the nuclear fuel cycle. It also includes country specific graphs which illustrate the main material flow in the nuclear fuel cycle. These illustrations are intended to help clarify the essential nuclear fuel cycle activities in each country and international relationships.

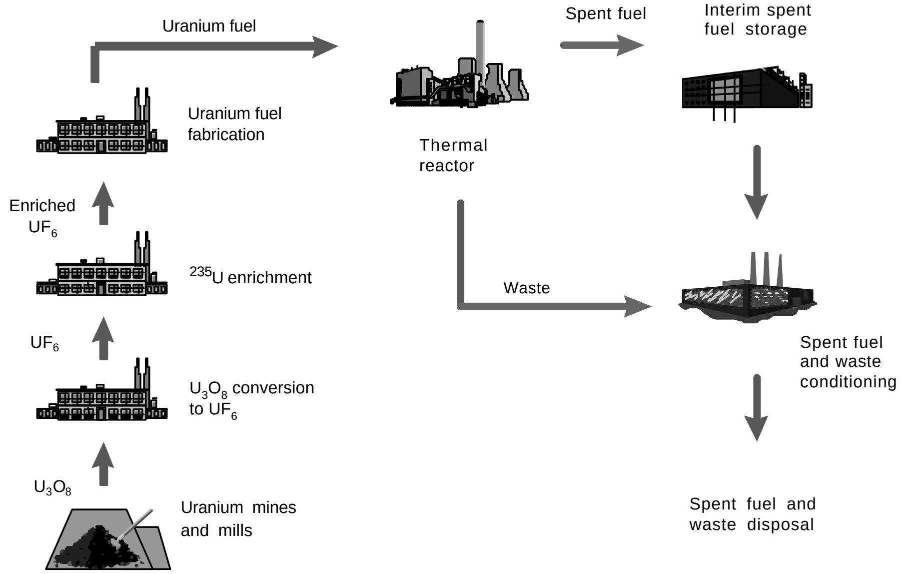

FIG. 1. Open fuel cycle.

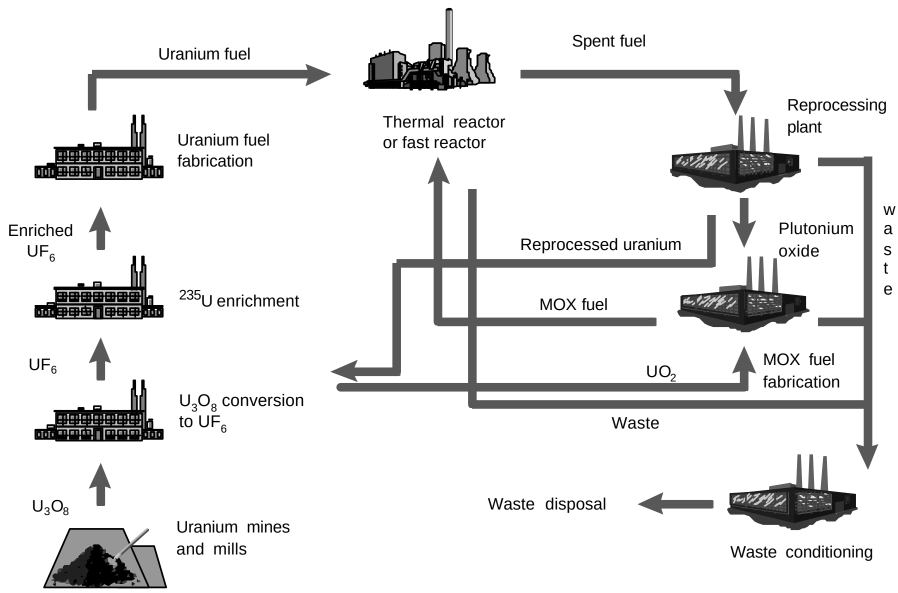

FIG. 2. Closed fuel cycle.

2. REVIEW OF WORLDWIDE ACTIVITIES ON THE NUCLEAR FUEL CYCLE

2.1. 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. Uranium-235 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. ISL 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 drive off 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 on 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 of natural uranium annually. At present, the main uranium producing countries are Australia, Canada, China, Kazakhstan, Namibia, Niger, the Russian Federation, South Africa, Ukraine, the United States of America and Uzbekistan.

2.2. 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 three such forms in common usage: 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 sent to any enrichment plant (subject only to limitations which apply to material of certain origin and which are based on trade restrictions between countries). Five countries operate commercial scale U_3O_8 to UF_6 conversion facilities: Canada, France, the Russian Federation, the United Kingdom and the USA.

In Canada, Cameco operates the Port Hope facility (capacity 12 500 t U/a). In France, Comurhex operates the Malvesi and Pierrelatte plants (total capacity 14 000 t U/a). In the the Russian Federation, Minatom operates the Sverdlovsk and Angarsk plants (total capacity 34 000 t U/a). In the UK, British Nuclear Fuels plc (BNFL) operates the Springfields Line 4 plant (capacity 6000 t U/a) and in the USA, Honeywell International operates the Metropolis plant (capacity 12 700 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), 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 being made for the construction of facilities dedicated to the production of UF_6 from REPU. These include Comurhex’s Pierrelatte 2 plant (France) and BNFL’s Line 3 plant (UK).

2.3. 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 (GD). In GD, 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 its economic 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.

Enrichment is expressed in terms of the separative work unit (SWU), which is 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.

There are five organizations operating commercial scale enrichment plants: Eurodif, Minatom, Japan Nuclear Fuel Limited (JNFL), Urenco and the United States Enrichment Corporation (USEC). Eurodif is a joint venture between several countries (Belgium, France, Islamic Republic of Iran, 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 which have a total capacity of 15 million SWU/a. In Japan, JNFL has, since 1992, operated a plant with a capacity of 1.1 million SWU/a. Urenco is a joint venture between companies in Germany, Netherlands and the UK and operates facilities at Gronau (Germany), Almelo (Netherlands) and Capenhurst (UK). All facilities are centrifuge plants having a total capacity of 3.9 million SWU/a. USEC, which was privatized in 1998, operates two diffusion plants: Paducah, Kentucky (11.3 million SWU/a) and Portsmouth, Ohio (7.4 million SWU/a).

Companies using the older diffusion technology, i.e. USEC and Eurodif, have been developing laser isotope separation. The favoured approach is atomic vapour laser isotope separation, which uses uranium metal. The advantages of this approach are much lower energy consumption and a large increase in enrichment from a single stage. Disadvantages include the requirement for a metal feed and a metal product, which means that additional facilities would have to be built in order to produce the feed and convert the product into a form acceptable to fuel fabricators.

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

A typical LWR (900 MW(e)) needs about 20 t of heavy metal (HM) fuel annually. In cases where fuel is made from natural uranium, it is enriched to about 4% of ^{235}U from roughly 160 t of UF_6 feed through the expenditure of about 10 000 SWU.

2.4. 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. Uranium hexafluoride is converted to uranium dioxide (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 Zircaloy (a zirconium–tin 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 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 Zircaloy 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. Whilst 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 1999, fuel for commercial nuclear reactors was fabricated in 17 countries. These countries have a total fabrication capacity of about 18 000 t U/a (fuel assemblies and elements).

Nuclear fuel requirements worldwide in 1999 were estimated to be around 10 000 t HM, which is equivalent to about 56% 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. China, Republic of Korea, Romania, Ukraine) and those planning to initiate nuclear programmes (e.g. Turkey, Indonesia). The overcapacity is mostly attributable to LWR uranium fuel fabrication, which has about twice the capacity required.

2.5. 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 from an 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 producers of heavy water are Argentina, Canada, China, India and Romania.

2.6. 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 the nuclear weapon 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 there to be more advantages in implementing 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 approaches (open and closed) have their respective advantages and disadvantages.

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

Discharged fuel elements may be placed in dry storage after having resided for a period of several years in the spent fuel pool. 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.

Spent fuel has been transported from AR storage facilities to AFR storage facilities for either interim storage or reprocessing. An excellent safety record has been established over the last 25 years during which more than 88 000 t HM has been shipped by sea, road and rail.

All the world's nuclear power reactors are based on a uranium mining capacity of 45 356 t U, and a combined AR and AFR storage capacity of about 232 000 t HM.

Tables I–III provide capacity data on specific aspects of nuclear fuel cycle facilities (NFCFs).

TABLE I. CAPACITY OF NFCFs RELATED TO LWRs, AGRs AND FRs

Type of facility	Capacity (t HM/a)
Conversion to UF_6	80 092
Enrichment	51 500
Fuel fabrication	12 409
Reprocessing	5 081

Note: The number of LWRs (PWR, BWR, WWER, RBMK) and other reactors (AGR, FR) connected to the grid which use enriched fuel is 382. Their total capacity is 329.8 GW(e).

TABLE II. CAPACITY OF NFCFs RELATED TO PHWRs AND GCRs

Type of facility	Capacity (t HM/a)
Conversion to UO_2 and U	5 600
Fuel fabrication	5 017

Note: The number of PHWRs and GCRs connected to the grid is 51. Their total capacity is 19.3 GW(e).

TABLE III. CAPACITY OF NATIONAL NFCFs

Country	Facility					
	Mining and milling (t U/a)	Conversion to UF_6 (t U/a)	Enrichment (10^6 SWU/a)	Fuel fabrication (t HM/a)	Reprocessing (t HM/a)	SF storage (AR+AFR) (t HM)
Argentina	120	62	0.02	150		6500
Armenia						88
Australia	8200					
Belgium				540		2000
Brazil	400	80		120		318
Bulgaria						1156
Canada	11 830	12 500		2702		35 271
China[a]	740	400	1.1	100		420
Czech Republic	680					936
Finland						2115
France	600	14 350	10.8	1090	1600	25 762
Germany			1.8	650		14 920
Hungary						500
India	210			510.3	260	3515
Japan			1.25	1689.3	120	11 521
Kazakhstan	2500					30
Republic of Korea				800		8738
Lithuania						2101
Mexico						984
Mongolia	150					
Namibia	4000					
Netherlands			1.5			86
Niger	2910					
Pakistan	30		0.005	20		160
Portugal	170					
Romania	300			110		940
Russian Federation	3500	34 000	15	2571.5	401	20 928
Slovakia						1050
Slovenia						361
South Africa	1700			1		670
Spain	255			300		3820
Sweden				600		6500
Switzerland						904
Ukraine	1000					5150
UK		6000	1.3	1950	2700	12 000
USA	3761	12 700	18.7	3900		62 000
Uzbekistan	2300					

[a] IAEA estimates.

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

TABLE IV. URANIUM (U_3O_8) SUPPLY/DEMAND

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

TABLE V. CONVERSION TO UF_6: SUPPLY/DEMAND

Customer	Supplier					
	Canada	France	UK	USA	Russian Federation	Domestic
Armenia					x	
Belgium	x	x	x	x		
Brazil			x	x		
Bulgaria					x	
China						x
Czech Republic	x	x			x	
Finland	x	x			x	
France				x	x	x
Germany	x	x	x	x	x	
Hungary					x	
Japan	x	x	x	x		
Republic of Korea	x	x	x	x	x	
Lithuania					x	
Mexico	x	x				
Netherlands			x			
Russian Federation						x
Slovakia					x	
Slovenia		x		x	x	
South Africa		x				
Spain	x	x	x	x	x	
Sweden	x	x	x	x	x	
Switzerland	x	x	x	x	x	
Ukraine					x	
UK	x					x
USA	x	x	x		x	x

TABLE VI. URANIUM ENRICHMENT: SUPPLY/DEMAND

Customer	Supplier				
	Eurodif	USA	Urenco	Russian Federation	Domestic
Argentina				x	x
Armenia				x	
Belgium	x	x	x	x	
Brazil		x	x		
Bulgaria				x	
China					x
Czech Republic		x		x	
Finland	x		x	x	
France		x	x	x	x
Germany	x	x	x	x	
Hungary				x	
India					x
Japan	x	x	x		x
Kazakhstan				x	
Republic of Korea	x	x	x	x	
Lithuania				x	
Mexico		x			
Netherlands		x	x		
Russian Federation					x
Slovakia				x	
Slovenia		x		x	
South Africa	x	x	x	x	
Spain	x	x		x	
Sweden	x	x	x	x	
Switzerland	x	x	x	x	
Ukraine				x	
UK		x	x	x	
USA	x		x	x	x

TABLE VII. FUEL FABRICATION: SUPPLY/DEMAND (finished fuel assemblies)[a]

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

[a] This table also includes MOX fuel.

TABLE VIII. FUEL REPROCESSING: SUPPLY/DEMAND (oxide and metal)[a]

Customer	Supplier			
	France	UK	Russian Federation	Domestic
Belgium	x			
France				x
Germany	x	x		
Hungary			x	
India				x
Japan	x	x		
Netherlands	x	x		
Russian Federation				x
Switzerland	x	x		
Ukraine			x	
UK				x

[a] The above table details those countries that had fuel reprocessed during 1999.

3. COUNTRY NUCLEAR FUEL CYCLE PROFILES

3.1. ARGENTINA

Nucleoeléctrica Argentina SA operates two nuclear power plants: Atucha 1, a pressure vessel type 340 MW(e) PHWR imported from Germany; and Embalse, a CANDU 600 MW(e) PHWR imported from Canada. The nuclear units account for less than 10% of the electricity generation capacity of the country but provided some 12% of the electricity supply in 1999 (Fig. 3).

The new Government may decide on the completion of Atucha 2, a pressure vessel type 700 MW(e) PHWR of Siemens design which is likely to start operation by 2004.

Nuclear fuel cycle policy

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

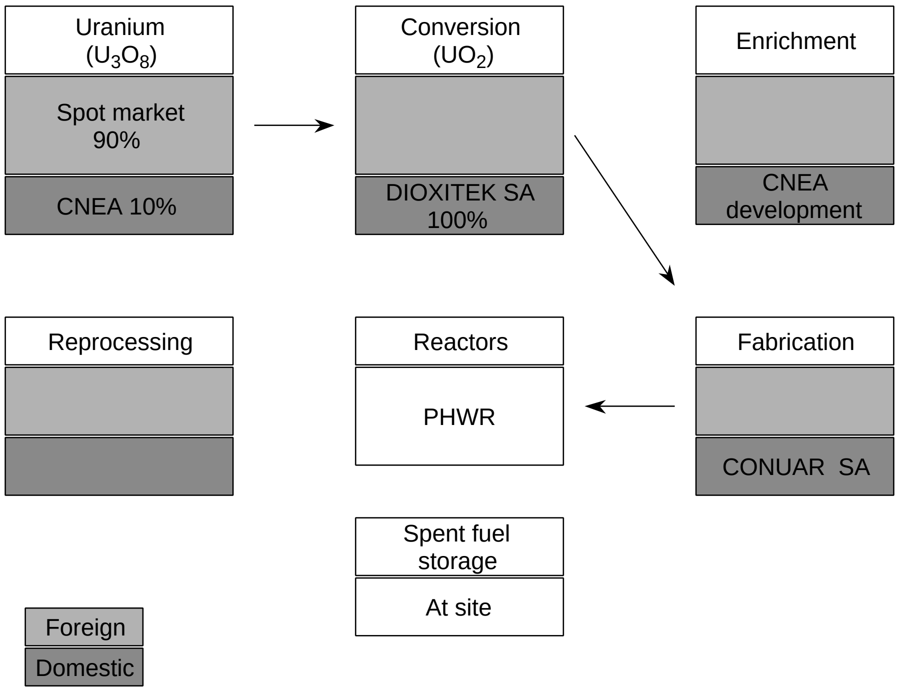

FIG. 3. Material flow in the nuclear fuel cycle: Argentina.

