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Foreword

Dear reader,

I am pleased to present you the Annual Report of the Euratom Supply Agency (ESA) for 2016.

This year's Report follows the same structure as the previous one. Chapter 1 includes an outline of ESA's activities in 2016 and a concise presentation of nuclear energy developments in the EU. Chapter 2 gives an overview of the world market for nuclear fuels, while Chapter 3 contains ESA's evaluations of the fuel market in the EU. For the first time this Chapter also includes an analysis of deliveries of conversion services. Chapters 4 and 5 focus, respectively, on the security of supply and on medical radioisotopes, while Chapter 6 sets out ESA's work programme for 2017.

ESA continued, in the course of the year, to assume responsibility for the EU nuclear common supply policy, in the interest of a regular and equitable access to supply for EU users. In close cooperation with its Advisory Committee, ESA promoted, through the activities of the Nuclear Market Observatory, transparency and predictability in that field.

2016 was, by many aspects, a remarkable year for ESA.

Thanks to the support of our Advisory Committee, we managed to revise our rules for balancing demand and supply. The ones still in force date back to 1960 and were only partially amended in 1975. We hope that the procedure for adoption and entry into force of the new rules, presently pending with the European Commission, can be concluded in the coming months. This would provide ESA and its stakeholders with an up-to-date foundation for their work.

Follow-up work to the Memorandum of Understanding between ESA and the United States Department of Energy/National Nuclear Security Administration (DoE-NNSA) on the exchange of high-enriched uranium (HEU) continued in 2016. The Memorandum aims to ensure the supply of HEU for European research reactors and producers of radioisotopes in conformity with the policy of HEU reduction in civil uses, which has been developed through the Nuclear Security Summit process. The release of a joint statement by ESA and the DoE-NNSA in March 2016, in the margins of the Washington Nuclear Security Summit, was one of the year's highlights.

Security of fuel supply for research reactors, in the interest of both scientific research and the production of radioisotopes, for the period after the future conversion of such reactors to operate with low-enriched uranium (LEU, 19.75 %), continued to draw the attention of ESA. In the course of the year, we published the Report on Securing the European Supply of 19.75 % Enriched Uranium Fuel. The report was published to further feed public reflection on the matter, in agreement with ESA's Advisory Committee; it was drafted by a dedicated working group of the Advisory Committee and subsequently endorsed by the latter in 2013.

Last but not least, 2016 was a year of change for ESA.

Both Stamatios Tsalas, the Agency's Director-General who had served since July 2011, and Ute Blohm-Hieber, the Head of Unit, left on well-deserved retirement in the course of the year.

I have had the honour to head ESA since November last year. I feel lucky, and grateful to my predecessor, for the competent and motivated team I found at the Agency, including the new Head of Unit having already previously served in the same position. They have enthusiastically supported me from my very first day in office.

Trusting that the Agency will continue to deliver high-quality work and be respected as an important contributor in its field, I take particular pride in signing the foreword of the first Annual Report for which I am responsible.

Marian O'Leary

Director-General of the Euratom Supply Agency

Contents

Abbreviations

CIS	Commonwealth of Independent States
ESA	Euratom Supply Agency
Euratom	European Atomic Energy Community
IAEA	International Atomic Energy Agency
ITRE	European Parliament Committee on Industry, Research and Energy
IEA	International Energy Agency
NEA	Nuclear Energy Agency
(US) DoE	United States Department of Energy
(US) NRC	United States Nuclear Regulatory Commission
USEC	United States Enrichment Corporation
DU	depleted uranium
ERU	enriched reprocessed uranium
EUP	enriched uranium product
HEU	high-enriched uranium
kgU	(metric) kilogram of uranium (1 000 g)
lb	pound
LEU	low-enriched uranium
MOX	mixed-oxide [fuel] (uranium mixed with plutonium oxide)
RET	re-enriched tails
RepU	reprocessed uranium
SWU	separative work unit (see glossary for detailed definition)
tHM	(metric) tonne of heavy metal
tSW	1 000 SWU
tU	(metric) tonne of uranium (1 000 kg)
U_3O_8	triuranium octoxide
UF_6	uranium hexafluoride
BWR	boiling water reactor
EPR	evolutionary/European pressurised water reactor
LWR	light water reactor
NPP	nuclear power plant
PWR	pressurised water reactor
RBMK	light water graphite-moderated reactor (Russian design)
VVER/WWER	pressurised water reactor (Russian design)
kWh	kilowatt-hour
MWh	megawatt-hour (1 000 kWh)
GWh	gigawatt-hour (1 million kWh)
TWh	terawatt-hour (1 billion kWh)
MW/GW	megawatt/gigawatt
MWe/GWe	megawatt/gigawatt (electrical output)

1. ESA activities and nuclear energy developments in the EU

ESA operations

Mandate and core activities

The Euratom Treaty created a common nuclear market in the EU. Article 52 of the Treaty established ESA to ensure a regular and equitable supply of nuclear fuels to EU users in line with the objectives of Article 2(d). To this end, ESA applies a supply policy based on the principle of equal access of all users to ores and nuclear fuel. It focuses on improving the security of supply to users located in the EU, thus also contributing to the viability of the EU nuclear industry. In particular, it recommends that Euratom utilities operating nuclear power plants (NPPs) maintain stocks of nuclear materials and cover their requirements by entering into long-term contracts that diversify their sources of supply. This is to prevent excessive dependence of EU users on any single, third-country supply source. Diversification should cover all stages of the fuel cycle.

ESA's mandate is, therefore, to exercise its powers and, as required by its statutes, to monitor the market to ensure that the activities of individual users reflect the values set out above. ESA implements the EU supply policy for nuclear materials by concluding supply contracts for nuclear material whenever one of the contracting parties is an EU utility, an operator of a research reactor in the EU, or an EU producer selling or buying nuclear material. ESA has a right of option on nuclear materials produced in the Member States. Under the Euratom Treaty, ESA also monitors transactions involving services in the nuclear fuel cycle (conversion, enrichment and fuel fabrication). Operators are required to submit notifications giving details of their commitments. ESA verifies compliance with the upstream contract and acknowledges these notifications.

In 2016, ESA processed 344 transactions, including contracts, amendments and notifications, and thus helped to ensure the security of supply of nuclear materials.

ESA's 2015 Annual Report was published on ESA's website in June 2016. As every year, ESA presented its annual calculation of different types of average natural uranium prices: MAC-3, multiannual and spot prices. The report is available on the EU Bookshop website in paper, pdf and e-book (EPUB) versions [1].

In 2016, in line with its statutory obligations, ESA's nuclear fuel market observatory continued to publish the nuclear news digests, quarterly uranium market reports, price trends and the

[1] https://bookshop.europa.eu/en/euratom-supply-agency-annual-report-2015-pbMJAA16001/.

weekly nuclear news brief (for readers in the European Commission). Greater transparency in the EU natural uranium market reduces uncertainty and helps to improve security of supply.

In 2016, ESA issued four quarterly uranium market reports and provided four updates of its nuclear news digests. The quarterly uranium market report reflects global and specific Euratom developments on the nuclear market. This includes general data about natural uranium supply contracts signed by EU utilities, descriptions of activity on the natural uranium market in the EU, and the quarterly spot-price index for natural uranium whenever three or more ordinary spot contracts have been concluded.

In May 2016, the ESA Advisory Committee gave its positive opinion on ESA's draft proposal for updated Agency Rules to bring the rules in line with current market practices. However, before entering into force, the proposed rules have to be approved by the European Commission. This process was still not finalised at the beginning of 2017.

Following a widening of the ESA's observatory role in 2013 to cover aspects of the supply of medical radioisotopes in the EU, in 2016 ESA continued to coordinate actions to improve the security of supply of Molybdenum-99/ Technetium-99 m — the most vital medical radioisotope — by chairing the European Observatory on the Supply of Medical Radioisotopes ([2]).

In addition to these activities, in a follow-up to the Agency's report to the European Commission on the medical radioisotopes, published in 2015 ([3]), ESA was involved in the work carried out by the Dutch Presidency on the Position Paper on the 'Security of supply of medical radioisotopes'. The paper was presented to energy ministers at the Energy Council meeting held in June 2016 ([4]).

Another closely related aspect is the supply of uranium for fuel and target fabrication for the European research reactors where the medical radioisotopes are produced. To that end, in close cooperation with the Member States concerned, ESA continued to facilitate the supply of HEU to users who still need it, in compliance with international nuclear security commitments. In 2016, ESA arranged for several meetings to discuss the implementation of the Memorandum of Understanding signed with the US DOE-NNSA in 2014 on the exchange of HEU needed to supply European research reactors and radioisotope production facilities. The important development in this context was the drawing up of a list of materials eligible for exchange under the Memorandum of Understanding and the release of a Joint Statement on EU-US HEU exchange at the 2016 Nuclear Security Summit in Washington ([5]). The overall balance of HEU quantities to be requested by Euratom Member States and HEU quantities to be shipped to the United States for downblending or to be recycled and downblended in Europe has been achieved as envisaged by the Memorandum and a significant proportion of the materials identified has already been shipped to the U.S.