Mining and milling

The Sierra Pintada mine and milling centre at San Rafael, Mendoza, is in operation at a low rate of production, owing to economic reasons which favour the import of material bought on the spot market. 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 underway (1999) 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. The use of REPU is under development as raw material for slightly enriched uranium (SEU) fuel. This plant is operated by DIOXITEK SA. The Pilcaniyeu conversion plant of the Comisión Nacional de Energía Atómica (CNEA), located near S.C. de Bariloche in Rio Negro Province, has a capacity of 62 t HM/a (UO_2 to UF_6).

Enrichment

CNEA's GD pilot plant at Pilcaniyeu has a capacity of 20 000 SWU/a. This plant is in the process of being optimized by the introduction of axial compressors and a new generation of membranes. These developments may allow the plant to operate competitively at a low level of production of SEU material.

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, 50 km 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 fuel cost of the system by 30%, improve the performance of aged CANDU reactors and improve safety. The operator of this plant is CONUAR SA.

Spent fuel management

Atucha 1 nuclear power plant has two pools for the storage of its spent fuel under water. Embalse nuclear power plant has a pool with 10-years' spent fuel storage capacity and vertical dry silos. Both Atucha and Embalse provide intermediate to long term storage options pending a decision being taken on the reprocessing or final disposal of the irradiated fuel.

Heavy water production

The Arroyito heavy water production facility located in Neuquen Province is in operation and has a capacity of 200 t/a.

3.2. ARMENIA

Armenia has one nuclear power plant (ANPP) at Metsamor, which consists of two power units with WWER 440/270 type reactors. Unit 1 started operation in 1976; unit 2 in 1980. In 1989, after the country's destructive earthquake of late 1988, the plant was shut down, even though the ANPP 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 1999, the ANPP produced 2.08 billion kW·h of electrical energy, representing 36% of all electricity generated in Armenia that year (Fig. 4).

Nuclear fuel cycle policy

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

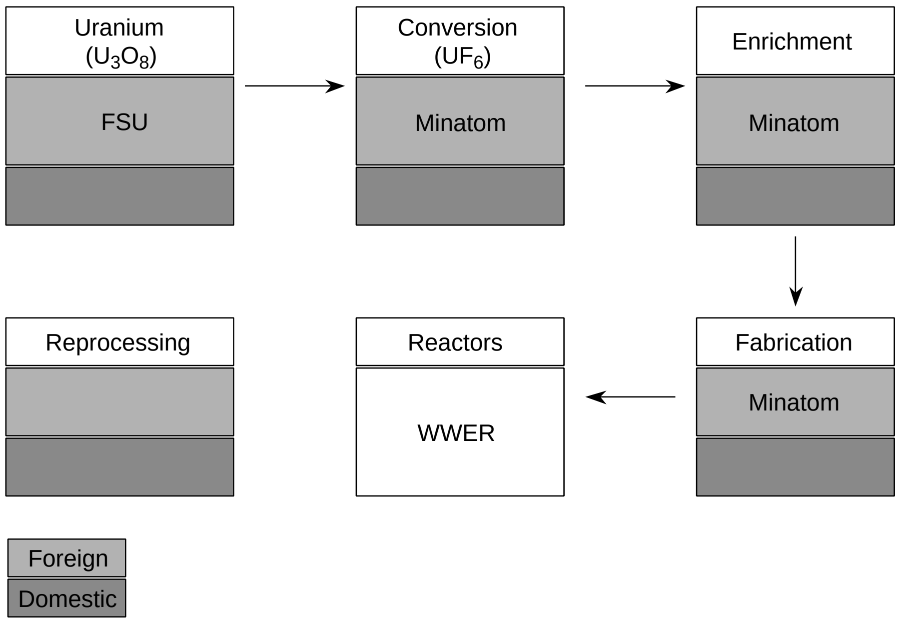

FIG. 4. Material flow in the nuclear fuel cycle: Armenia. Foreign organization — Minatom (Russian Federation).

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 ANPP. A spent fuel dry storage facility has already been constructed in Metsamor (1996–1998), but this is not yet in operation. The first portion of spent fuel is expected to be loaded into the storage facility shortly.

3.3. AUSTRALIA

Following its election in March 1996, the Liberal/National Government introduced a new policy for the approval of new uranium mines and exports and one which is subject to strict environmental, heritage and nuclear safeguards requirements being met.

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 two commercial mining/milling operations: Ranger and Olympic Dam. Ranger consists of an open cut mining operation and a concentration plant. The plant has a production capability of 6000 t U/a. Olympic Dam, with a capacity of 4600 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. Two pilot plants started operation at Beverley and Honeymoon in 1998.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.4. BELGIUM

Seven PWRs are in operation and have a total capacity of 5712 MW(e). With the nuclear sector accounting for 60% of total electricity production in 1997, Belgium now ranks second behind France in terms of the percentage share of electricity produced by the nuclear power sector among Organisation for Economic Co-operation and Development (OECD) countries (Fig. 5).

Nuclear fuel cycle policy

◦ Open nuclear fuel cycle
• Closed nuclear fuel cycle
◦ No decision yet
◦ Not applicable

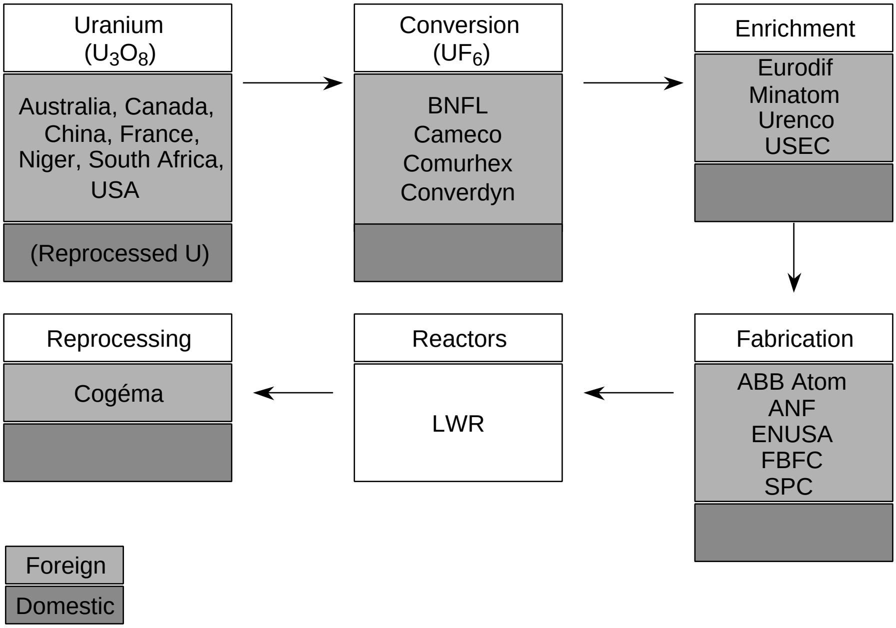

FIG. 5. Material flow in the nuclear fuel cycle: Belgium. Foreign organizations: ABB Atom (Sweden), ANF (Germany), BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), Minatom (Russian Federation), SPC (USA), Urenco (Germany, Netherlands, UK), USEC (USA). One of the FBFC fabrication plants is located at Dessel in Belgium.

Mining and milling

No significant uranium resources have been reported in Belgium. Prayon Rupel Technologies Company is extracting uranium from phosphates imported from Morocco. The plant capacity is 45 t U/a.

Conversion

None

Enrichment

None

Fabrication

Franco-Belge de Fabrication de Combustible (FBFC) operates 500 t U/a PWR and BWR fuel plants at Dessel. Belgonucléaire operates a 40 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 are currently 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 one operating nuclear power plant — Angra 1, a 657 MW(e) Westinghouse PWR. This unit, owned and operated by Eletronuclear, has been in operation since December 1984 and provides about 1% of the country's electricity

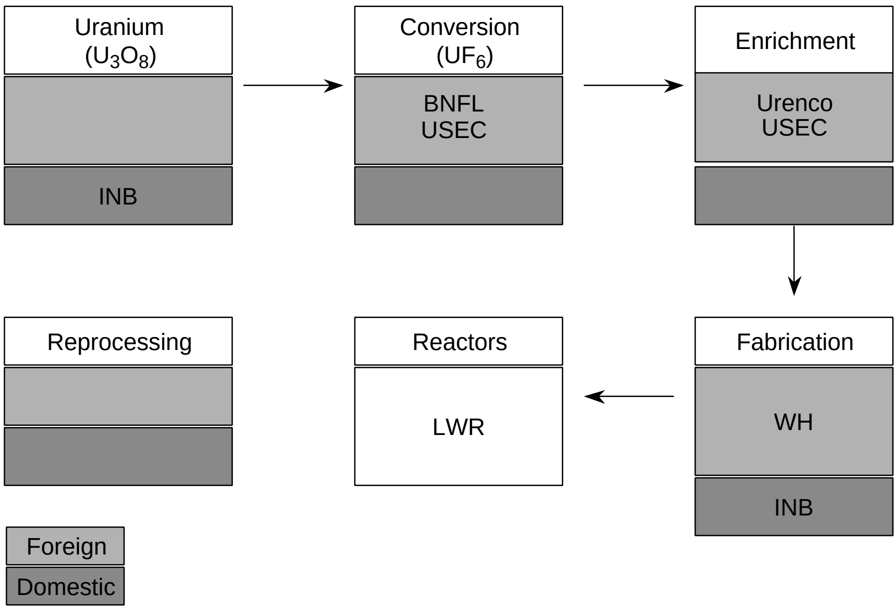

FIG. 6. Material flow in the nuclear fuel cycle: Brazil. Foreign organizations: BNFL (UK), Urenco (Germany, Netherlands, UK), USEC (USA), WH (USA).

supply, more than 90% of which comes from hydroelectric plants (Fig. 6). Angra 2, a 1300 MW(e) Siemens design PWR, started operation in 2000.

Nuclear fuel cycle policy

- ◦ Open nuclear fuel cycle
- ◦ Closed nuclear fuel cycle
- • No decision yet
- ◦ Not applicable

Mining and milling

Poços de Caldas–CIPC mining and ore processing plant, which had a capacity of 400 t U/a, was closed in 1997. Its production will be replaced by Industrias Nucleares do Brasil’s (INB) Caetité mining and milling plant, which was scheduled to start in March 2000 with an initial capacity of 360 t U/a. INB is planning to use the CIPC plant to recover rare earths from monazite sand.

Conversion

A pilot plant of 80 t U/a capacity is under construction. There are no plans to install a commercial plant in the near future.

Enrichment

INB plans to install a 200 t SWU/a centrifuge enrichment plant in the Resende Industrial Plant in the State of Rio de Janeiro. This plant will have an initial capacity of 100 t SWU/a and is planned to become operational in 2002.

Fabrication

The INB UO_2 pellet fabrication plant (capacity 120 t U/a) started operation in 1999 and the reconversion plant (capacity 165 t U/a) is under construction. 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.

Spent fuel management

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

3.6. BULGARIA

Bulgaria has 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 generation capacity of about 3.5 GW(e). The first reactor started operation in 1974. Nuclear generation accounts for 45% of the country's total electricity production (Fig. 7). There is a plan to shut down and decommission units 1 and 2 of Kozloduy nuclear power plant, comprising WWER 440/230 reactors. There are no firm plans for the construction of additional nuclear power plants.

Nuclear fuel cycle policy

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

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 from the 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, some spent fuel is still being returned to the Russian Federation for reprocessing under the same conditions.

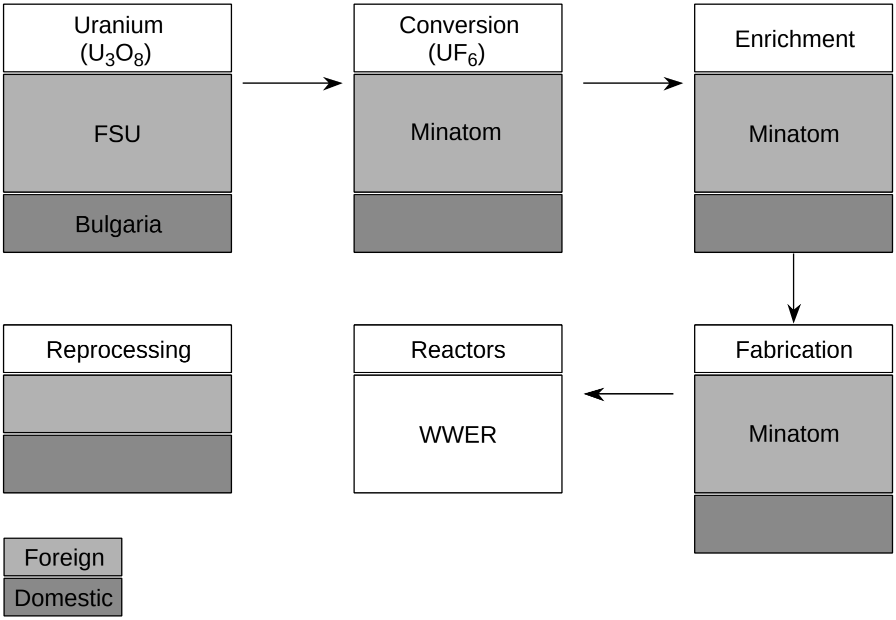

FIG. 7. Material flow in the nuclear fuel cycle: Bulgaria. Foreign organization — Minatom (Russian Federation).

Spent fuel from the WWER 1000 units will be reprocessed in the Russian Federation and the high level waste returned to Bulgaria. The wet AFR spent fuel storage facility (capacity 600 t HM) at the Kozloduy nuclear power plant is in operation. The building of an additional cask type dry spent fuel storage facility is envisaged.

3.7. CANADA

Canada operates five 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. On average, nuclear power generation accounts for 15% of the country's total electricity production (Fig. 8).

Canada is the world's leading producer and exporter of uranium, with an output of some 11 000 t U in 1998, representing about 33% of total world production.

Nuclear fuel cycle policy

- ● Open nuclear fuel cycle
- ○ Closed nuclear fuel cycle

- No decision yet
- Not applicable

Mining and milling

There are three uranium mines in operation in Saskatchewan: McArthur River (6900 t U/a), Cluff Lake (2370 t U/a) and McClean Lake (2300 t U/a), and two more are planned. Mining has ceased at Key Lake (5700 t U/a) and Rabbit Lake (4700 t U/a), but McArthur River ore now feeds the Key Lake mill and stockpiled ore is processed at the Rabbit Lake mill. Operations were suspended at Cluff Lake in December 2000.

Conversion

Cameco Corporation operates the Blind River plant in Ontario (capacity 18 000 t U/a as UO_2) 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).