The Agency's mission in support of security of supply received new impetus following the adoption and publication, in May 2014, of the European Commission Communication on the European Energy Security Strategy ([6]). In this context, in 2016 ESA published a paper version of the 'Report on the feasibility and opportunity to build a European capacity for the production of metallic LEU, at 19.75 %' ([7]), drafted in 2013 by the Working Group of ESA's Advisory Committee. It is worth noting that the worldwide supply of LEU, at 19.75 %, is barely secured in the long term. The report remains therefore relevant to the international discussion on metallic LEU supply and can provide a useful input to any cooperative initiative in this area, including with interested countries outside the EU.

Activities of the Advisory Committee

In line with ESA's statutes, the Advisory Committee assists the Agency in carrying out its tasks by giving opinions and providing analyses and information. The Advisory Committee also acts as a link between ESA, producers and users in the nuclear industry, as well as Member State governments.

In 2016, the Advisory Committee met twice. At the first meeting on 13 May, the topics on the agenda were the committee's opinions on ESA's 2015 Annual Report and on ESA's audited accounts for 2015. The committee also discussed the progress achieved by the Working Group on Prices and Security of Supply and the Working Group on Intermediaries. The most important outcome of the meeting was the positive opinion given by the committee on ESA's draft proposal for updated Agency Rules. During the meeting, updates were given on ESA's latest discussions on the supply of HEU and LEU for research reactor fuel and targets used for the medical radioisotope production, namely in the context of the Memorandum of Understanding on HEU exchange, signed in 2014. The committee also agreed that its 2013 report on the European production of LEU (19.75 %) should be published, provided the figures it includes are deemed up-to-date. Due to the retirement of the chairperson, the committee elected a new chairperson for the remainder of its current term.

The second meeting took place on 27 October. The committee discussed the closing activities of the Working Group on Intermediaries and the status report of the Working Group on Prices and Security of Supply. The committee took note of the updates provided on the draft budget of ESA for the financial year 2017 and on ESA's work programme for 2017. The com-

(2) http://ec.europa.eu/euratom/observatory_radioisotopes.html.
(3) http://ec.europa.eu/euratom/docs/ESA-MEP-web_final%20 14.09.2015.pdf.
(4) http://data.consilium.europa.eu/doc/document/ST-8403-2016-INIT/en/pdf.
(5) http://www.nss2016.org/document-center-docs/2016/4/1/joint-statement-on-eu-us-heu-exchange.
(6) http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&qid=1407855611566.
(7) http://ec.europa.eu/euratom/docs/ESA-MEP-rapport.pdf.

mittee also provided a favourable opinion on the estimate of ESA's revenue and expenditure for the 2018 financial year.

International cooperation

ESA has long-standing and well-established relationships on nuclear energy with two major international organisations: the IAEA and the OECD Nuclear Energy Agency (NEA). In 2016, ESA continued its cooperation with both these organisations by participating in two working groups — the joint NEA/IAEA Uranium Group ([8]) and the NEA High-Level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) ([9]) — as well as the Nuclear Development Committee (NDC) ([10]). At the joint NEA/IAEA Uranium Group meeting in October 2016, ESA presented its latest analysis of the EU nuclear market. At the HLG-MR meetings held in February and July 2016, ESA represented the European Observatory on the Supply of Medical Radioisotopes. In September 2016, ESA took part in the World Nuclear Association Symposium — the global nuclear industry's annual event. In October, ESA participated in a workshop organised by the IAEA on the LEU Fuel Bank to be established in Kazakhstan.

ESA administrative issues

The Agency, established directly by Article 52 of the Euratom Treaty, has been operating since 1 June 1960.

It is endowed with legal personality and financial autonomy (Article 54 of the Euratom Treaty) and operates under the supervision of the European Commission (Article 53) on a non-profit-making basis.

Seat

The seat of ESA has been in Luxembourg since 2004 (Article 2 of the statutes). Together with the European Commission, the Agency has concluded a seat agreement with the Luxembourg government.

Financing

ESA's present financial situation results from the Council decision (adopted in 1960) to postpone, sine die, the introduction of a charge on transactions (contracts for purchase of nuclear materials by EU utilities). In accordance with Article 54 of the Euratom Treaty, this charge was intended to cover the operating costs of the Agency. Since 1960, therefore, the Euratom Supply Agency has relied on the European Commission, which covers the bulk of the Agency's administrative needs (staff, offices, and minor expenses) and additionally grants ESA a financial contribution based on ESA's budget estimate.

Financial Regulation

For its financial operations, ESA applies the relevant provisions of its statutes as well as the EU Financial Regulation ([11]) and the accounting rules and methods established by the European Commission.

Article 1(2) of the EU Financial Regulation stipulates that 'this regulation shall apply to the implementation of the budget for the Euratom Supply Agency'.

Financial accounts and implementation of the budget

In 2016, the assets owned by the Agency totalled EUR 638 019. They were financed by liabilities of EUR 10 774 (2 %) and equity of EUR 627 245 (98 %). The Agency has a capital of EUR 5 856 000. An instalment of 10 % of the capital is paid at the time of a Member State's accession to the EU. On 31 December 2016, the amount of the instalment called up and reflected in ESA's accounts stood at EUR 585 600.

In 2016, the Agency's budget remained stable at EUR 125 000 (compared to 2015). Its revenue and expenditure were in balance. The budget was financed by a contribution from the European Commission's heading 32.01.07 'Euratom contribution for operation of the Supply Agency' (EUR 119 000) and by own revenue (bank interest on the paid-up capital, for approximately EUR 6 000).

ESA's expenses consist only of administrative costs. The Agency neither manages operational budget lines nor provides grants. The bulk of the Agency's administrative expenses, including salaries, premises, infrastructure, training, and some IT equipment, is covered directly by the European Commission budget, and is not acknowledged in the Agency's accounts. Salaries are paid by the European Commission in line with the provisions of Article 4 of ESA's statutes and are not charged to the Agency's budget. This off-budget expenditure and the underlying transactions are included in the EU annual accounts and are considered as non-exchange transactions for the Agency. ESA's running costs are partly covered by its own budget; this includes staff missions, IT equipment for its own computer centre, and media subscriptions.

ESA's financial statements from 31 December 2016 show a budget execution of EUR 117 926, or 94 % of commitment

([8]) http://www.oecd-nea.org/ndd/uranium.
([9]) http://www.oecd-nea.org/med-radio/security/.
([10]) http://www.oecd-nea.org/ndd/ndc/.

([11]) Regulation (EU, Euratom) No 966/2012 of the European Parliament and of the Council on the financial rules applicable to the general budget of the Union and repealing Council Regulation (EC, Euratom) No 1605/2002 (OJ L 298, 26.10.2012), and in particular Article 1(2) thereof.

appropriations (against 99 % in 2015). Unused amounts are returned to the EU budget.

The budget and final annual accounts are published on ESA's website (http://ec.europa.eu/euratom/index_en.html).

External audit by the Court of Auditors

The European Court of Auditors audits ESA's operations on an annual basis. The Court's responsibility is to provide the European Parliament and the Council with a statement of assurance as to the reliability of the annual accounts and the legality and regularity of the underlying transactions.

ESA takes due account of the opinions expressed by the Court. In 2016, the Court provided a positive opinion on the reliability of the accounts and on the legality and regularity of the underlying transactions for the financial year 2015.

Discharge

The European Parliament, acting on a Council recommendation, is the discharge authority for ESA. On 28 April 2016, the European Parliament granted ESA's Director-General discharge for the implementation of the budget for the 2014 financial year ([12]).

Staff

During 2016, ESA's Director-General and Head of Unit retired and were replaced. At the end of the year, ESA had 17 permanent posts, one of which became vacant following retirement of the job holder. ESA staff are European Commission officials, in accordance with Article 4 of ESA's statutes ([13]).

EU nuclear energy policy in 2016

With the objective of implementing and further developing the framework for nuclear safety, security, non-proliferation and radiation protection, a number of measures were taken at EU level.

Strategic agenda for nuclear energy

As part of the Energy Union Strategy ([14]) implementation and in accordance with Article 40 of the Euratom Treaty ([15]), the Directorate-General for Energy of the European Commission presented the latest nuclear illustrative programme in 2016 ([16]). The programme provides a full overview of developments and investments needed in the nuclear field in the EU for all the steps of the nuclear lifecycle with a 2050 horizon. In 2017 the focus will be on the follow-up actions, including actions to increase safety and cost-efficiency of nuclear power plants, such as standardisation of reactor designs and their supply chain, as well as progress in harmonising licensing requirements among EU Member States.

In March 2016, the European Commission adopted a Recommendation on the application of Article 103 of the Euratom Treaty ([17]). It aims to provide greater legal certainty to Member States as to the compatibility of their draft bilateral agreements with Euratom law.

In 2016, the European Commission continued its preparatory work on updating the notification requirements for nuclear investment projects pursuant to Article 41 of the Euratom Treaty. The initiative aims to take into account the current state of the European nuclear industry, in particular investments aimed at the long-term operation of nuclear power plants. The Commission also wants to ensure compliance with Euratom safety requirements, while making the procedure more efficient and transparent for all stakeholders.

Nuclear safety directive

Work continued in 2016 to ensure effective implementation of the reinforced EU nuclear safety framework. The European Commission is supporting the Member States in transposing the amended Nuclear Safety Directive ([18]) into national law by organising dedicated workshops and working with the European Nuclear Safety Regulators Group (ENSREG) ([19]). Steps have been taken to facilitate the effective implementation of the first topical peer review on 'ageing management of nuclear (power plants' under the amended Nuclear Safety Directive, in coordination with ENSREG, due to start in 2017.

Safe management of radioactive waste and spent fuel

Under the Directive for the responsible and safe management of spent fuel and radioactive waste ([20]), efforts focused in 2016 on assessing the notified transposition measures by Member States and reviewing the required national programmes. In 2017, the European Commission will publish its first report to the European Parliament and the Council on the implementation of the Directive, based on the national reports

([12]) European Parliament decision of 28.4.2016 (2015/2185(DEC)).

([13]) Council Decision 2008/114/EC, Euratom of 12 February 2008 establishing Statutes for the Euratom Supply Agency (OJ L 41, 15.2.2008, p. 15), and in particular Articles 4, 6 and 7 of the Annex thereto.

([14]) https://ec.europa.eu/priorities/energy-union-and-climate_en.

([15]) ISBN 978-92-824-2554-1

([16]) The final version (after opinion of the European Economic and Social Committee) was presented in May 2017; http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:237:FIN.

([17]) https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v6_1.pdf.

([18]) OJ L 219, 25.7.2014, pp. 42-52.

([19]) http://ensreg.eu/

([20]) OJ L 199, 2.8.2011, pp. 48-56.

submitted by the Member States ([21]). The report will draw a clear picture of the current situation of spent fuel and radioactive waste management in the EU, including a comprehensive inventory of spent fuel and radioactive waste present on the EU's territory. This will provide transparency to EU citizens on this important issue. Following up on the analysis presented in the nuclear illustrative programme, the report is intended to contribute to an informed debate on the investment needs and the management of nuclear liabilities in the back-end of the fuel cycle. Taking into account the recommendations in the European Court of Auditors' special report No 22/2016 on the EU nuclear decommissioning assistance programmes to Bulgaria, Lithuania and Slovakia, the report will launch a debate on options for disposal, including regional and other EU-based solutions.

EU support for nuclear decommissioning assistance programmes

In June 2016, the European Commission presented to the European Parliament and the Council a report on the implementation of the nuclear decommissioning assistance programme to Bulgaria, Lithuania and Slovakia in 2015 and previous years ([22]). It also adopted the 2016 annual work programmes and associated financing decisions, allocating EUR 135.644 million for the implementation of the actions. Management and supervision of the programmes are being further strengthened in line with recommendations from the Internal Audit Service and the European Court of Auditors.

Radiation protection

On radiation protection, the Council adopted in January 2016 Regulation (Euratom) 2016/52 laying down maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency ([23]). It provides more flexible procedures allowing specific reactions to any nuclear accident or radiological emergency. Work is ongoing to assess Member States' transposition measures under Council Directive 2013/51/Euratom (the 'Euratom Drinking Water Directive') ([24]).

Six on-site inspection visits of Member States' facilities to monitor radioactivity levels were carried out in 2016 under Article 35 of the Euratom Treaty. Six Commission opinions were delivered in 2016 on general data submitted by Member States on the plans for the disposal of radioactive waste pursuant to Article 37 of the Euratom Treaty.

Nuclear emergency preparedness and response

On nuclear emergency preparedness and response, the activities of the Directorate-General for Energy focused on a more coherent implementation of the revised Basic Safety Standards Directive ([25]) requirements. A European roundtable was organised on nuclear emergency preparedness and response, followed by a seminar with the participation of civil society groups on public information issues. The topic was also discussed at the 2016 European Nuclear Energy Forum (ENEF) conference.

European Nuclear Energy Forum

The ENEF conference was held in Bratislava in October 2016 ([26]). It focused on investment priorities in the nuclear energy sector, nuclear energy and the new market design, as well as nuclear emergency preparedness and response plans in Member States. The conference was very successful in bringing back on board civil society representatives, which contributed to a well-balanced discussion among all stakeholders.

Convention on Nuclear Safety

On behalf of the Euratom Community fulfilling its obligations under the Convention on Nuclear Safety (CNS) ([27]), the European Commission, in collaboration with the Euratom Member States, issued a report on the implementation of the CNS in view of the 7th Review Meeting of Contracting Parties scheduled for 2017.

Non-power uses of nuclear and radiation technology

For non-power applications of nuclear and radiation technology, the Directorate-General for Energy launched a study on medical, industrial and research applications of nuclear and radiation technology. The results will feed into the ongoing preparatory work for the development of a strategic agenda for medical, industrial and research applications of nuclear and radiation technology (SAMIRA) ([28]).

Stress tests

On the external dimension of nuclear energy policy, the European Commission intensified its work to support the implementation of risk and safety assessments (stress tests) of nuclear power plants in EU neighbouring countries. A peer review

([21]) The report was submitted in May 2017; http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:236:FIN
([22]) https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-405-EN-F1-1.PDF
([23]) OJ L 13, 20.1.2016, p. 2-11.
([24]) OJ L 296, 7.11.2013, pp. 12-21.
([25]) OJ L 13, 17.1.2014, pp.1-69.
([26]) https://ec.europa.eu/energy/en/events/european-nuclear-energy-forum-enef-plenary-meeting
([27]) http://www-ns.iaea.org/conventions/nuclear-safety.asp .
([28]) https://ec.europa.eu/energy/en/news/commission-launches-call-tender-study-nuclear-and-radiation-technology .

of nuclear stress tests took place in Armenia in June 2016, with the participation of experts from the Commission and EU Member States. This review will be followed up in 2017. A high-level visit to Belarus was organised in September 2016 to review progress in the implementation of the stress test process for the Ostrovets NPP. In March 2016, the Commission organised a fact-finding mission to Ankara to assess Turkey's alignment with the Euratom legislation in the context of the potential opening of accession negotiations on Chapter XV 'Energy'.

Joint Comprehensive Plan of Action

Following the Implementation Day of the Joint Comprehensive Plan of Action (JCPoA) ([29]) with Iran on 16 January 2016, the European Commission held high-level contacts with Iranian authorities to assess possible areas for cooperation on energy matters, including the peaceful use of nuclear energy. In 2017, the Commission will continue to support implementation of the JCPoA on nuclear safety cooperation, with a focus on nuclear governance.

International Thermonuclear Experimental Reactor (ITER)

In 2016, the Directorate-General for Energy took steps to improve the supervision and governance of the ITER ([30]) project and increase European participation in it. On the international project and its execution, efforts launched in 2015 to revise the project's baseline led to an agreement in November 2016 on an updated schedule of the project. Furthermore, the successful completion of all the ITER Organisation's milestones in 2016 has confirmed full adherence of all parties to the global commitments. It has also shown the efforts they have made to ensure the project steadily advances. The ITER Council also took measures to improve the governance by reviewing the practices and rules of the ITER governing bodies.

Main developments in the EU Member States

The recently formed Energy Union allows each Member State to decide whether nuclear energy should be part of its energy mix. Therefore, the countries which plan to keep nuclear energy as one of their energy sources share the view that it can contribute to cleaner electricity. However, some national energy policies published in 2016 have fixed a ceiling for the share of nuclear in their respective range of energy generation sources. Major investments are required in nuclear new build, lifetime extension and safety upgrades, improved fuel-cycle operation, decommissioning and waste management.

Progress was made during 2016 on new uranium mining projects in Spain and Greenland. Focus was on diversifying sources of supply and addressing safety-related issues. Although several reactors were kept offline longer than the usual annual outage period, no reactors were permanently shut down. Nuclear plant construction continued in France, Finland and Slovakia. Compared to 2015, moderate progress was reported on new build projects and intentions to build in Bulgaria, the Czech Republic, Hungary, Poland, Finland, and the United Kingdom. The Lithuanian new build project, on the other hand, was put on hold. Regulatory approval has been granted for operational lifetime extension of certain nuclear power reactors in Hungary and the Czech Republic. Decisions on operating lifetimes depend on current and forecast electricity market conditions and sometimes also on social and political factors. Such decisions are always subject to a safety review by the competent national regulator. In Sweden, four reactors are expected to be closed earlier than planned because they are deemed unprofitable. Several countries have launched projects on waste management.

China continued to assert itself as an increasingly important player on the EU market by expressing its interest in becoming involved in nuclear projects. It would also like to enter into cooperation agreements for knowledge-sharing on nuclear reactor construction projects.

([29]) http://eeas.europa.eu/archives/docs/statements-eeas/docs/iran_agreement/iran_joint-comprehensive-plan-of-action_en.pdf .

([30]) https://www.iter.org/ .

Table 1. Nuclear power reactors in the EU in 2016

Country	Reactors in operation (under construction)	Net capacity (MWe)
Belgium	7	5 943
Bulgaria	2	1 926
Czech Republic	6	3 940
Germany	8	10 728
Spain	7	7 121
France	58 (1)	63 130 (1 750)
Hungary	4	1 889
Netherlands	1	485
Romania	2	1 310
Slovenia/Croatia (*)	1	696
Slovakia	4 (2)	1 816 (942)
Finland	4 (1)	2 764 (1 700)
Sweden	9	8 849
United Kingdom	15	8 883
Total	128 (4)	119 480 (4 392)

(*) Croatia's power company HEP owns a 50 % stake in the Krško NPP in Slovenia.