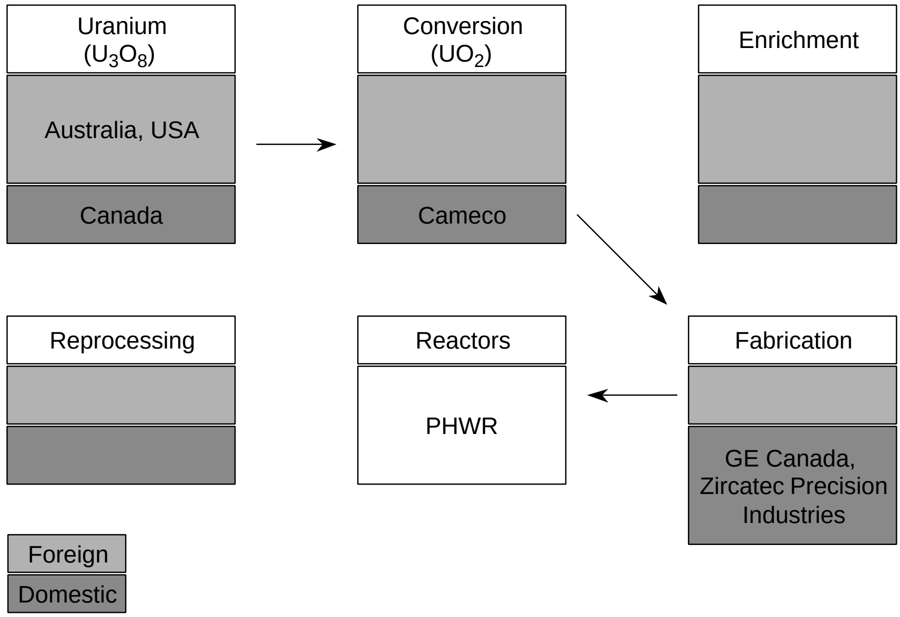

FIG. 8. Material flow in the nuclear fuel cycle: Canada.

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

Nuclear fuel waste is stored on-site in pools or dry silos. With respect to the long term management of this waste, 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, it was not demonstrated to have broad public support. It is expected that a waste management organization will be set up by the nuclear utilities and that this organization will submit a revised concept. The Government of Canada is currently examining required oversight of the waste management organization, including provision of new legislation. Ministers will likely decide on this matter in the near future.

Heavy water production

The BHWP-B facility was shut down in 1997.

3.8. CHINA

Three units of 2100 MW(e) nuclear power plants are in operation and 8 units of 6400 MW(e) are under construction. As of April 1999, nuclear electricity generation represented 1.16% of the total electricity generated (Fig. 9). China’s goal is to develop a total of 20 GW(e) nuclear capacity by 2010 and 40 GW(e) by 2020 which will constitute 4% and 5% respectively of the total estimated installed electrical capacities for 2010 and 2020, i.e. 500 GW(e) and 800 GW(e).

Nuclear fuel cycle policy

◦ Open nuclear fuel cycle
• Closed nuclear fuel cycle

- No decision yet
- Not applicable

Mining and milling

In 1999, the Fuzhou centre processed 300 t U in the form of chemical concentrate. The Chongyi centre produced 120 t U using heap leaching. The Yining centre, using ISL, supplied 100 t U. The Lantian centre produced 100 t U using both surface and underground heap leaching. The Benxi centre produced 120 t U, also using surface and underground heap leaching. A total of 740 t U was produced at these facilities.

Conversion

The UF_6 conversion facility near Lanzhou (capacity 400 t U/a) has been in operation since 1963.

Enrichment

China has two enrichment plants; one is the Lanzhou Nuclear Fuel Complex, which uses the diffusion and centrifugal processes; the other is the Shanxi Nuclear Fuel Complex which uses the centrifugal process. The total separative work capacity matches the demands of the nuclear power development programme.

Fabrication

The Yibin fabrication plant in Sichuan province has been producing fuel for Qinshan nuclear power plant since 1984 and currently has a capacity of 150 t HM/a. The Yibin fabrication plant has been modernized with the goal of providing fuel to all Chinese PWRs. This evolution was based on a contract with Framatome to transfer fuel fabrication technology to China. This plant has fabricated the first load and reloads for the Qinshan nuclear power plants and also fuel assembly reloads for the Daya Bay nuclear power plants.

The Baotou nuclear fuel fabrication plant is building a CANDU fuel production line which will have a throughput of 200 t U/a.

Spent fuel management

The civil reprocessing pilot plant with a capacity of 300 kg HM/d is under construction in Lanzhou and is scheduled to be commissioned sometime in the near future.

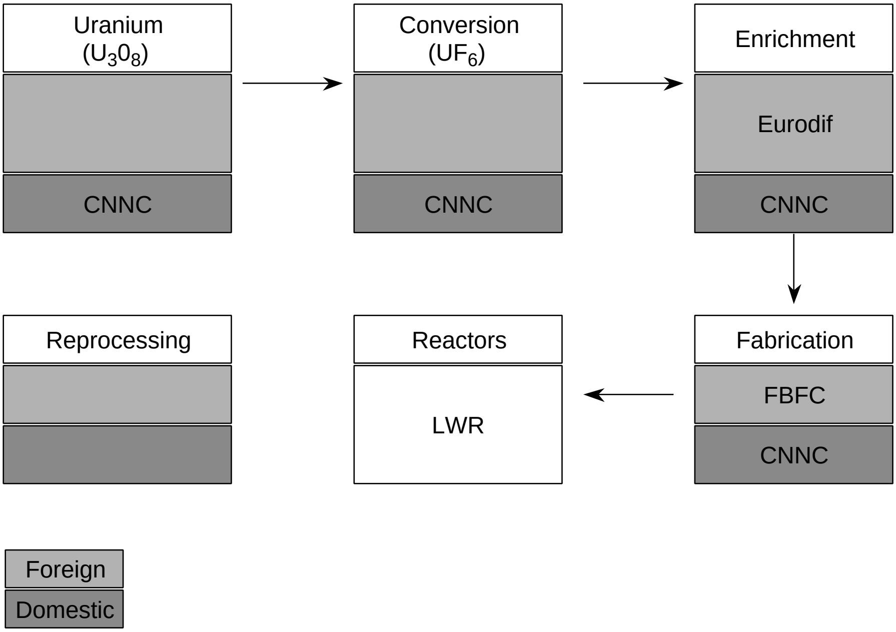

FIG. 9. Material flow in the nuclear fuel cycle: China. Foreign organizations: Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France).

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)), providing 19% of the country's electricity supply (Fig. 10). The first reactor started operation in 1985. Two new WWER 1000 reactors are under construction at the Temelin nuclear power plant.

Nuclear fuel cycle policy

- ○ Open nuclear fuel cycle
- ○ Closed nuclear fuel cycle
- ○ No decision yet

- ○ Not applicable
- ● No information available

Mining and milling

Currently, only one mine remains in operation — the Rozna underground mine in western Moravia (capacity 500 t U/a).

Conversion

None

Enrichment

None

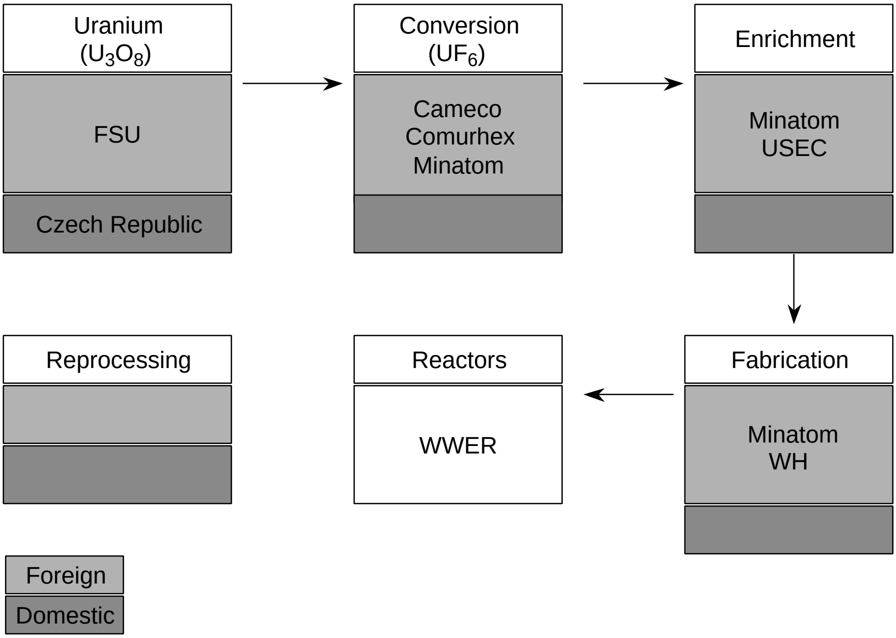

FIG. 10. Material flow in the nuclear fuel cycle: Czech Republic. Foreign organizations: Cameco (Canada), Comurhex (France), Minatom (Russian Federation), USEC (USA), WH (USA).

Fabrication

Fuel for the existing WWER 440 units at Dukovany is flown in from the Russian Federation. US Westinghouse has been selected as the fuel contractor to supply the new WWER 1000 units under construction at Temelin.

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. A dry storage facility (cask type) with a capacity of 600 t HM is in operation at the Dukovany nuclear power plant.

3.10. FINLAND

In 1999, Finland's four nuclear power plants, which have a combined capacity of 2.66 GW(e) net, provided 22.1 TW·h of electricity, equivalent to 33% of total electricity output (Fig. 11). Currently, no additional nuclear capacity is being firmly planned by the Government, and the construction of a fifth reactor is still under discussion in sections of the industry. Fortum Power and Heat Oy (Fortum) and Teollisuuden Voima Oy (TVO), the utilities operating the Loviisa (Fortum) and Olkiluoto (TVO) nuclear power plants, have both concluded environmental impact studies with respect to the construction of new nuclear capacity.

Nuclear fuel cycle policy

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

Mining and milling

Finland produced 30 t of uranium between 1958 and 1961. Currently, there is no mine in operation.

Conversion

None

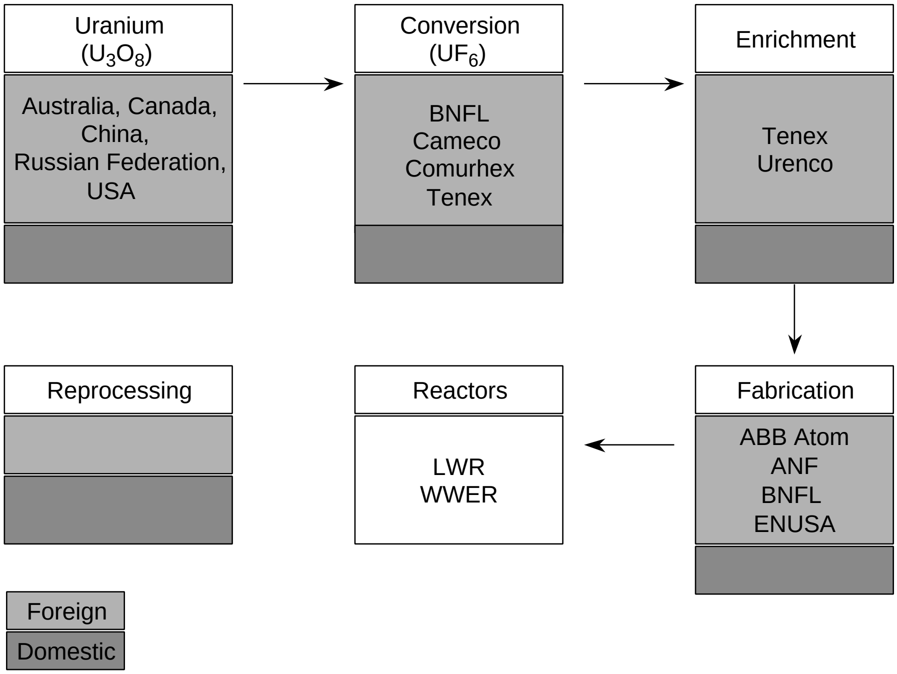

FIG. 11. Material flow in the nuclear fuel cycle: Finland. Foreign organizations: ABB Atom (Sweden), ANF (Germany), BNFL (UK), Cameco (Canada), Comurhex (France), ENUSA (Spain), Tenex (Russian Federation), USEC (USA).

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 245 t HM is in operation at the Loviisa nuclear power plant and after the ongoing extension is completed its capacity will increase to 610 t HM. At the Olkiluoto nuclear power plant, a wet storage facility for spent fuel, termed the TVO–KPA Store, is in operation and has a capacity of 1204 t HM.

A project for the final disposal of spent fuel was started in the early 1980s. The nuclear waste management company Posiva Oy is now in the process of deciding on the site. The construction of the encapsulation and disposal facility is scheduled to start around 2010, with operation scheduled to commence in the early 2020s.

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 place massive reliance for electricity generation on PWRs and the country currently has 58 PWR units, totalling 61.5 GW(e) of capacity, which produced 375 TW·h in 1999 (75% of total electricity production). There are no reactors currently under construction in France, pending a decision being taken on a possible order for an EPR (advanced reactor design). The State 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 reprocessed uranium in PWRs (Fig. 12). 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 (conversion, enrichment, fuel fabrication and reprocessing) to foreign utilities.

Nuclear fuel cycle policy

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

Mining and milling

Cogéma operates one mine in France — Jouac (capacity 650 t U/a). It also operates mines in Niger through the activities of SOMAIR and COMINAK, and in Canada and the USA through Cogéma Resources. It also has financial interests in Australian mines and in projects in central Asia.

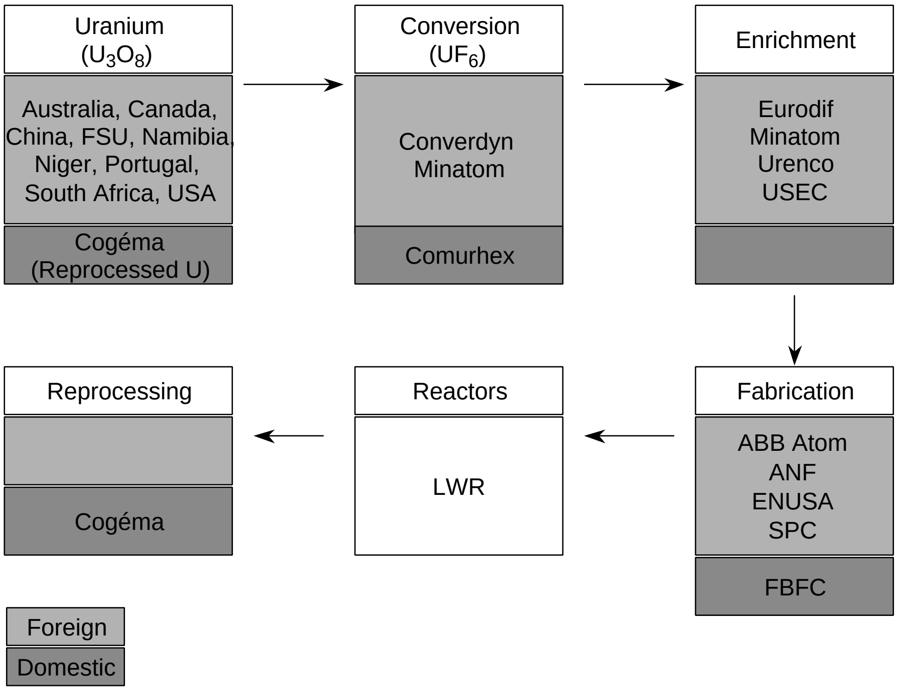

FIG. 12. Material flow in the nuclear fuel cycle: France. Foreign organizations: ABB Atom (Sweden), ANF (Germany), Converdyn (USA), ENUSA (Spain), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), Minatom (Russian Federation), SPC (USA), Urenco (Germany, Netherlands, UK), USEC (USA).