Source: World Nuclear Association (WNA).

As shown in Table 1, at the end of 2016 a total of 128 nuclear power reactors of different designs were in operation in the EU, producing 26.5 % of its electricity. As in 2015, four more were under construction.

Country-specific developments in 2016

Belgium: The 962-MW Unit 1 at Tihange NPP was kept offline for more than 3 months, until mid-August, for the annual maintenance and refuelling outage and for long term operation works (+10y). Experts participating in the International Atomic Energy Agency (IAEA) mission in February on safe long term operation at Doel Units 1 and 2 stated that up to now works are going on in line with IAEA standards for long term operation. Of a combined generating capacity of roughly 6 000 MW, the Belgian nuclear fleet will be phased out by the end of 2025. In a recently issued report, the International Energy Agency (IEA) concluded that Belgium's energy policy objectives of ensuring the security of supply and reducing greenhouse emissions would be difficult to attain in the context of the current phase-out policy. In June, the Belgian government adopted the first Belgian national programme for the management of spent fuel and radioactive waste.

Bulgaria: According to official statements from the ministry of energy, the country has been looking for a strategic investor to cooperate in expanding the country's nuclear capacity, and it seems that China has shown a certain level of interest in that. Bulgaria declared it will commit itself to a nuclear power construction project, provided no state guarantees are required by the respective investor, country or company.

Czech Republic: In a statement released on 30 March, the Czech utility ČEZ, a.s. (CEZ) announced the signature of two nuclear cooperation agreements between Czech and Chinese nuclear companies. One agreement paves the way for Czech companies to become sub-contractors for Chinese reactor projects in third countries. The other agreement provides for the steps required for Chinese companies to obtain design approval for Generation III reactors.

In May, CEZ announced extended outages of Units 2 (from September 2016 into 2017) and 3 (from April to October 2016) of the Dukovany NPP. This was to perform intensive checks on pipe welds to clear up any doubts about the reliability and safety of the facilities. CEZ announced in July that it had provided all the necessary documents requested by the Czech ministry of the environment to start an environmental impact assessment (EIA) on adding up to two new reactors at the Dukovany site. However, this EIA could take several years to complete. The four existing units at Dukovany are expected to continue operating until at least 2035 and will then be closed on a gradual basis. During the year, Unit 1 was licensed for continued operation subject to ongoing reporting, and Unit 2 had its licence extended by a year pending checks during refuelling shutdowns.

Unit 1 at the Temelin NPP also underwent a longer than anticipated outage in 2016, following extended pressure checks on equipment. Shut down for safety checks and a refuelling outage since 26 August, the unit was connected to the transmission grid on 25 December.

CEZ and Westinghouse have signed an agreement for the delivery of six lead test assemblies (LTA) for the Temelin NPP. This is an indication that CEZ is seriously trying to improve its security of supply by diversifying its nuclear fuel sources.

The Czech Republic's radioactive waste disposal authority signed a four-year contract with Finland's Posiva to deliver knowhow for selecting the Czech Republic's planned waste disposal site. The Czech Republic is currently assessing seven sites for its deep geological repository, with the final site to be selected in 2025.

Denmark: Denmark and Greenland signed an agreement on the future commercial export of uranium mined in Greenland. This marks the end of the 1988 mining ban on uranium and radioactive elements in Greenland. The agreement allows the Kvanefjeld uranium and rare earth project in southern Greenland to advance. It also states that EU regulations will serve as a basis for new legislation on safeguards and dual-use export controls. Uranium ore and concentrates from Greenland will be subject to a safeguards reporting system similar to Euratom's, and their exports subject to a bilateral nuclear cooperation agreement.

Germany: During the third quarter of 2016, German utilities E.ON (currently PreussenElektra), RWE, EnBW and Vattenfall finalised with the German Federal Government the terms of the agreement proposed in April 2016 on funding the country's nuclear phase-out. In line with the recommendations of the German commission for the review of the financing for the phase-out of nuclear energy, the proposal called for nuclear power utilities to transfer provisions for nuclear waste into a state fund. Accordingly, after the draft law takes effect, probably in 2017, the country's 'big four' utilities would transfer EUR 23.3 billion in provisions to the federal government. This would go to cover the interim storage, transport, and final disposal of spent fuel, operational and high-level waste, as well as low- and medium-level waste from decommissioned reactors. The utilities would afterwards have no further financial obligation for storage and disposal.

In a statement published on 6 December, Germany's Supreme Court ruled that the country's 2011 nuclear phase-out law is constitutional. However, it also recognised that the rights of the nuclear power operators (E.ON, RWE and Vattenfall) had been partly infringed. The Court stated that the government should compensate the companies for their investments in the plants, based on Germany's post-2009 plan of extending reactor operating lifetimes by about 12 years. The new compensation rules must be in place by 30 June 2018.

Spain: Spain's nuclear regulator, CSN, was expected to make a decision in November on whether to renew the operating licence for the 466-MW Garoña NPP, Spain's oldest nuclear reactor. Potentially, CSN would allow the shut unit to return to service, subject to safety upgrades. However, it was not until February 2017 that the decision was taken to renew the NPP's operating licence.

Also in November, Spain's nuclear regulator announced that it had approved a series of modifications to be performed at three NPPs (the 2 093-MW Almaraz, 1 066-MW Trillo and 1 092-MW Cofrente). This was part of the EU-mandated post-Fukushima stress tests conducted in 2012. The modifications include the installation of passive autocatalytic hydrogen recombiners, the construction of Emergency Management Centres on the three sites and a general revision of emergency plans.

Berkeley Energia Ltd. announced in December that it had completed key land acquisitions of over 500 hectares, which will accelerate the development of its 100 %-owned Salamanca uranium project in western Spain. It is expected that construction of the processing plant and initial infrastructure will start in the first quarter of 2017. A recently completed definitive feasibility study (DFS) at Salamanca indicated an initial mine life of 14 years, producing an average of 3.5 million pounds U_3O_8 (± 1 350 tU) per year from an open pit mining operation. After initial ramp-up, production would average 4.4 million pounds U_3O_8 (± 1 693 tU) per year during 10 years.

France: Based on several governmental instruments adopted during 2016, the French nuclear safety regulator (ASN) will acquire additional tools to strengthen its effective oversight of nuclear installations. This is in line with a June 2006 law on transparency and security in the nuclear field. In particular, it will have the ability to supervise safety-related work carried out by subcontractors.

On 21 April, Electricité de France (EDF) and Rosenergoatom renewed for five years an agreement for cooperation between the operators of the French and Russian nuclear fleets. The fields covered by the agreement include reactor operations and life extensions, decommissioning and radiation waste management, as well as research and development.

France's multi-annual energy plan was published on 28 October with a draft proposal by the French energy ministry to reduce the country's annual nuclear energy generation by 10 to 65 TWh by 2023. The proposal estimates that generation by renewable sources would increase to 150 TWh-167 TWh by 2023, up from the 102 TWh produced in 2015.

The AREVA group has continued its legal and financial restructuring under its strategic roadmap. As part of its restructuring plan to reduce its total debt of EUR 7 billion, which was due, in part, to liabilities stemming from delays in the Olkiluoto-3 EPR project, AREVA has agreed to sell a majority stake of its reactor unit to EDF. According to an EDF statement of 16 November, the deal will include the following: EDF acquires a majority stake in AREVA's reactor unit; EDF will buy a newly created subsidiary of Areva NP, called

New NP. New NP comprises Areva NP's activities involving the design and manufacturing of nuclear reactors and associated equipment, manufacturing and design of nuclear fuel assemblies and services to the French nuclear fleet. EDF will acquire up to 75 % of New NP, but that would later be reduced to a target stake of at least 51 %, depending on negotiations with other potential investors. The transaction is expected to be completed during the second half of 2017 and remains subject to favourable conclusions from the ASN on the quality of the reactor pressure vessel at the Flamanville-3 EPR under construction.

AREVA has also created another company named New AREVA which is in charge of nuclear fuel activities, namely mining, chemistry, enrichment and recycling activities as well as dismantling, logistics and engineering services. At some point in time, the French state should become the direct majority owner of New Areva, jointly with other minor shareholders, the first two being nuclear Japanese companies.

Following the 2015 discovery of widespread carbon segregation problems in critical nuclear plant components, ASN ordered stopping some reactors for further inspections. In 2016, up to 20 of the country's 58 reactors were offline. Early December, ASN stated that it agreed in principle with EDF that 10 of France's 900 megawatt pressurised water reactors (PWRs) are safe to restart. EDF was expecting that 11 out of the 12 reactors offline at the end of the year would be reconnected to the grid early 2017.

End 2016, EDF declared that, by standardising components and equipment, it is striving to reduce by 25 % to 30 % the current costs of the EPRs under construction. The EPR New Model, or EPR NM, would be the flagship model to replace the existing French nuclear fleet as older reactors reach the end of their operating lives. The basic design for EDF's EPR NM is 30 % complete, with a first unit expected to be commissioned late in the next decade. The first new reactors are expected to be available by 2030.