Conversion

Comurhex is operating 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 reprocessed uranium and for the defluorination of depleted uranium.

Enrichment

Enrichment is performed by Eurodif at its GD plant located in Pierrelatte (capacity 10 800 t SWU/a). Cogéma is studying the installation of centrifuges at Pierrelatte and is financing research on laser enrichment technology (the SILVA process).

Fuel fabrication

FBFC fabricates UO_2 fuel at its Romans plant from enriched natural or reprocessed uranium (capacities 750 t HM/a and 200 t HM/a respectively). It also operates plant in Belgium.

MOX fuels are fabricated by Cogéma at Cadarache and by Melox at Marcoule; the plants having a total capacity of 130 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 in 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 in 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 15 000 t HM by the end of 1999.

Waste disposal

Low level wastes are transported to the Andra site at Soulaines (capacity one 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

Commissariat à l'énergie atomique (CEA) started exploration after World War II and a uranium discovery was made in 1956. CEA and a group of mining companies incorporated COMUF in 1951 and this company has been producing uranium since then.

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 to the end of 1996 amounted to 26 109 t. Mounana production centre was in operation from 1988 until 1997, and Mikolongou production centre was in operation from 1991 until 1999, when all mine production ceased.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.13. GERMANY

With the exception of repositories for final disposal, which are the responsibility of the Federal Government, all NFCFs are private enterprises.

In 1999, 13 PWRs and 6 BWRs were in operation; their total capacity amounting to about 22.2 GW(e). Nuclear power generation accounts for 32% 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

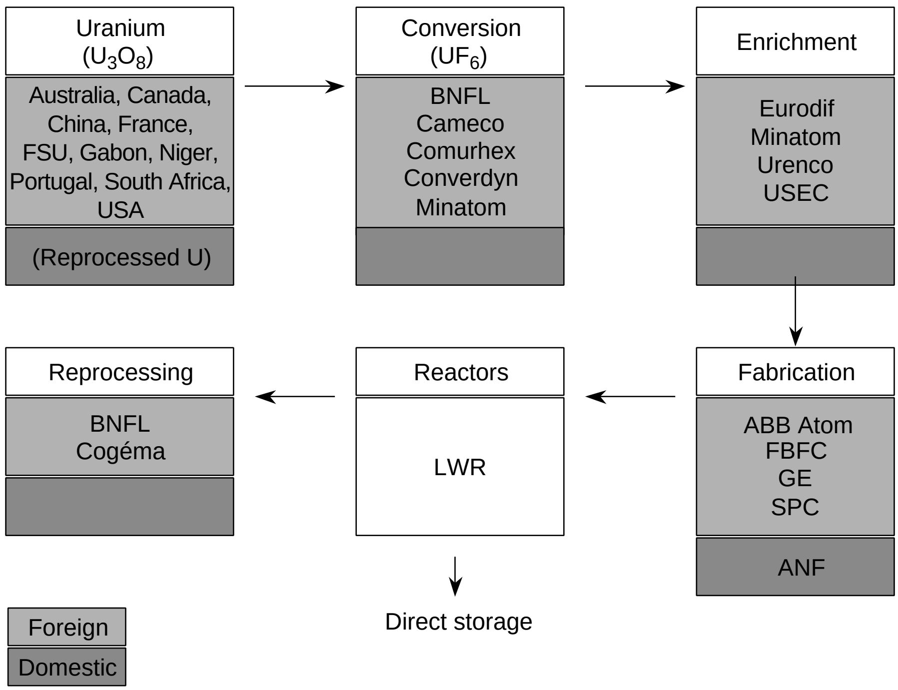

FIG. 13. Material flow in the nuclear fuel cycle: Germany. Foreign organizations: ABB Atom (Sweden), BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), GE (USA), Minatom (Russian Federation), SPC (USA), Urenco (Germany, Netherlands, UK), USEC (USA).

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 up to a maximum ^{235}U concentration of 5 wt%. The plant started operation with a capacity of 0.4 million SWU/a in 1985 and this has since been expanded to 1.8 million SWU/a.

Fabrication

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

Spent fuel management

All domestic reprocessing activities have ceased; utilities now 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).

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)) until a repository is commissioned. High level waste from reprocessing is returned to Germany and is also stored at the BLG facility. With the commissioning of a repository for the final disposal of high level waste and spent fuel, the criteria to be met by these materials for disposal will be prescribed. Corresponding conditioning prior to disposal will be executed at the conditioning plant.

Uranium and plutonium recovered in foreign reprocessing plants are recycled as uranium fuel and MOX fuel.

3.14. HUNGARY

Four nuclear power reactors (WWER 440/213 units) are in operation at Paks nuclear power plant and these have a total capacity of 1729 MW(e). The first reactor started operation in 1983. Nuclear generation accounts for 40% of the country’s total electricity production (Fig. 14).

Nuclear fuel cycle policy

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

Mining and milling

The Mecsekuran Lic/Cserkut mining and ore processing facility produced up to 500 t U/a, which corresponded to half the requirement 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

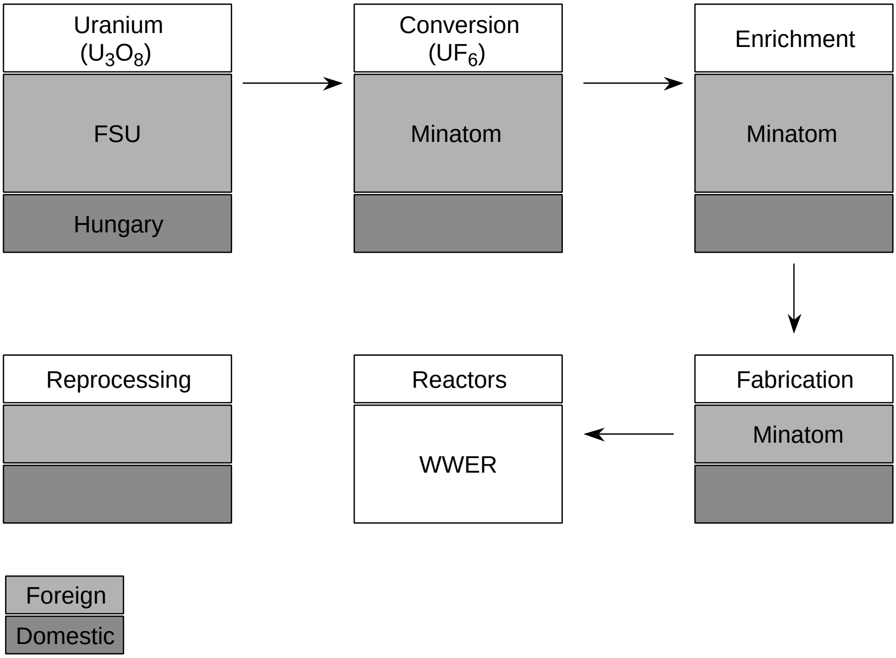

FIG. 14. Material flow in the nuclear fuel cycle: Hungary. Foreign organization — Minatom (Russian Federation).

Fabrication

There is no domestic fuel fabrication; at present, nuclear fuel is flown in from the Russian Federation. BNFL (UK) is developing advanced fuel designs for the Paks nuclear power plant in conjunction with TVO (Finland).

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 U, Pu or high level waste needing to be returned. At present, some of the spent fuel continues to be returned to the Russian Federation under the same arrangement.

At Paks nuclear power plant, the AFR dry storage facility (modular vault dry storage) is in operation. The capacity of the first phase is 160 t HM.

3.15. INDIA

India's first nuclear reactor started operation in 1969. Two BWRs and eight PHWRs were in operation in 1999, their total capacity being 1695 MW(e). Nuclear power generation accounted for 2% of total power generation. 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 and has several plants in operation. These nuclear programmes are undertaken by governmental bodies.

Nuclear fuel cycle policy

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

Mining and milling

Three uranium mines (Jaduguda, Bhatin and Narwapahar) are in operation in the Singhbhum Thrust Belt of Bihar State. Three uranium recovery plants located

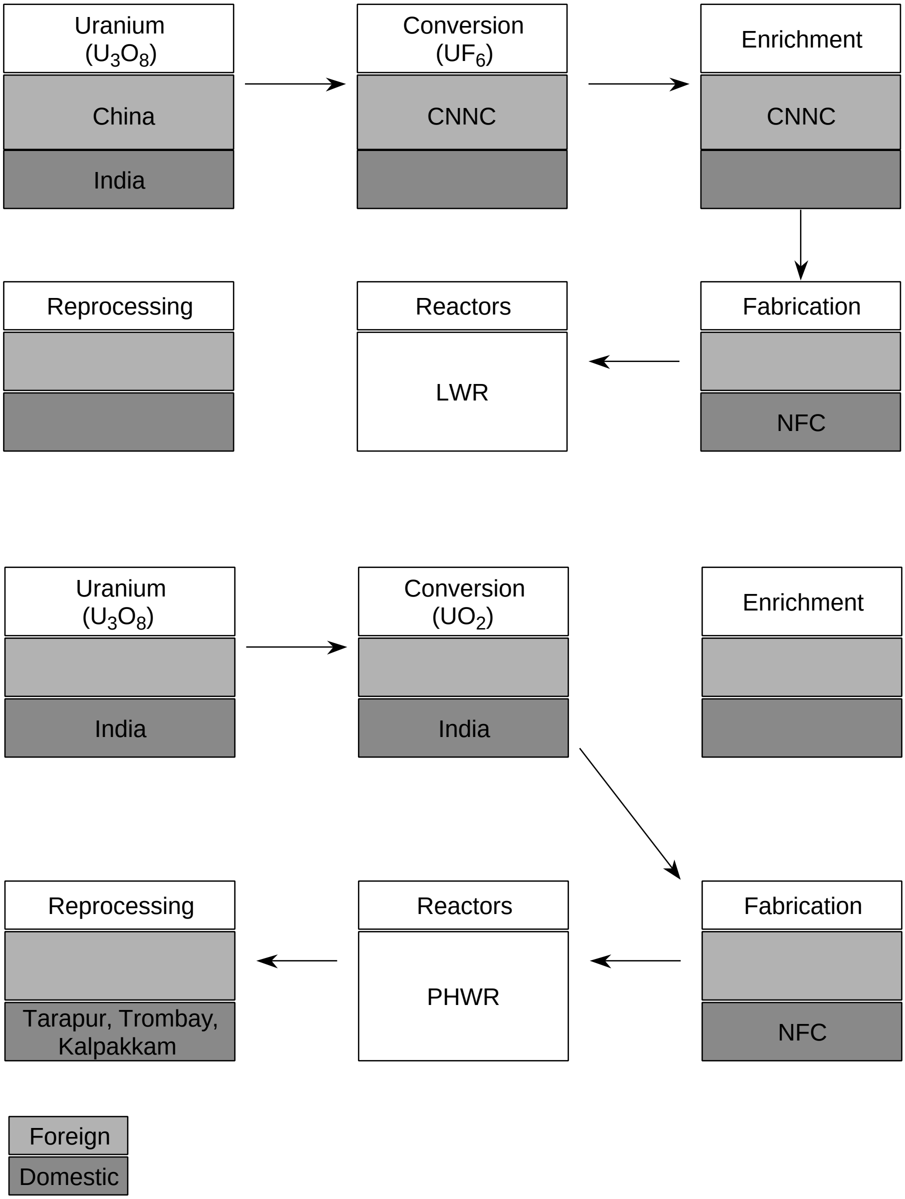

FIG. 15. Material flow in the nuclear fuel cycle: India. Foreign organization — CNNC (China).

near copper concentrators also recover uranium mineral concentrates from copper mill tails.

Uranium ore produced from the Jaduguda, Bhatin and Narwapahar mines, together with uranium mineral concentrates from the uranium recovery plants, are processed in the mill located at Jaduguda. This mill has a production capacity of 270 t U/a.

Conversion

The Trombay conversion plant (conversion to uranium metal) is in operation and has a capacity of 100 t U/a. The Nuclear Fuel Complex (NFC)–Hyderabad conversion plant (conversion to UO_2) is in operation and has a capacity of 300 t U/a.

Enrichment

There are two pilot enrichment facilities, both of which use the centrifuge process.

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 completed the supply to BWRs of fuel bundles fabricated from enriched UF_6. Fabrication of MOX fuel sub-assemblies and carrier sub-assemblies for the fast breeder test reactor has been completed.

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 Zircaloy. There are three zirconium sponge facilities and two Zircaloy tubing facilities.

The Bhabha Atomic Research Centre has moved four MOX fuel assemblies to the BWR reactor. Two of these assemblies are undergoing irradiation.

Spent fuel management

In the 1960s, India developed a technology for reprocessing natural uranium oxide fuel from its CANDU type heavy water reactors using a pilot scale plant at the Trombay research centre. A second plant, with a capacity of 100 t HM/a, was put into service at Tarapur in 1977, and the refurbished Trombay plant, which has a capacity of 60 t HM/a, was restarted in 1985.

A third plant opened in 1996 at Kalpakkam. This plant, which has the capacity to reprocess 100 t HM/a, will separate plutonium destined to be used for fueling India's prototype fast breeder reactor, planned for the Kalpakkam site.

Heavy water production

Several heavy water production facilities are in operation: Baroda (45 t/a), Hazira (80 t/a), Kota (80 t/a), Manuguru (185 t/a), Nangal (8 t/a), Talcher (62.5 t/a), Thal-Vaishet (78 t/a) and Tuticorin (49 t/a).

3.16. JAPAN

Nuclear power generation began in Japan in 1963. Since then, LWRs have been constructed consecutively by ten electricity companies. The advanced thermal reactor (ATR), which is a heavy water moderated, light water cooled reactor (HWLWR), and the fast breeder reactor have been developed by the Japan Nuclear Cycle Development Institute (JNC) which is funded by the Government. In 1999, 23 PWRs, 28 BWRs and the ATR were in operation; their total capacity being about 45 GW(e). Nuclear electricity generation accounted for about a third of the total electricity generated in 1999 (Fig. 16). The development of nuclear fuel cycle technology has been mainly performed by JNC, although some commercial facilities are operated or have been constructed by the private sector.

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. As of 1999, JNC held reserves of about 40 000 t U through its interests in uranium deposits in Canada, Australia, USA, Niger and Zimbabwe. These interests will be transferred to the private sector within a few years. Besides JNC, four private companies also hold interests in uranium production and development projects in Canada, Australia and Niger. The annual requirement for natural uranium for LWRs amounted to about 9000 t U in financial year 1999.