Further progress was achieved on the construction of the Jules Horowitz Reactor (JHR) during 2016. Before the end of the year, the structural part of the hot cells, subsequent to the integration of the heavy doors, had been completed, and construction of the nuclear buildings is nearing completion.

In 2016, CERCA (AREVA NP) accelerated the renovation programme of its fabrication facility, launching a series of major works to meet safety and security requirements and ensure a sustainable supply for its customers.

Hungary: During 2016, the European Commission examined two main aspects relating to the Paks II expansion project, namely the procurement procedure and whether funding of the project amounts to State aid. On 17 November it closed the infringement procedure it had launched against Hungary over public procurement rules in connection with this project. MVM Paks II received an environmental licence in late September and subsequently submitted a site licence application for the two new units. The first unit is to be completed in 2025 and the second in 2026.

Hungary's National Atomic Energy Authority publicly announced end 2016 that, following a one-year review, it had granted Paks I-Unit 3 the permit to operate until 31 December 2036. This was an extension of 20 years beyond the reactor's original 30-year licence. No major conditions were imposed, apart from additional inspections and repairs to be carried out in the near future. Paks currently meets almost 40 % of Hungary's electricity demand, and accounts for more than 50 % of domestic power generation. The company is preparing Paks I- Unit 4 for a similar lifetime extension by the time its original licence expires in 2017.

Lithuania: According to the national energy strategy released in November, the country has decided to put on hold the construction of the 3 400-MW Visaginas NPP, until the project either becomes cost effective under market conditions or necessary for energy security. Cooperation with the project's main contractor, Hitachi, continues on energy technologies and efficiency.

Lithuania is also trying to secure additional funding from the European Union and other sources to decommission the Ignalina NPP, closed in 2009. The country has raised concerns about the safety and transparency of the Ostrovets NPP in neighbouring Belarus.

Poland: Polska Grupa Energetyczna — Elektrownia Jądrowa, the company responsible for Poland's nuclear power project, confirmed in the beginning of 2016 that it had chosen two potential sites for the country's first NPP, on which further environmental testing would be performed. Both sites are located in northern Poland, close to the Baltic Sea.

Following IAEA's conclusion that Poland has implemented all the recommendations and suggestions of the 2013 integrated nuclear infrastructure review (INIR) mission, representatives of the Polish ministry of energy have underlined that Poland is taking all the necessary measures to ensure its nuclear power programme meets the highest standards of safety and security and best international practices.

Romania: State-owned China General Nuclear Power Corporation, which in 2015 signed a preliminary project agreement with Romanian state-owned nuclear company Nuclearelectrica to add two new reactors with a capacity of at least 720 MW each at Cernavoda NPP, declared in early 2016 that the Romanian government would support the project through potential electricity market reforms, rate mechanisms and financial incentives.

In September, Romania's ministry of energy, sole shareholder of the state company National Uranium Company (CNU), issued a draft emergency ordinance (EO) for review by the European Commission. The EO stated that Romania's government wants to grant CNU a capital injection of 62 million lei (EUR 15 million) as rescue aid to cover the company's current expenditures for 6 months. According to the Romanian authorities, the closure of the company, which produces the fuel for Romania's sole NPP, would affect the country's energy security. This rescue package was approved by the European Commission, but Romania has to present a restructuring and liquidation plan for CNU in the event of a default.

Slovakia: In its proposed legislative programme for the period to 2020, the Slovak government analysed possible further steps to prepare for a new nuclear reactor at the Bohunice site. The ministry of environment issued the final statement for the project of the new NPP at Bohunice site, recommending the construction of one pressurised water reactor of generation III+, with net installed electrical power of up to 1 700 MWe and related facilities. Estimated designed lifetime of the plant is 60 years. This statement marks the completion of the environmental impact assessment process launched in 2013.

Finland: Preparatory works continued throughout 2016 for Fennovoima's planned Hanhikivi NPP in northern Finland. Construction of the NPP itself will start after receiving the construction licence. The 1 200 megawatt Russian VVER-1200 reactor is expected to begin commercial operation in 2024 and will be adapted to comply with Finnish national, European and other relevant international regulations and requirements.

In April, the Finnish Teollisuuden Voima Oyj (TVO) utility applied to the Finnish ministry of employment and the economy for a 20-year operating license for Olkiluoto-3, the 1 600-MW EPR currently under construction and expected to start full commercial operation at the end of 2018. TVO hopes to receive the licence at the end of 2017, for the period 2018-2038, and later on have it renewed. It expects to operate the reactor for 60 years. In October AREVA reported that the project had achieved two major milestones with the recent start of nuclear circuit clearing and completion of full-scope simulator testing.

After receiving approval from the Finnish radiation & nuclear safety authority (STUK) to start construction of the world's first repository, the waste management company Posiva signed a contract with YIT Construction for the excavation of the first tunnels in December 2016.

Sweden: Early 2016, OKG, operator of the Oskarshamn NPP, announced that, due to a combination of low electricity prices and high taxes and fees, Units 1 and 2 were considered unprofitable and would be closed earlier than scheduled. Thus, Sweden's oldest reactor, the 492-MW Oskarshamn-1 Unit, will be permanently shut down mid-2017, at a date to be agreed upon jointly by the Swedish radiation safety authority and the local land and environment court. As for the 661-MW Oskarshamn-2 Unit, its permanent closure will also occur before 2020.

Following a multi-party political agreement reached mid-2016 to abolish the capacity tax on nuclear power in Sweden in 2019, Vattenfall stated it would operate the three Forsmark reactors, with a total installed capacity of 3 388 MW, until the end of their technical lifetimes, about 60 years each. Early 2017, Vattenfall will decide whether or not to invest in the upgrades needed to extend lifespans for Units 3 and 4 at the Ringhals NPP.

Unit 2 at the Ringhals NPP returned to the electricity grid on 26 November, more than two years after the 910-MW reactor had been taken offline for repairs. The station has been allowed to operate with conditions until the end of 2019, when it is scheduled to be permanently shut down.

Vattenfall has signed the first commercial contract with the Russian fuel fabricator TVEL for the supply of TVS-K fuel assemblies, for use in the Ringhals NPP.

United Kingdom: In February, EDF Energy made public its intention to have the operating lives of four of the eight AGR-type units it operates in the UK extended by an average of eight years per plant. It is thus expected that Heysham 1 and Hartlepool will have their operational lives extended by 5 years until 2024, while Heysham 2 and Torness will see their closure dates postponed to 2030. In November, the company announced that it would hold three rounds of public planning consultation, on the construction of its proposed 3 200-MW Sizewell C NPP in eastern England, before submitting an application for a development consent order.

In May, Horizon Nuclear Power announced that a new joint venture between Hitachi Nuclear Energy Europe Ltd., Bechtel Management Company, Ltd., and JGC Corporation Ltd, called Menter Newydd, had been set up to provide help in the construction of the Wylfa Newydd NPP. Later in July, Horizon Nuclear Power and its parent company Hitachi reported the signature of a cooperation agreement with Japan Atomic Power Company (JAPC) under the terms of which JAPC would assist with construction costing, licensing, and commissioning planning issues for the proposed NPP.

On 15 September, the UK government made official its decision to proceed with the Hinkley Point C project for the construction of two European pressurised reactors (EPRs). The government has also established a new policy towards future foreign investment in critical infrastructure in the UK that provides for oversight to determine whether foreign ownership in key infrastructure projects poses a risk to national security. In a press release, EDF stated that it intends to maintain a controlling stake in Hinkley Point C as specified by the government's new policy, which is viewed as compatible with future potential nuclear build projects at Sizewell C and Bradwell B. EDF expects electricity generation from the first planned reactor at Hinkley Point C to begin in 2025.

NuGen, a Toshiba and ENGIE joint venture, has stated that it expects its proposed Moorside project to build three Westinghouse AP1000 reactors adjacent to the Sellafield reprocessing site to be finalised in late 2025. A final investment decision is expected before the end of 2018.

2. World market for nuclear fuels

This chapter presents a short overview of the main developments in 2016 that affected the global supply and demand balance and the security of supply at different stages of the fuel cycle. It relies on data collected from various specialised publications.

According to the World Nuclear Association, as of 31 December 2016 there were 447 nuclear reactors operational in 31 countries, with a generation capacity of 391.3 GWe able to supply over 11 % of the world's electricity. World nuclear power generation increased by 1.9 % in 2016, driven mostly by the Asia-Pacific region.

According to the International Energy Agency's latest world energy outlook ([31]), between early 2015 and the end of 2016, 19 new nuclear reactors began operation, and construction started on another nine reactors. Currently, there are 60 nuclear reactors under construction, i.e. around 64 GW of new nuclear capacity, principally in China, but also in Russia, the United Arab Emirates, the United States, Korea, the European Union and India. One seventh of the global nuclear fleet is 40 years old or more, but moves are underway in some jurisdictions (e.g. the United States) to extend nuclear plant lifetimes to 60 or even 80 years.

The latest energy outlook issued by the US-DOE's Energy Information Administration estimates that nuclear electricity generation will almost double by 2040, compared to the 2012 figures. The increase from 2.3 billion MWh to 4.5 billion MWh will be primarily due to substantial growth in China and to new reactor builds in India, the countries with the two highest forecast annual growth rates of nuclear generation. Nuclear power will be the second fastest growing source of electricity generation, after renewables, increasing at a 2.3 % annual rate from 2012 to 2040, while it is estimated that its share of total electricity generation worldwide will increase from 10.8 % to 12.3 %. Overall, world electricity generation is expected to rise from 21.6 billion MWh in 2012 to 36.5 billion MWh in 2040, a 68 % increase.

As part of its 2016-2020 national strategy, China plans to double its nuclear generation capacity to 58 GWe by the end of 2020, up from 28.3 GWe at the end of 2015. It is expanding its strategic uranium reserve to meet the future growth of its domestic nuclear power programme. China's natural uranium demand is expected to reach 11 000 tU by 2020 and 24 000 tU by 2030, exceeding production from domestic mines and Chinese-owned mines overseas. In September, the IAEA concluded that China's nuclear regulatory framework had improved significantly. However, various challenges remain, mainly as regards China's ability to effectively oversee its rapidly growing nuclear energy programme, handle long-term operation of reactors, and manage spent fuel.

([31]) IEA, World Energy Outlook 2016, p.243.

Early 2016, Units 3 and 4 at the Takahama NPP in Japan were briefly reconnected to the grid but later taken offline again because of a district court injunction triggered by continuing safety concerns expressed by the public. Following the restart of Unit 3 at the Ikata NPP in August, Japan had three reactors (out of 42) in operation end of 2016. Units 1 and 2 at Takahama NPP, in operation for more than 40 years, were granted a 20-year lifetime extension in June, as Japan's nuclear regulation authority (NRA) concluded they meet post-Fukushima safety standards. Kansai Electric, the reactor operator, must still complete the NRA's extensive screening process for both reactors before they can restart operations in 2019. On 16 December, Japan and Russia signed a bilateral agreement providing for cooperation on civilian nuclear power issues, including the promotion of nuclear technology and the decommissioning of the Fukushima I NPP.

Nuclear Power Corporation of India Ltd. and India's ministry of external affairs have started negotiations with EDF on the Jaitapur project to build six EPRs. India's current nuclear liability regime continues to present challenges for reactor vendors. In November, India signed a bilateral nuclear cooperation agreement with Japan to export nuclear technology and reactors from Japan to India. As there are certain components needed for US and French reactors that are currently only manufactured in Japan, Westinghouse and EDF will thus be able to export reactors to India. India continues to seek membership in the Nuclear Suppliers Group.

By the end of 2016, the NRC had extended the licences of 87 reactors in the US, 88 % of the US total, beyond 40 years, and about 30 have been operating for 40-60 years. The NRC declared it was analysing licence renewal applications for eight further units. Almost all of the US power reactors are, therefore, likely to have 60-year lifetimes, with owners undertaking major capital works to upgrade them at around 30-40 years. However, in recent years US operators have also closed or announced the planned closure of several reactors for economic reasons.

In Russia, the first VVER-1200 reactor, Unit 1 of the Novovoronezh II NPP, was connected to the network in August, and was expected to start commercial operation in early 2017. A second VVER-1200 reactor is also under construction at Novovoronezh and is scheduled to be completed in 2018 and achieve full commercial operation in early 2019.

Natural uranium production

In 2016, global uranium production increased by 3 % compared with 2015, totalling 62 328 tonnes of uranium. As in 2015, the top three uranium-producing countries were Kazakhstan, Canada and Australia.

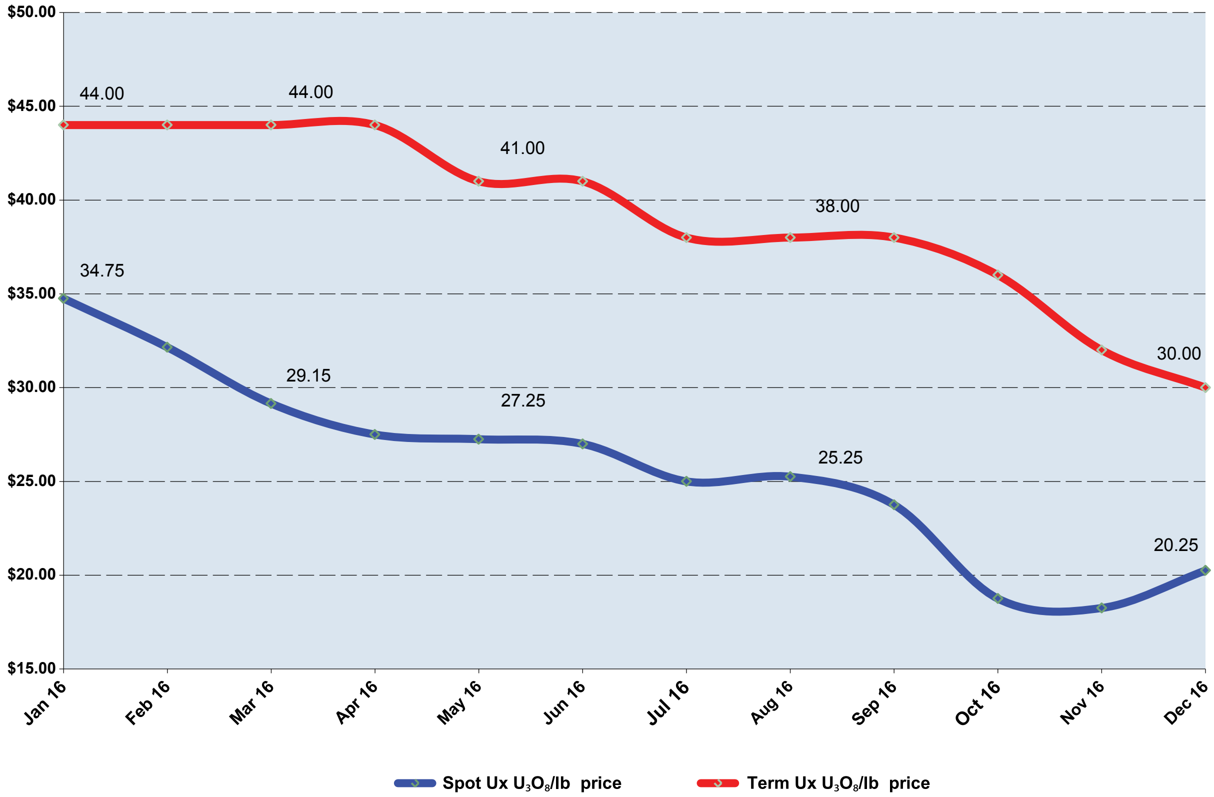
Kazakhstan remained the world's leading uranium producer in 2016, accounting for 40 % of total worldwide uranium output. The country's uranium production accounted for 24 617 tU in 2016, approximately the same output as in 2015. Canada's production was estimated at around 14 040 tU in 2016, almost 5 % higher than the 2015 data. Australia's production increased by almost 11 % compared to 2015, totalling 6 270 tU at the end of 2016.

Table 2. Natural uranium estimate production in 2016 (compared with 2015, in tonnes of uranium)

Region/country	Production 2016 (estimate)	Production 2015 (final)	Share in 2016 (%)	Share in 2015 (%)	Change 2016/2015 (%)
Kazakhstan	24 617	23 800	40	39	3
Canada	14 040	13 325	23	22	5
Australia	6 270	5 654	10	9	11
Niger	3 500	4 116	6	7	-15
Namibia	3 462	2 993	6	5	16
Russia	3 000	3 055	5	5	-2
Uzbekistan	2 423	2 385	4	4	2
China	1 745	1 616	3	3	8
United States	1 115	1 256	2	2	-11
Ukraine	1 000	1 200	2	2	-17
Others	810	703	1	1	15
South Africa	346	393	1	1	-12
Total	63 328	60 496	100	100	3

Source: Data from the WNA and specialised publications (totals may not add up due to rounding).

Figure 1. Monthly spot and term U_3O_8/lb prices (in USD)



Source: The Ux Consulting Company.

The Ux spot price fell continuously during 2016. It began the year at USD 34.75 per pound and gradually slipped down below USD 20.00 per pound in October to reach its yearly minimum in November at the level of USD 18.25 per pound. In December it increased, ending the year at USD 20.25 per pound.

The Ux long-term price was stable until the end of April and accounted for USD 44.00 per pound. Then, for the rest of the year it dropped and reached its yearly minimum at USD 30.00 per pound at the end of December.

Secondary sources of supply

In 2016, world uranium production continued to provide the bulk of world reactor requirements, complemented by secondary supply sources, which included government-held or commercial inventories of natural and enriched uranium, down-blended weapons-grade uranium, reprocessed uranium (RepU) and plutonium recovered from spent fuel, re-enriched depleted uranium and uranium saved through underfeeding.

According to various industry reports, depleted uranium represents a significant source of uranium (WNA estimates the world stock at about 1.6 million tonnes) that could displace primary production by being re-enriched to the level of either natural uranium or LEU. It is estimated that over 50 000 tonnes of depleted uranium tails are added annually to the existing stocks. They are either stored as UF6 or deconverted, in France, Russia and the US, back to U_3O_8, a more stable and less toxic chemical form, more suited for long-term storage. As depleted uranium could potentially be used as fuel in future generations of fast neutron reactors, in the long-term perspective it needs to be seen as a resource.