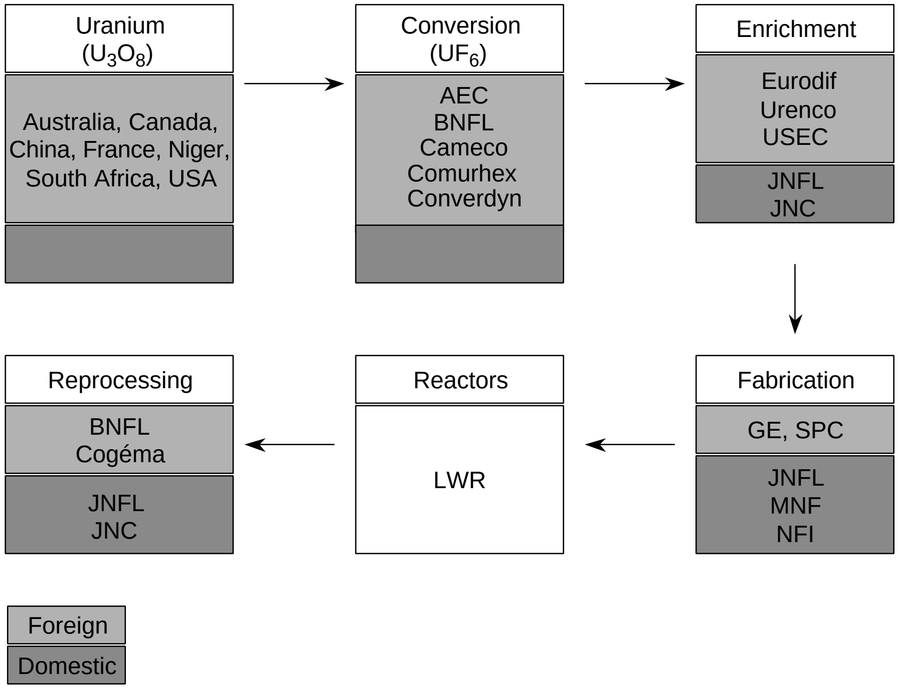

FIG. 16. Material flow in the nuclear fuel cycle: Japan. Foreign organizations: AEC (South Africa), BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), GE (USA), SPC (USA), Urenco (Germany, Netherlands, UK), USEC (USA).

Conversion

There are no commercial conversion facilities in Japan, but a commercial reconversion facility, which has a capacity of 475 t U/a, is being operated by a private company. Japan depends on foreign countries (USA, Canada, UK and France) to meet all its conversion requirements.

Enrichment

The domestic development of uranium enrichment technology by use of 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 Japan Nuclear Fuel Ltd (JNFL) since 1992. The scale of this commercial plant is to be expanded to 1500 t SWU/a. The requirement for enrichment amounted to about 5900 t SWU in financial year 1999, over 80% of which was met by foreign countries.

Fabrication

Nuclear fuel fabrication for LWRs is almost always undertaken in Japan. There are four facilities for LWR fuel fabrication having a total capacity of 1674 t U/a and these are operated by private companies. JNC has two MOX fuel fabrication facilities: a 10 t MOX/a line for the HWLWR and a 5 t MOX/a line for the FBR. Cumulative MOX fuel production as of March 1998 reached about 155 t. There are three Zircaloy tubing facilities in Japan.

Spent fuel management

Up to the end of 1999, there were no spent fuel storage facilities at AFR sites in Japan. As regards reprocessing, JNC's Tokai reprocessing plant has been in operation and its cumulative production of reprocessed fuels had reached about 936 t U by the end of 1999. There are also contracts for reprocessing with the UK and France. Under these contracts, about 5600 t U of spent fuel from LWRs has been shipped to both countries, the transportation ending in September 1998. Besides the Tokai reprocessing plant, a domestic reprocessing plant with a capacity of 800 t U/a is under construction by JNFL at Rokkasho-mura. The aim is to start plant operation in July 2005. As for radioactive waste storage and disposal, there is a low level waste disposal centre with a current (end of 1999) capacity of 80 000 m^3, and a high level vitrified waste storage centre with a current (end of 1999) capacity of 1440 canisters at Rokkaho-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 started operation in 1973. Prior to closure, nuclear generation accounted for 0.6% of the country's total electricity production (Fig. 17). There are some plans to construct a new nuclear power plant and these are currently being evaluated.

Nuclear fuel cycle policy

- ◦ Open nuclear fuel cycle
- ◦ Closed nuclear fuel cycle

- ◦ No decision yet
- ◦ Not applicable
- • No information available

Mining and milling

The entire current uranium production capability is associated with the five ISL production centres (Tsentralae, Stepnoe, No. 6, Katko and Ankay) which have an aggregate production capacity of 4000 t U/a.

Conversion

None

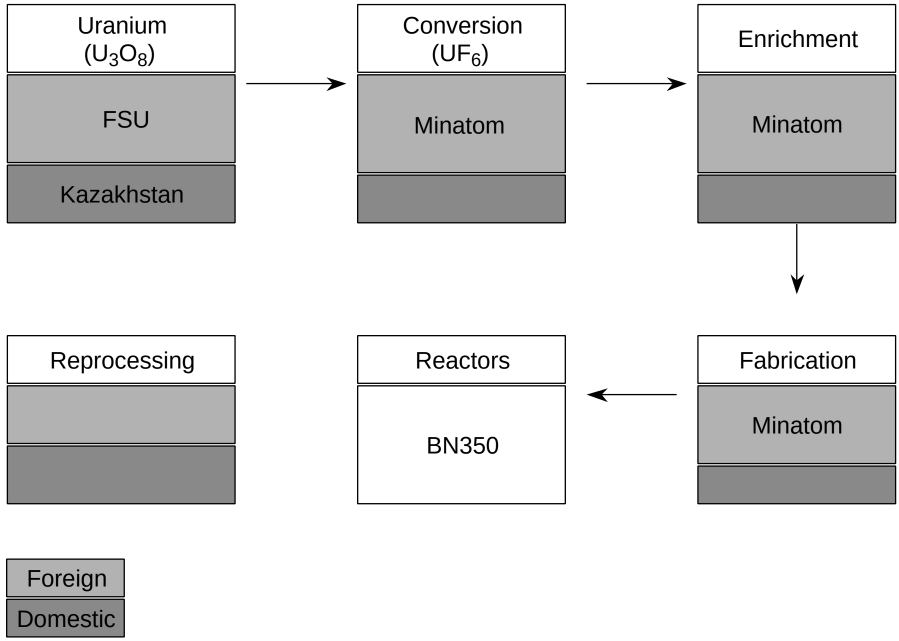

FIG. 17. Material flow in the nuclear fuel cycle: Kazakhstan. Foreign organization — Minatom (Russian Federation).

Enrichment

None

Fabrication

UST-Kamenogorsk fuel fabrication plant (powder and pellets) is in operation and has a capacity of 800 t HM/a, supplying both WWER and RBMK reactors. 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.

3.18. REPUBLIC OF KOREA

In 1999, 12 PWRs and 4 PHWRs were in operation (total capacity 13 715 MW(e)). Kori Unit 1 was the first nuclear power plant, becoming operational in 1978. Four PWRs are under construction.

Nuclear power generation capacity accounts for 29.2% of the country’s total electricity generation capacity and in 1999 the proportion of nuclear electricity generated amounted to 43.1% (Fig. 18).

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 (KEPCO) has invested in uranium exploration/development programmes in the USA and Canada. Some exploration programmes ended in 1999 with the sale of equity stakes in Ciger 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 is not in operation.

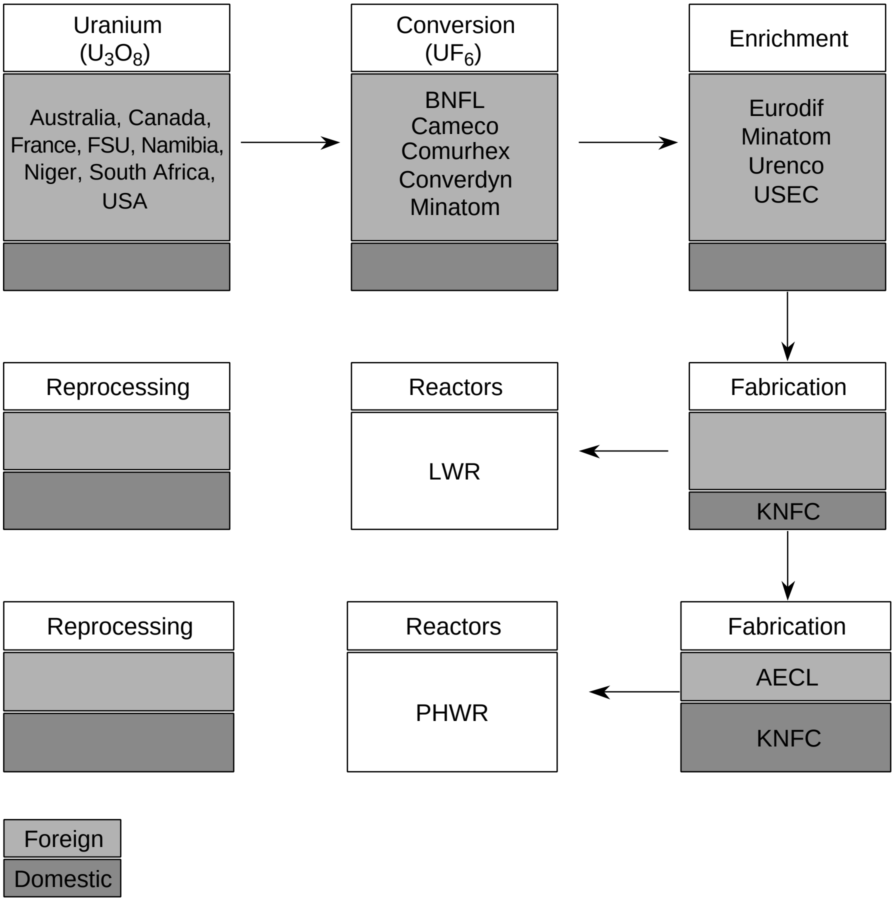

FIG. 18. Material flow in the nuclear fuel cycle: Republic of Korea. Foreign organizations: AECL (Canada), BNFL (UK), Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), Minatom (Russian Federation), Urenco (Germany, Netherlands, UK), USEC (USA).

Fabrication

The Korea Nuclear Fuel Company Ltd (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. KNFC has operated the ammonium uranyl carbonate reconversion process (capacity 200 t U/a) since 1990 and the dry reconversion process (capacity 200 t U/a) from 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. KNFC built the PHWR (CANDU) fuel fabrication plant in 1997 and this has a capacity of 400 t U/a.

Spent fuel management

Currently, all spent fuels are stored at each plant. 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 in 1984. KAERI was designated in 1986 as the national radioactive waste management organization. The Nuclear Environment Technology Institute (NETEC) was established in 1997 and, as a special division of KEPCO, is responsible for radioactive waste management transferred from KAERI. The site acquisition for radioactive waste management facilities will be implemented transparently in order to gain public understanding and the agreement of local communities surrounding the facility site. NETEC is preparing the project management and technical aspects of the interim storage facility for spent fuel.

3.19. LITHUANIA

The two 1300 MW(e) LWGR (RBMK) power reactors at Ignalina nuclear power plant accounted for 73.1% of all electricity generated in Lithuania during 1999 (Fig. 19). The combined capacity is 1185 MW(e). The first reactor started operation in 1984. In 1999, electricity exports to Belarus and Latvia amounted to 3.3 TW·h. The licence for the operation of unit 1 at the Ignalina nuclear power plant was granted on 29 July 1999.

Nuclear fuel cycle policy

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

Mining and milling

None

Conversion

None

Enrichment

None

Fabrication

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

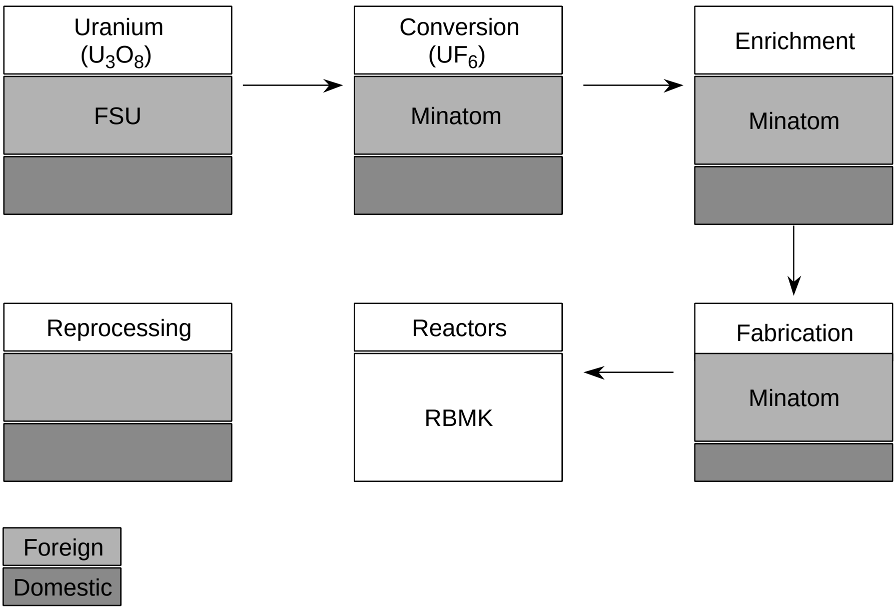

FIG. 19. Material flow in the nuclear fuel cycle: Lithuania. Foreign organization — Minatom (Russian Federation).

Spent fuel management

Spent fuel storage has been commissioned. Twenty Castor 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 was stored in the pools constructed next to the reactors.

3.20. MEXICO

The two BWRs at the Laguna Verde facility, which have a combined capacity of 1308 MW(e), generated 6% of domestic electricity production (10 TW·h) in 1997 (Fig. 20).

Nuclear fuel cycle policy

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

Mining and milling

From 1969 until 1971, the Mining Development Commission operated a plant at Villa Aldama, Chihuahua. 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 the US Department of Energy.

Fabrication

Fuel fabrication requirements are met by General Electric in the USA.

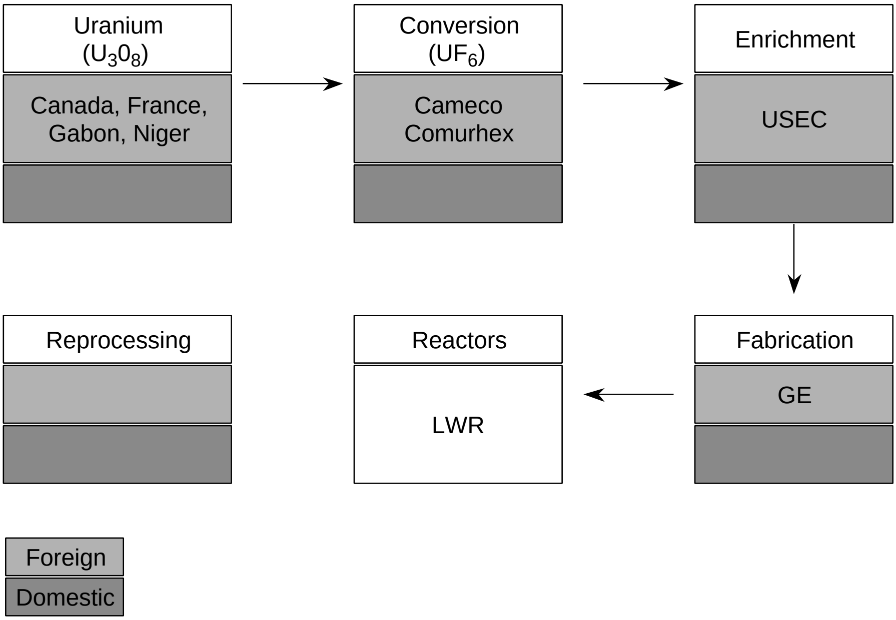

FIG. 20. Material flow in the nuclear fuel cycle: Mexico. Foreign organizations: Cameco (Canada), Comurhex (France), GE (USA), USEC (USA).

A fuel fabrication facility (capacity 5 t HM/a) for the Centro Nuclear de México BWR was in operation from 1980 until 1996 when it was shut down for economic reasons.

Spent fuel management

None

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 terminated in 1995. During that period, 499 587 t of ores were mined and transported to the Russian Federation for processing. Three companies, the Central Asia Uranium Company (a joint venture between Mongolian, Russian and US organizations), Gurvansaikhan (a joint venture between Mongolian, Russian and US organizations) and Koge-Gobi (a Mongolian–French joint venture), plan to restart production by 2003, provided market conditions are favourable. All production centres plan to use ISL techniques.

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 4500 t U/a. Rössing Uranium Ltd is a mixed enterprise with private and governmental shareholders.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.23. NETHERLANDS

In 1998, the Netherlands' only reactor, the 449 MW(e) PWR at Borssele, provided 3.4 TW·h of electricity, equivalent to 4% of domestic electricity output (Fig. 21). Although a major modernization programme costing US $250 million was undertaken in 1997, the Government has since decided to shut down the reactor at the end of 2003.

The nuclear power station of Dodewaard stopped producing electricity in March 1997. The Dutch Electricity Generating Board decided to close down this plant mainly for economic reasons, a decision triggered by market liberalization.

Nuclear fuel cycle policy

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

Mining and milling

None

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 (UK). The Dutch Government owns 99% of the shares in UCN.

The current capacity of Urenco Nederland is 1500 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 at the Almelo site has been built, officially inaugurated by the Minister of Economic Affairs on 9 March 2000.

Urenco uses advanced gas ultracentrifuge technology for the enrichment of uranium.

Fabrication

None

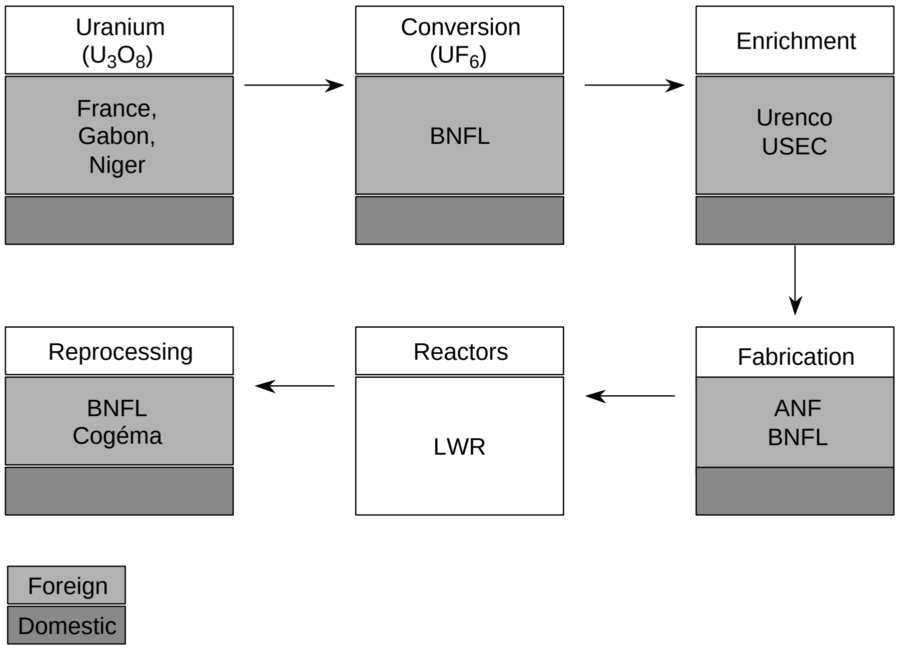

FIG. 21. Material flow in the nuclear fuel cycle: Netherlands. Foreign organizations: ANF (Germany), BNFL (UK), Cogéma (France), Urenco (Germany, Netherlands, UK), USEC (USA).

Spent fuel management

Spent fuel is to be 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'Air (SOMAIR) and Compagnie Minière d'Akonta (COMINAK), which have mined uraniferous sandstone deposits since 1970 and 1978, respectively. SOMAIR has a production capability of 1800 t U/a from open pit operations, while COMINAK's production capability of 2350 t U/a derives from underground mining. The Government owns 33% of the production; foreign governments and a private foreign mining company owning the remainder.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

3.25. PAKISTAN

The Kanupp nuclear unit in operation in Pakistan is a 125 MW(e) PHWR imported from Canada, which generated nearly 0.4 TW·h in 1997 (Fig. 22). Nuclear power provides less than 1% of the country's electricity supply. One PWR unit with a capacity of 300 MW(e) is under construction.

Nuclear fuel cycle policy

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

Mining and milling

Two plants are operative: the Dera Ghazi Khan pilot plant has a capacity of 50 t U/a and the Issa Khel/Qabool Khel pilot plant 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

None

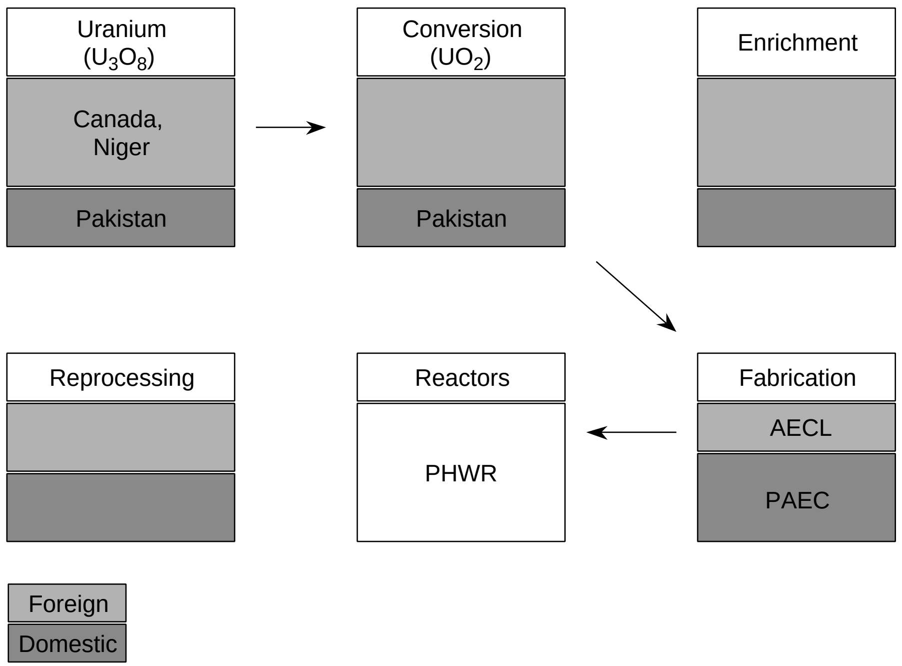

FIG. 22. Material flow in the nuclear fuel cycle: Pakistan. Foreign organization — AECL (Canada).

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, the Urgeiriça production mill, which has a nominal production capacity of 170 t U/a, is operating at reduced capacity. The produced concentrate (25 t U/a) comes from low grade ore treated by heap leaching, with a minor proportion derived from ISL.

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 accounts for 10% of Romania's total electricity production (Fig. 23). Four other CANDU units are either under construction or are being held in abeyance. The actual nuclear power programme is expected to start operation of Cernavoda's second unit by 2005 at the latest and the last three units after 2010.

There are also front end nuclear fuel cycle industrial facilities that have been developed to supply nuclear fuel and heavy water for domestic purposes.

Nuclear fuel cycle policy

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

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 operates three uranium mining branches: Bihor (E.M. Bihor), Banat (E.M. Banat) and Suceava (E.M. Crucea).

E.M. Bihor and E.M. Banat are under close out. E.M. Crucea is in operation and has a production capacity of 100 t U/a. Its production will be increased by the commissioning of a new mining area at Tulghes. 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 two modules:

- ‘R’ type module for uranium milling and concentration (nominal capacity 300 t U(U_3O_8)/a)
- ‘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 the production capacity is reduced to about 100 t U(U_3O_8)/a for the R plant and on request (by the Pitesti Fuel Fabrication Plant

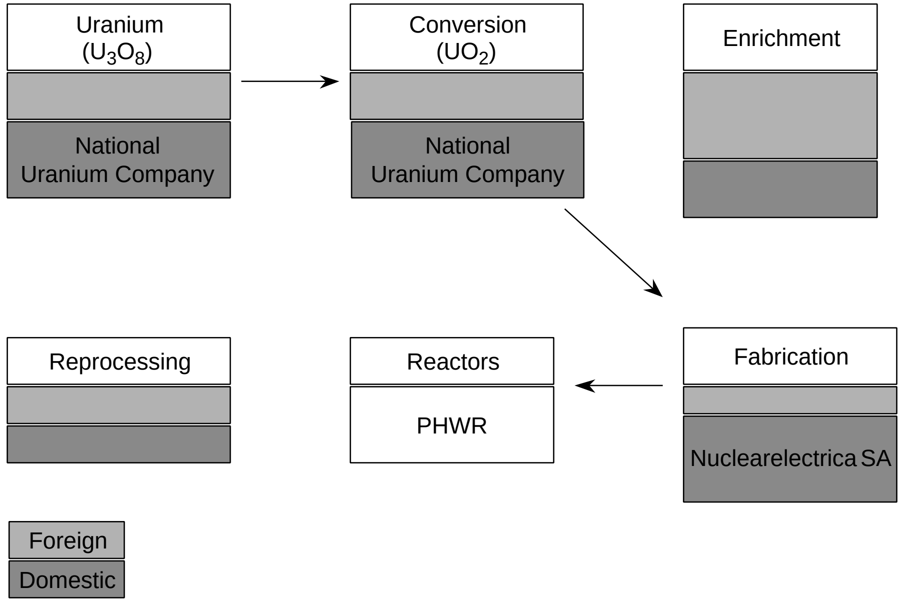

FIG. 23. Material flow in the nuclear fuel cycle: Romania.

(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 Cernavoda nuclear power plant requirements. FCN Pitesti has been qualified by AECL as a CANDU fuel supplier.

Spent fuel management

To date, spent fuel arising from the operation of Cernavoda nuclear power plant unit 1 has been stored on-site in the water filled pool near the reactor. An interim dry storage silo on the site will become operational in 2003.

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; its operational capacity in 1999 was 180 t.

3.28. RUSSIAN FEDERATION

The Russian Federation has 13 WWERs, 15 LWGRs (RBMK) and 1 FBR in operation which have a total capacity of about 19.8 GW(e) (Fig. 24). The first WWER reactor started operation in 1964. Nuclear generation accounted for 14% of the country's total electricity production in 1999. Four 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. Part of the NFCFs are State owned (Minatom); the other part being managed by joint stock companies (JSC TVEL, Rosenergoatom, Atomstroi, etc.) in which controlling interests are retained by the State.

Nuclear fuel cycle policy

- ◦ Open nuclear fuel cycle
- • Closed nuclear fuel cycle

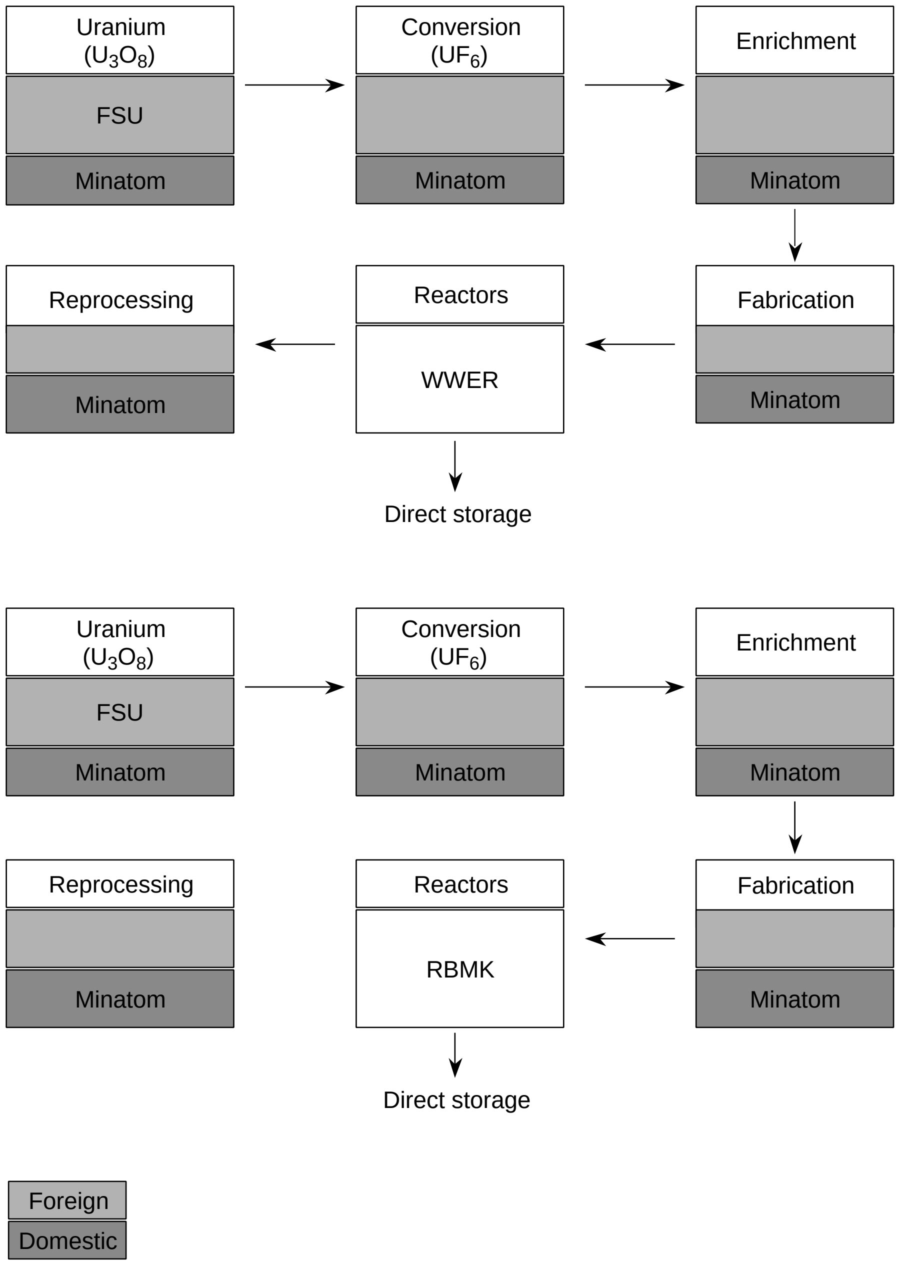

FIG. 24. Material flow in the nuclear fuel cycle: Russian Federation. Fuel pellets for WWER 1000's are produced in Kazakhstan. WWER 1000 spent fuels take the direct storage option; WWER 440 spent fuels are reprocessed. Reprocessed uranium recovered from WWER 440 spent fuel is used in RBMK reactors.