Due to the current global enrichment overcapacity, tails assays have been driven downward at enrichment facilities to underfeed the centrifuge plants and create a source of secondary supply that has grown significantly in the last few years, i.e. uranium saved through underfeeding. End 2015, WNA estimated that global underfeeding and tails re-enrichment contribute up to 7 000 tU of supply per year.

Uranium exploration and mine development projects

According to the OECD/NEA and IAEA 'Red Book' — 'Uranium 2016, Resources, Production and Demand', the currently defined resource base could more than adequately meet the high scenario uranium demand estimates through 2035. However timely investments are necessary for resources to be converted into ready-to-use natural uranium. Oversupplied and saturated with significant stocks, the global uranium market will continue to face various concerns, like pricing pressures, geopolitical factors, technical challenges and increasing expectations from the governments in the countries hosting uranium mining.

Berkeley Energia Ltd. reported that site development works had started at the Salamanca uranium project in Spain. Conventional open pit and transfer mining methods will be used to mine the Retortillo, Zona 7, and Alameda uranium deposits at Salamanca. In July, the company announced that it had completed the definitive feasibility study for the project, which shows an initial mine schedule of 14 years and an average annual production of 3.5 million pounds U_3O_8 (around 1 350 tU) from an open pit mining operation. First production is expected in 2018.

Boss Resources Ltd., owner of the Honeymoon in-situ recovery (ISR) project in South Australia, whose expansion is currently on hold, has recently declared its intention to start a targeted exploration and drilling programme to expand the project's current resource and be able to complete, by 2017, an updated definitive feasibility study at the mine. Production could begin at Honeymoon in mid-2019.

Mid-2016, AREVA Resources Canada Inc. confirmed that the Canadian Nuclear Safety Commission (CNSC) had granted the McClean Lake uranium mill approval to increase production to 24 million pounds U_3O_8 (around 9 230 tU) per year, an 85 % increase from the mill's previously licensed capacity of 13 million pounds U_3O_8 (around 5 000 tU) yearly.

BHP Billiton stated that it would pursue an underground development pathway for Olympic Dam mine in South Australia which, subject to various approvals and investments, could lead to an increased production of copper, gold, silver, and uranium as by-product.

On 30 December, the first drum of uranium ore concentrates was produced at the Husab mine in Namibia, marking the successful operation of all sections of the operating chain and processing plant. During 2017, optimisation of the plant will continue, and production will progressively be ramped up towards the target of 15 million pounds U_3O_8 (around 5 800 tU) per year.

In November, the Finnish state-owned management firm Terrafame Oy announced its intention to start processing uranium at the Sotkamo nickel mine in Finland. Previously owned by Talvivaara, which filed for bankruptcy in November 2014, the mine already has a uranium extraction plant onsite, but actual uranium production still requires approval and environmental permits from the relevant authorities in Finland. The uranium production capacity of the Sotkamo mine could almost entirely cover Finland's domestic requirements.

As for Cameco Corp., it announced that it had suspended production at its Rabbit Lake uranium mine in northern Saskatchewan and reduced production at its ISR operations in the US by deferring new well field development.

Conversion

Conversion plants are operating commercially in the US, Canada, France, Russia and China. The main new plant is Areva's Comurhex II, operating between two sites in France. China's capacity is expected to grow considerably through to 2025 and beyond to keep pace with domestic requirements.

In 2016, world nameplate primary conversion capacity was estimated at around 59 000 tU. Although the actual conversion production is generally less than nameplate (according to the WNA, capacity utilisation is about 79 % of nameplate), supply provided by primary and secondary conversion sources was well above the global demand for conversion services. Part of the supply continued to be provided by secondary conversion sources. Secondary supply of equivalent conversion services includes UF_6 material from commercial and government inventories, enricher underfeeding, and depleted uranium tails recovery. Uranium and plutonium recycling effectively adds to this. According to WNA, secondary sources are projected to provide less than 14 000 tU to 2022.

Table 3. Commercial UF_6 conversion facilities

Company	Nameplate capacity in 2015 (tU as UF_6)	Share of global capacity (%)
Comurhex (AREVA) (France)	15 000	25.4
ConverDyn (United States)	15 000	25.4
Cameco (Canada)	12 500	21.2
Atomenergoprom (Rosatom) (Russia)	12 500	21.2
CNNC (China)	4 000	6.8
Ipen (Brazil)	100	0.2
Total nameplate capacity	59 100	100

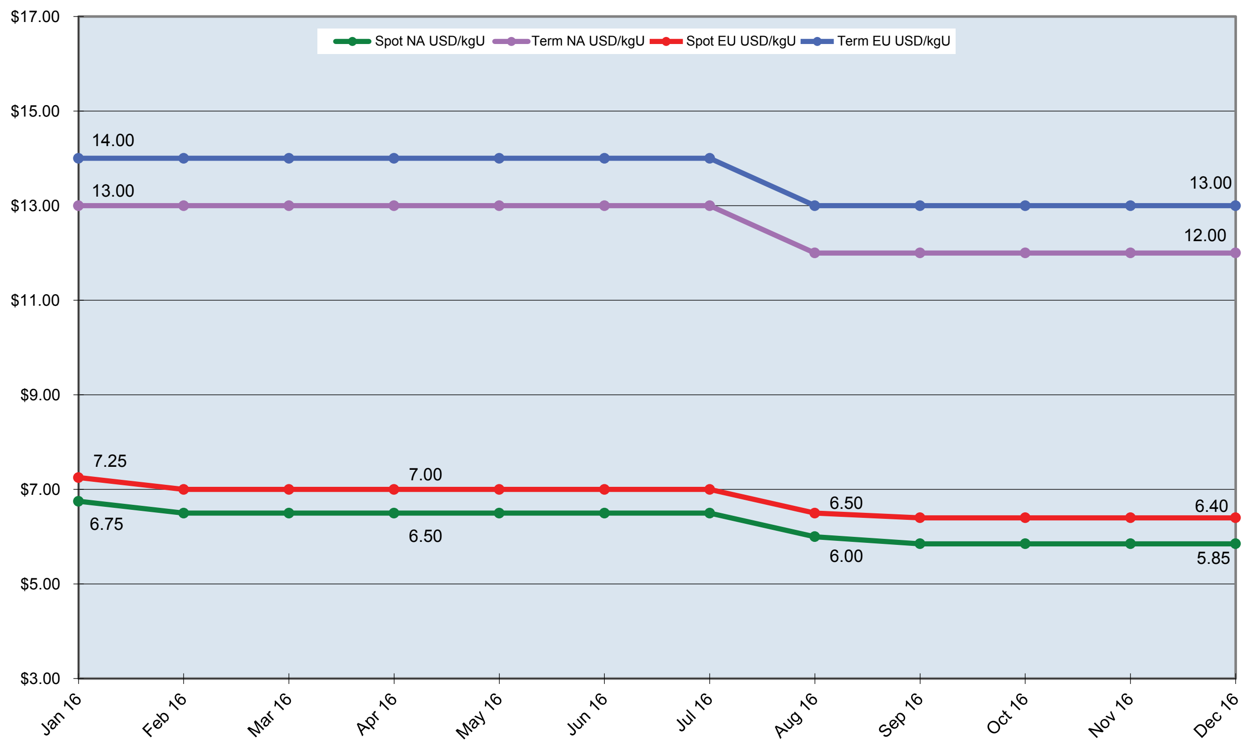
Source: WNA, The Nuclear Fuel Report — Global Scenarios for Demand and Supply Availability 2015-2035.

Cameco Corporation submitted an application for a 10 year-renewal of its Port Hope Conversion Facility Operating Licence. The new licence was granted in February 2017.

Cameco and Kazatomprom stated their intention to complete a feasibility study on the design, construction and operation of a uranium refinery in Kazakhstan, with the capacity to produce 6 000 tU of UO3 per year. Should the two companies decide to build the refinery, their respective ownership interests would be 71.67 % for Kazatomprom and 28.33 % for Cameco. Kazatomprom would also have a five-year option to license Cameco's proprietary uranium conversion technology.

At the end of 2016, Honeywell decided to reduce the output of the Metropolis facility, the only uranium conversion plant in the US, from 15 000 tU to 7 000 tU, in response to the decrease in demand.

Figure 2. Uranium conversion price trends



Source: **The Ux Consulting Company.**

European and North American Ux spot conversion prices dropped from USD 7.25 per kgU and USD 6.75 per kgU respectively, to USD 7.00 per kgU and USD 6.50 per kgU and remained stable until the end of July. In August, prices decreased again and finally finished the year at USD 6.40 per kgU in the EU and USD 5.85 per kgU in the US.

The European and North American Ux term conversion prices were stable from January until end of July and amounted to USD 14.00 per kgU and USD 13.00 per kgU, respectively. They then started to drop in August to finish the year at USD 13.00 per kgU in the EU and USD 12.00 per kgU in the US.

Enrichment

In 2016, the demand for enrichment services was evaluated at around 47 000 tSW. According to the WNA's latest estimates, world enrichment requirements are expected to rise over the 2015-2030 period, reaching a level nearing 80 000 tSW by 2035. This is mainly due to new nuclear build prospects in Asian and Middle Eastern countries, particularly China and India.