- ◦ No decision yet
- ◦ Not applicable

Mining and milling

The Priargunsky Industrial Mining and Chemical Union has a capacity of 3500 t U/a using open pit, underground and ISL extraction methods. This facility is operated by JSC TVEL.

Conversion

Minatom operates Angarsk, Ekaterinburg and Tomsk conversion plants (conversion to UF_6), which have a total capacity of 34 000 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 Sverdlovsk. 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 TVEL at two plants: Electrostal and Novosibirsk. Electrostal produces fuel elements, assemblies, powder and pellets for WWER 440, WWER 1000, BN 350, BN 600 and RMBK 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). However, a new line for pellet production at the Novosibirsk plant started operation in 2000. 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 should 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 ice-breakers 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 power reactors are in operation at Bohunice nuclear power plant and two WWER reactors are in operation at Mochovce nuclear power

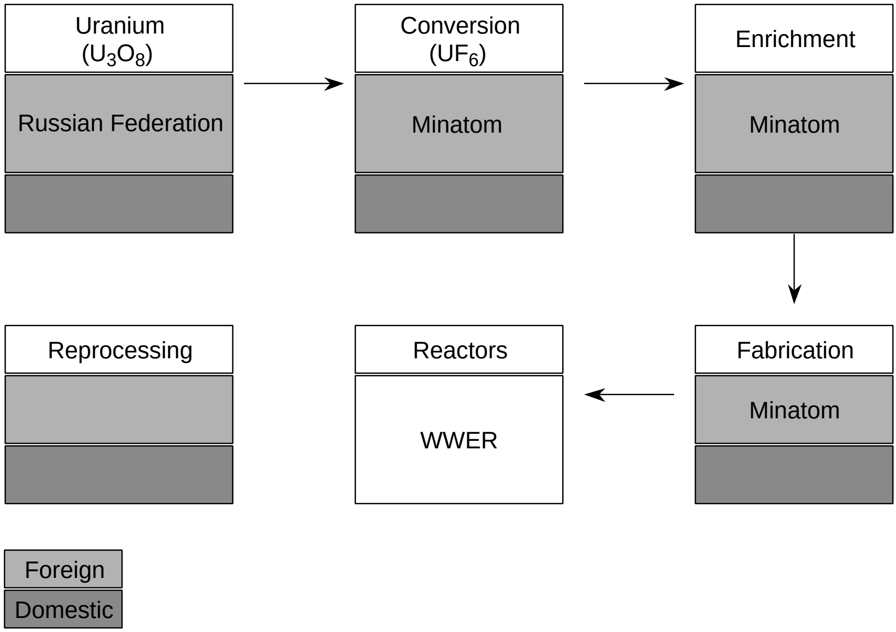

FIG. 25. Material flow in the nuclear fuel cycle: Slovakia. Foreign organization — Minatom (Russian Federation).

plant (the second unit at Mochovce started test operation at the end of 1999). 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 the operation was stopped. The first WWER reactor started operation in 1978.

Nuclear generation accounts for 47% of the country’s total electricity production (Fig. 25). The plan to construct two new WWER reactors at Mochovce nuclear power plant is currently under evaluation.

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

Up to 1987, a certain amount of spent fuel was returned to the Russian Federation. The AFR storage facility at Jaslovske Bohunice started operation in 1987. Its total storage capacity (after reconstruction) is 1693 t HM.

3.30. SLOVENIA

Slovenia has one 632 MW(e) PWR unit (imported from the USA) in operation. This unit supplies electricity to both the domestic market and Croatia. Nuclear power generation accounted for 40% of the country's total electricity production in 1997 (Fig. 26).

Nuclear fuel cycle policy

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

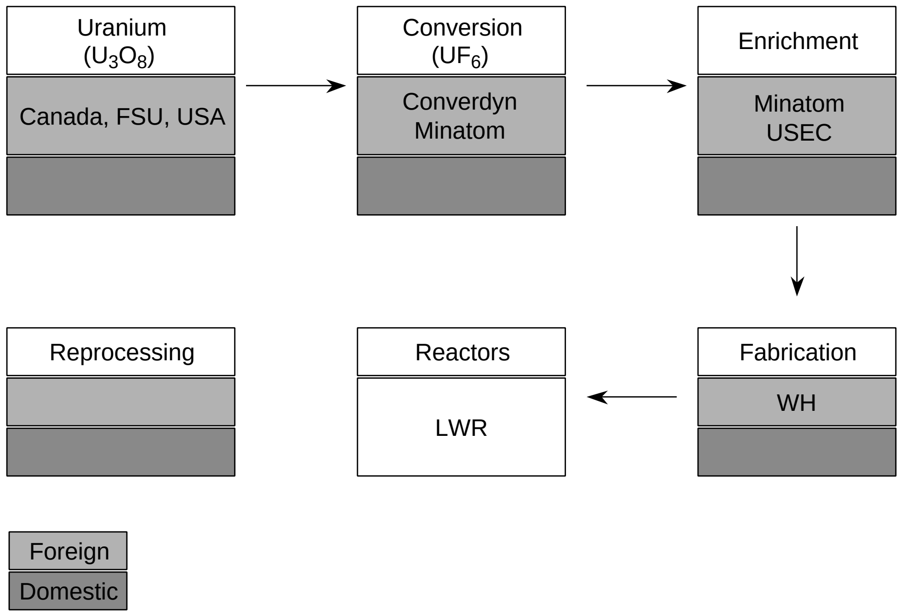

FIG. 26. Material flow in the nuclear fuel cycle: Slovenia. Foreign organizations: Converdyn (USA), Minatom (Russian Federation), USEC (USA), WH (USA).

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.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

A spent fuel storage pool (capacity 600 t HM) is in operation at the plant site.

3.31. SOUTH AFRICA

In 1998, two PWRs with a total capacity of 1842 MW(e) were in operation at the Koeberg nuclear power station in the Western Cape. This power station started operation in 1984. Total electricity generated from Koeberg in 1998 amounted to 13 601 GW·h. Nuclear power generation accounted for 7.43% (1998) of the country's total electricity production (Fig. 27). 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 100 MW high temperature reactors. A 'know-how' agreement has been signed with HTR GmbH (ABB–Siemens joint venture) in this regard.

Nuclear fuel cycle policy

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

Mining and milling

The three mines producing uranium at the end of 1998 were Hartebeestfontein, Vaal Reefs and Palabora. These mines produce uranium as a by-product; gold being the primary product of the first two and copper the primary product of the last. The total nominal production capacity is 2500 t U/a.

In 1998, total production of uranium oxide amounted to 1140 t. The Western Areas gold mining facility, which produced uranium as a by-product, was closed in 1998.

Conversion

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

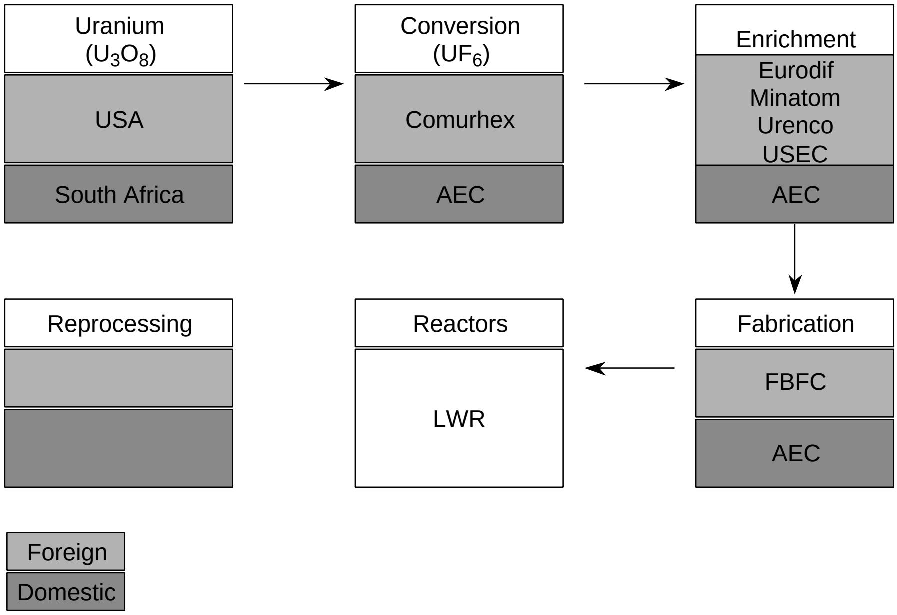

FIG. 27. Material flow in the nuclear fuel cycle: South Africa. Foreign organizations: Comurhex (France), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), Minatom (Russian Federation), Urenco (Germany, Netherlands, UK), USEC (USA). Note that AEC nuclear fuel cycle plants have now been closed down.

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 still 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 is in the process of increasing the storage capacity of its spent fuel storage pool at the Koeberg nuclear power station in order to make provision for all spent fuel to be stored in-pool for the life 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 1999, the net power of the plants totalled 7.47 GW(e). In 1999, their net electricity production amounted to 56.7 TW·h, which corresponded to about 30% of national electricity production (Fig. 28). The country currently has no plans to add further nuclear generating capacity.

Nuclear fuel cycle policy

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

Mining and milling

Empresa Nacional del Uranio S.A. (ENUSA) is the Spanish company, created in 1971, that provides products and services related to the front end of the nuclear fuel cycle. ENUSA has a uranium mine at Saelices el Chico (Salamanca) where one open pit mining area is being exploited. Owing to the present low market price of uranium, the mine does not have the resources to enable it to be exploited economically and mining activities were scheduled to stop at the end of 2000.

At Saelices el Chico (Salamanca), ENUSA operates the Quercus plant for producing uranium concentrates using the acid leach process (static and dynamic) which, from plant startup in 1993, has produced concentrates at the rate of 300 t U/a. The design production capacity of the plant is 950 t U/a.

Conversion

There is no domestic conversion; ENUSA has contracts with BNFL, Cameco, Converdyn, Comurhex and Techsnabexport (Russian Federation).

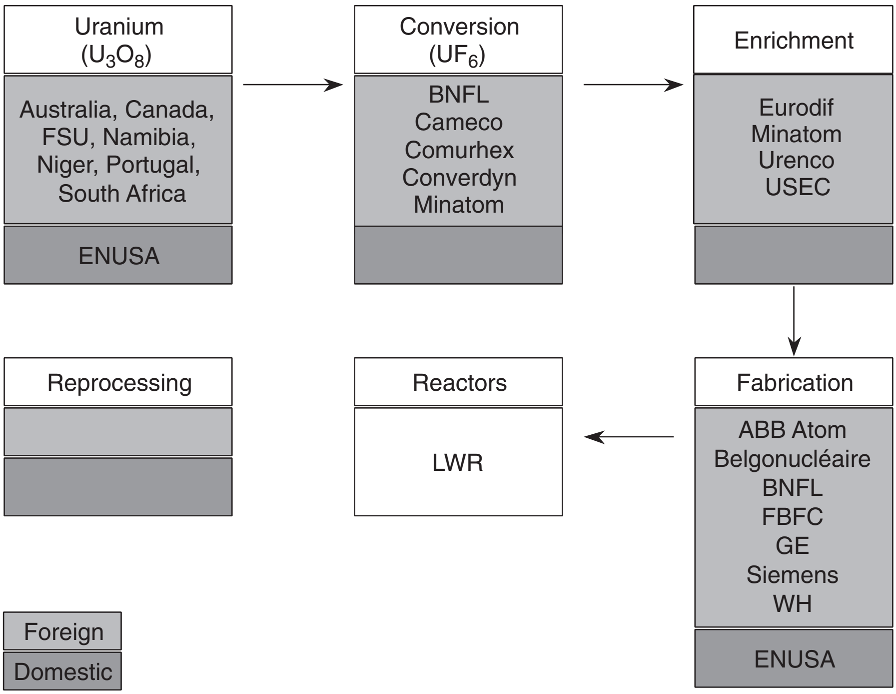

FIG. 28. Material flow in the nuclear fuel cycle: Spain. Foreign organizations: ABB Atom (Sweden), Belgonucléaire (Belgium), BNFL (UK), Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), GE (USA), Minatom (Russian Federation), Siemens (Germany), Urenco (Germany, Netherlands, UK), USEC (USA), WH (USA).

Enrichment

There is no domestic enrichment; ENUSA has contracts with Eurodif, USEC, Urenco and Techsnabexport.

Fabrication

ENUSA operates a fuel fabrication facility for BWR and PWR reactors in Juzbado (Salamanca). The maximum design capacity of this facility is 500 t U/a in fuel elements. During 1999, ENUSA fabricated 586 fuel elements containing 200 t U, of which 336 were for PWRs and 250 for BWRs. In 1999, 346 fuel elements were exported to Sweden, Belgium, Germany and Finland.

Spent fuel management

On 31 July 1999, the Government approved the Fifth Radioactive Waste Plan which provides for the following regarding spent fuel management, i.e. that provision be made for the storage of spent fuel in each nuclear plant pool and that individual temporary storage facilities be built on the plant sites, if necessary.

Beyond 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 which considers a deep geological repository and the other which is oriented towards partitioning and transmutation.

3.33. SWEDEN

In 1997, Sweden’s 12 nuclear power units, which have a combined installed capacity of 10.04 GW(e), provided 67 TW·h of electricity, equivalent to 46% of the country’s total output (Fig. 29). In February 1998, the Swedish Government announced its intention to withdraw the operating licence of Barseback-1, effective as of 1 July 1998, in line with new legislation covering the decommissioning of nuclear plants. However, the Governmental motion at that time failed. Finally, operation of Barseback-1 stopped in July 1999 and the official shutdown followed in November 1999.

Nuclear fuel cycle policy

- ◦ Open nuclear fuel cycle
- ◦ Closed nuclear fuel cycle

- ◦ No decision yet
- ◦ Not applicable
- • No information available

Mining and milling

None

Conversion

None

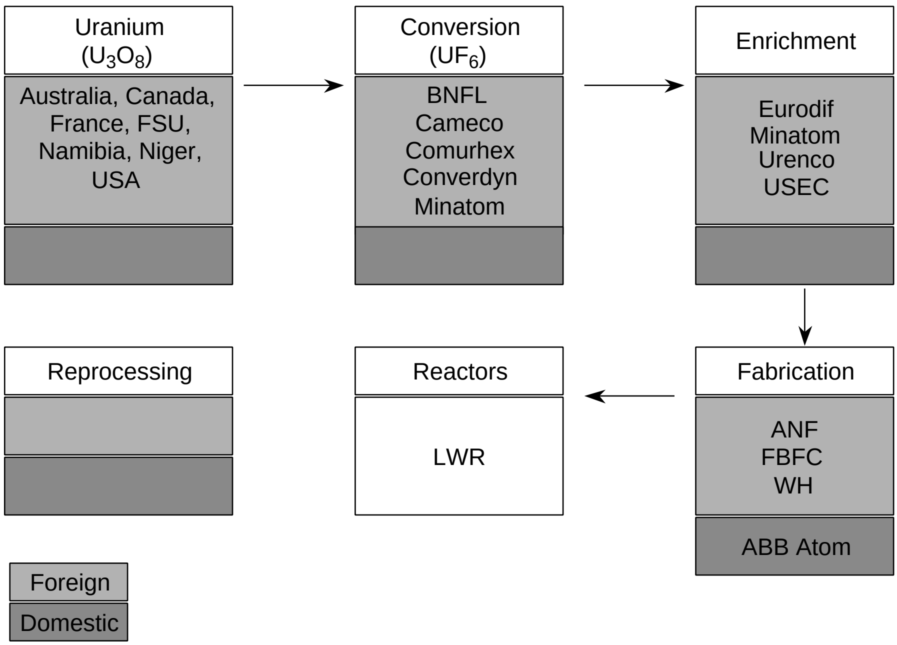

FIG. 29. Material flow in the nuclear fuel cycle: Sweden. Foreign organizations: ANF (Germany), BNFL (UK), Cameco (Canada), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), Minatom (Russian Federation), Urenco (Germany, Netherlands, UK), USEC (USA), WH (USA).

Enrichment

No enrichment is undertaken; enriched uranium is imported from USEC, Eurodif, Urenco and Minatom.

Fabrication

The ABB Atom fuel fabrication plant in Västerås is producing PWR and BWR fuels and has a capacity of 600 t U/a.

Spent fuel management

Prior to the decision being taken to phase out nuclear power in Sweden, contracts were established to reprocess some of Sweden's 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 fuel. Currently, all spent fuels are transported to the CLAB facility (wet storage, with a capacity of 5000 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 and have a total capacity of 3.2 GW(e), accounting for about 40% of the country's electricity generation (Fig. 30).

Nuclear fuel cycle policy

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

Mining and milling

None

Conversion

None

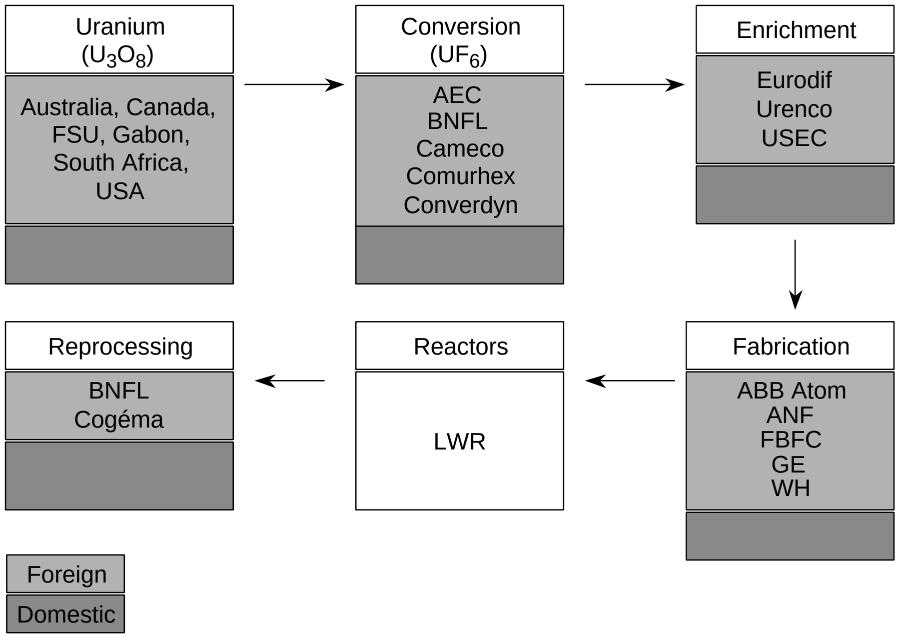

FIG. 30. Material flow in the nuclear fuel cycle: Switzerland. Foreign organizations: ABB Atom (Sweden), AEC (South Africa), ANF (Germany), BNFL (UK), Cameco (Canada), Cogéma (France), Comurhex (France), Converdyn (USA), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), FBFC (France), GE (USA), Urenco (Germany, Netherlands, UK), USEC (USA), WH (USA).

Enrichment

None

Fabrication

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

Spent fuel management

Spent fuels are to be reprocessed at the BNFL reprocessing plant in the UK and at the Cogéma reprocessing plant in France. Dry spent fuel interim storage facilities are under construction (ZWILAG).

3.35. UKRAINE

Thirteen WWERs (two WWER 440s and eleven WWER 1000s) and one LWGR (RBMK 1000) power reactor are in operation and have a total capacity of 12.818 GW(e). The capacity will be increased to 15.818 GW(e) by 2010. The first reactor, an RBMK 1000, started operation on 26 September 1977 at the Chernobyl nuclear power plant. Nuclear generation accounts for 47% of the country's total electricity production (Fig. 31). There are plans to construct new fuel cycle facilities, with the exception of enrichment plants, by 2010.

Nuclear fuel cycle policy

- ◦ Open nuclear fuel cycle
- ◦ Closed nuclear fuel cycle
- • No decision yet
- ◦ Not applicable

Mining and milling

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

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 is expected to be established 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 was routinely returned to the reprocessing plant RT-1 (PO Mayak for treating spent fuel from WWER 440s) and to the central storage facility at the Krasnoyarsk mining and chemical plant (reprocessing plant RT-2 for treating spent fuel from WWER 1000s) in the Russian Federation. After spent fuel reprocessing, radioactive wastes are to be taken back.

RBMK spent fuel is stored in AR storage pools and at the AFR wet spent fuel storage facility (SFSF-1) on the Chernobyl nuclear power plant site. The total capacity of the wet SFSF-1 is approximately 2000 t HM. Construction of a dry version, SFSF-2, is planned in the area of the Chernobyl nuclear power plant.

A dry AFR storage facility is under construction at Zaporizhzhya nuclear power plant which will have an initial stage capacity of approximately 160 t HM.

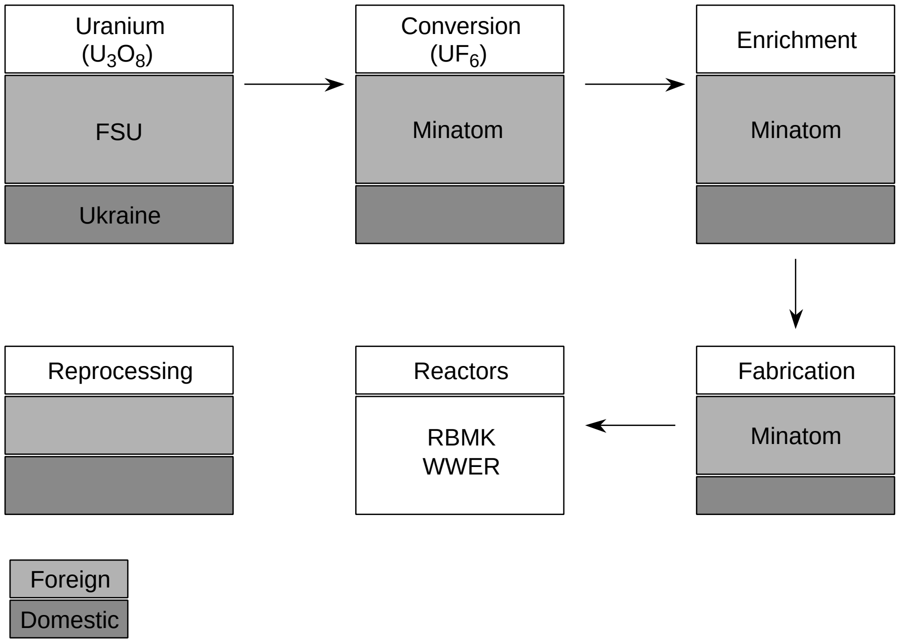

FIG. 31. Material flow in the nuclear fuel cycle: Ukraine. Foreign organization — Minatom (Russian Federation).

3.36. UNITED KINGDOM

Twenty GCRs, fourteen AGRs and one PWR are in operation and have a total capacity of 13 GW(e). Around 27% of the UK's electricity is generated by nuclear power (Fig. 32). A complete fuel cycle is provided by BNFL, both for the home market and for export.

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

BNFL 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. 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 1300 t SWU/a.

Fabrication

BNFL Fuel Business Group, located at Springfields, fabricates a number of different types of fuel. Current production capacities are: Magnox (1300 t U/a), AGR (290 t U/a) and LWR (330 t U/a).

The United Kingdom Atomic Energy Authority fabrication plant for material testing reactor fuel is in operation at Dounreay and has an annual capacity of 500 elements. Lead demonstration assemblies have also been manufactured for WWER fuel. WWER fuel will, in the future, be manufactured in the UK for export.

BNFL has successfully operated a small scale MOX fuel demonstration facility at Sellafield which has a capacity of 8 t HM/a. BNFL's commercial scale MOX plant is currently under construction and will have 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 1600 t HM/a. The thermal oxide reprocessing plant at Sellafield is now operating and has an operational capacity of 1200 t HM/a.

BNFL is operating 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.

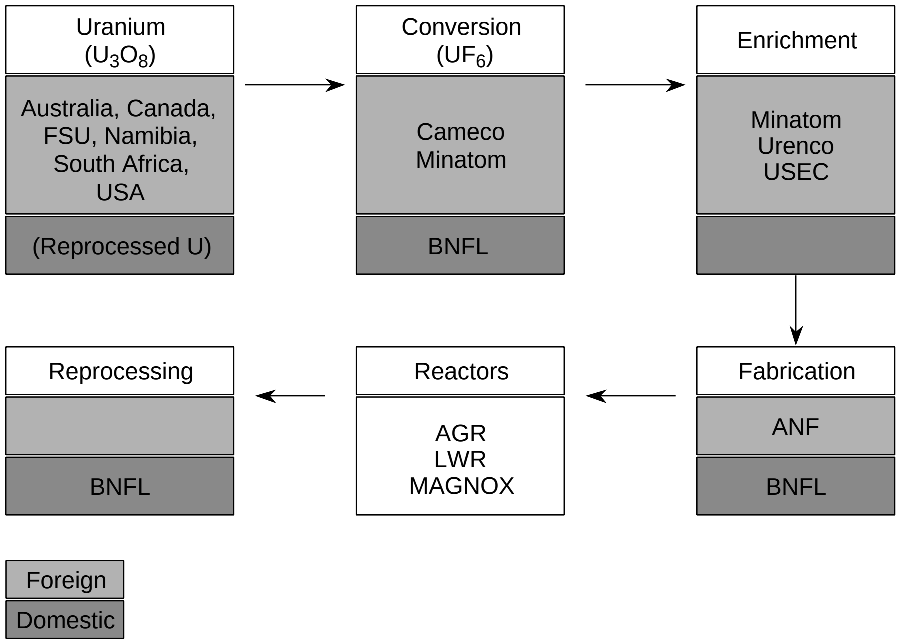

FIG.32. Material flow in the nuclear fuel cycle: UK. Foreign organizations: ANF (Germany), Cameco (Canada), Minatom (Russian Federation), Urenco (Germany, Netherlands, UK), USEC (USA).

3.37. UNITED STATES OF AMERICA

Nuclear power reactors in operation in the USA in 1999 comprised 69 PWRs and 34 BWRs, their total capacity amounting to 95.5 GW(e). They accounted for approximately 20% of the country's electricity generation in 1999 (Fig. 33). No new reactors are planned in the near term.

All types of front end fuel cycle service are provided to domestic and foreign customers.

Nuclear fuel cycle policy

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

Mining and milling

In 1999, 15 uranium mines and 7 milling facilities were operational in the USA. Approximately 1800 t U was produced.

Conversion

Allied Signal operates the only commercial UF_6 conversion plant in the USA. The plant is located in Metropolis, Illinois, and has a capacity of 12 700 t U/a.

Enrichment

USEC, which was privatized in 1998, operates uranium enrichment plants at Paducah, Kentucky, and Portsmouth, Ohio. The total capacity of the two plants is 18 700 t SWU/a.

Fabrication

Five LWR fuel fabrication plants were in operation in 1999: Global Nuclear Fuels (Wilmington, North Carolina, 1200 t U/a (BWR)), Westinghouse Electric Company (Columbia, South Carolina, 1150 t U/a (PWR)), Framatome/Cogéma Fuels (Lynchburg, Virginia, 400 t U/a (PWR)), CE Nuclear Power (Hematite, Missouri, 450 t U/a (PWR)), Siemens Power Corporation (Richland, Washington, 500 t U/a (PWR), 200 t U/a (BWR)).

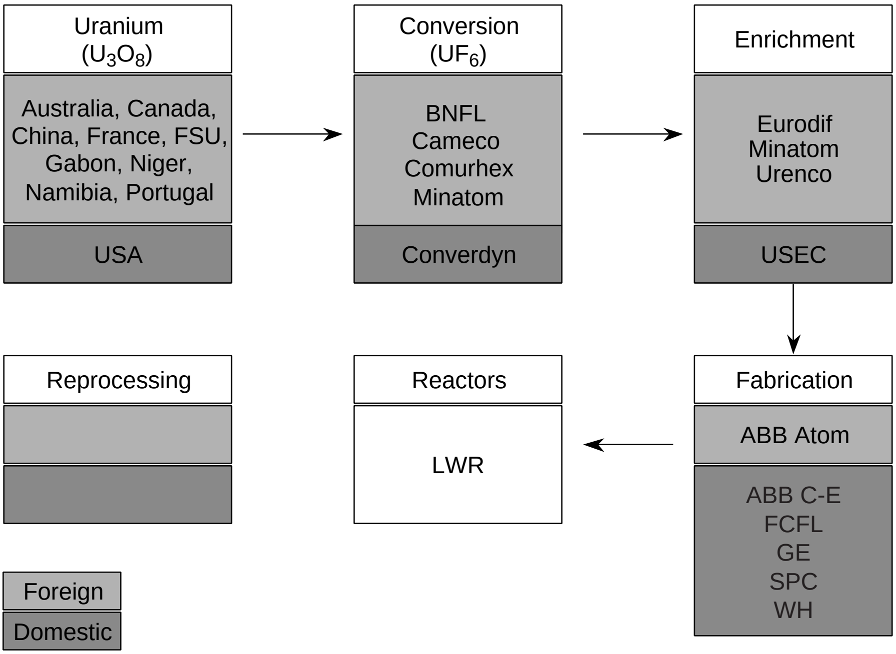

FIG. 33. Material flow in the nuclear fuel cycle: USA. Foreign organizations: ABB Atom (Sweden), BNFL (UK), Cameco (Canada), Comurhex (France), Eurodif (Belgium, France, Islamic Republic of Iran, Italy, Spain), Minatom (Russian Federation), Urenco (Germany, Netherlands, UK).

Spent fuel management

Approximately 41 000 t HM from commercial spent fuel was in inventory at the end of 1999, with 1840 t HM in dry storage facilities.

No commercial reprocessing plants are in operation; US utilities 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

The total production of uranium in Uzbekistan up to 1998 was 91 571 t. In 1999, ISL production was organized in 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.

Conversion

None

Enrichment

None

Fabrication

None

Spent fuel management

None

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