The current commercial enrichment nameplate capacity of approximately 57 000 tSW is considered to be sufficient to cover demand until 2020. Projected primary supplier capacities will be more than sufficient to meet enrichment demand at least through 2025. Secondary sources (derived from use of mixed oxide (MOX) and enriched reprocessed uranium (ERU)) will be available to meet world enrichment requirements beyond this date.

Large commercial enrichment plants are in operation in France, Germany, the Netherlands, the UK, the US and Russia, with smaller plants elsewhere. China's capacity is expanding considerably, in line with domestic requirements. With surplus capacity, some plants operate at low tails assays (underfeeding) to produce low-enriched uranium for sale.

Table 4. Operating commercial uranium enrichment facilities, with approximate 2016 capacity

Company	Nameplate capacity (tSW)	Share of global capacity (%)
TVEL/Tenex (Russia)	26 600	45
Urenco (UK/Germany/Netherlands/United States)	19 100	32.3
AREVA-GBII (France)	7 500	12.7
CNNC (China)	5 800	9.8
Others* (CNEA, INB, JNFL)	175	0.3
World total	59 175	100

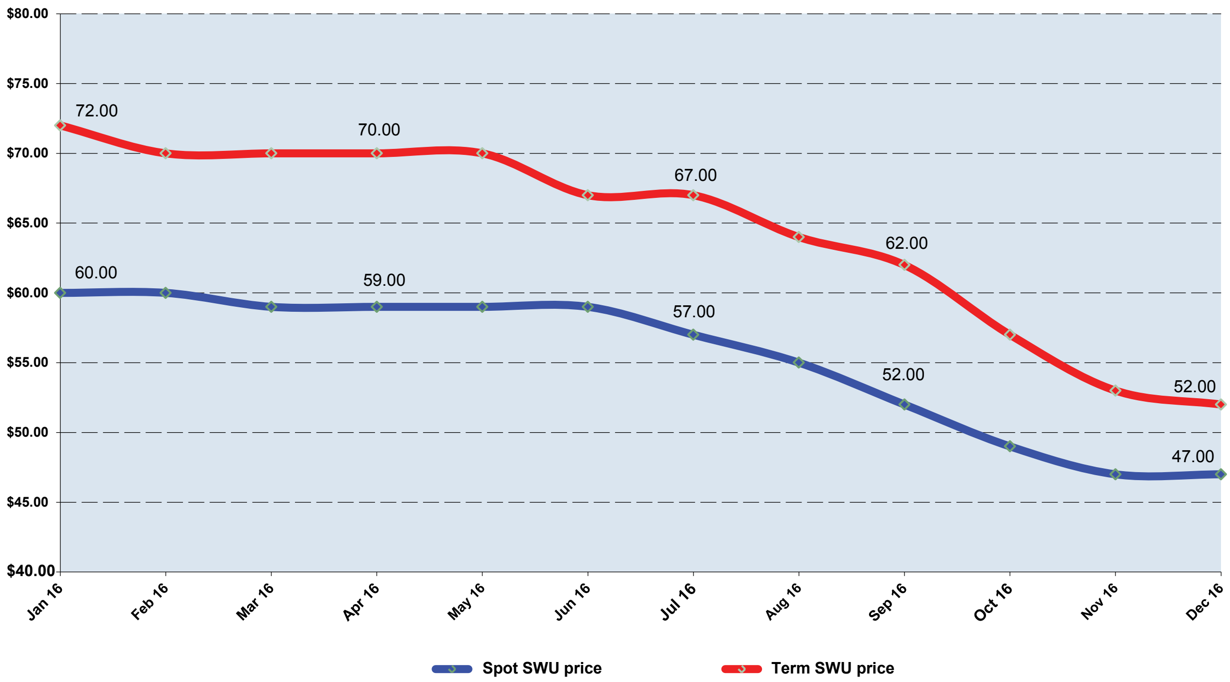
Source: WNA, *The Nuclear Fuel Report — Global Scenarios for Demand and Supply Availability 2015-2035.*
(*) CNEA, Argentina; INB, Brazil; JNFL, Japan.

AREVA's Georges Besse II enrichment plant at Tricastin reached its full production capacity of 7.5 million separative work units (SWUs) in 2016.

Early in February, Centrus Energy Corp. announced that it had stopped operating its American Centrifuge Program (ACP) demonstration cascade of centrifuge machines at its facility in Piketon, Ohio. Although it plans to demobilise the ACP demonstration cascade, Centrus intends to maintain its construction and operating licence from the US Nuclear Regulatory Commission (NRC) for a commercial plant, so as to preserve options for the future use of the facility.

End 2016, the DOE made public the signature of an agreement for the sale of depleted uranium to Global Laser Enrichment, LLC (GLE) over a 40-year period. The total amount of depleted uranium to be sold under the terms of the agreement is approximately 300000 tU. GLE plans to re-enrich it at a new, proposed GLE laser enrichment facility (PLEF), which is expected to be constructed in the early 2020s at Paducah, Kentucky, adjacent to the current DOE site. GLE is the exclusive licensee of the SILEX laser enrichment technology developed by Silex Systems Ltd. of Australia (Silex). The PLEF would become a commercial uranium enrichment production facility under a US NRC operating license.

Figure 3. Monthly spot and term SWU prices (in USD)



The spot Ux SWU price fell continuously during 2016. It began the year at USD 60.00 per SWU and slipped to USD 59.00 at the end of March, holding that level through the middle of the year. However, it started a strong downfall in the second half of the year, dropping to USD 57.00 in July, then falling to USD 55.00, USD 52.00, and USD 49.00 in August, September, and October, respectively. The decline continued into November, hitting USD 47.00 per SWU, which was the price level until the end of the year.

Similarly, the Ux long term SWU price also fell during 2016. It began the year at USD 72.00 per SWU and was relatively flat for the first half of the year. The price slipped to USD 70.00 per SWU at the end of February and then to USD 67.00 per SWU at the end of June. Additional declines were then noted each month starting in August, until the end of the year. As a result, the term price ended the year at USD 52.00 per SWU, a yearly decrease of almost 28 %, thus setting a new reported historical low.

Fabrication

Fuel fabrication demand is a mixture of first cores and subsequent reloads, with an overwhelming majority of demand coming from the reload side. The main fuel manufacturers are also the reactor vendors, usually supplying the initial cores and early reloads for reactors of their own design. The largest fuel fabrication capacity can be found in the EU (Germany, Spain, France, Sweden and the United Kingdom), Russia and the United States, and, except for the VVER fuel, the market is very competitive. Thus, a trend of continuously improving fuel design has emerged, focusing on enhanced burnups and improved performance.

During the first half of 2016, Global Nuclear Fuel-Americas (GNF-A) and the Russian nuclear fuel fabricator TVEL agreed to combine their expertise to fabricate and market fuel for the 35 PWRs currently operational in the US. The two companies will seek to obtain approval from the US NRC to supply PWRs with lead test assemblies using Russia's TVS-K design. TVEL will contribute its design expertise, engineering support, and initial fuel fabrication under the agreement, while GNF-A will carry out project management, pursue licensing with the NRC, and provide quality assurance and engineering services. Subsequent TVS-K assemblies will be fabricated at GNF-A's facility in Wilmington, North Carolina.

Spain's nuclear safety council (CSN) has granted a ten-year licence extension to ENUSA's fuel fabrication plant in Juzbado. In operation since 1985, the plant, fabricates fuel for PWRs and boiling water reactors (BWRs) in Spain and also exports fuel to other European nations.

End 2016, NAC Kazatomprom and China General Nuclear Power Corp. (CGN) reportedly started the construction of a fuel assembly (FA) fabrication facility in Kazakhstan. It will be managed through Ulba-FA, a joint venture between Kazatomprom's subsidiary Ulba Metallurgical Plant JSC (51 %) and CGN's subsidiary, CGN-URC (49 %). Under the terms of a contract signed with Ulba-FA, AREVA NP will be providing fuel assembly production technology, as well as engineering documentation, supply of key production equipment, and personnel training. Production is expected to start in 2020. The FA manufacturing plant is seen as one of Kazatomprom's strategic steps towards production diversification.

In 2016, Ukraine imported almost half of its nuclear fuel needs from Sweden, in line with the country's efforts to diversify its energy sources. Ukraine has gradually increased its cooperation with Westinghouse. After South-Ukrainian NPP, the second station to use both Russian and Swedish-made fuel was the six-unit 6 000-MW Zaporizhia NPP, Ukraine's largest NPP. Early 2017, South Ukraine-2 will become the third unit in Ukraine to use both Russian TVEL and Westinghouse fuel in its core.

TVEL, Rosatom's nuclear fuel subsidiary, signed the first commercial contract for the supply, starting 2021, of its TVS-K fuel assemblies to Vattenfall, for use in the Ringhals plant in Sweden. One of the Ringhals units is using TVS-K lead fuel assemblies under a contract signed in 2011.

In 2015, the European Commission started funding a project called European Supply of Safe Nuclear Fuel (ESSANUF)[32] to facilitate the licensing of alternative VVER-440 fuel. The project was awarded funding of EUR 2 million from Euratom. The project has participants from nine different corporations/organisations in a consortium that is coordinated by Westinghouse Electric Sweden AB. The overall aim of the project is to create greater security of energy supply and contribute to the security of supply of nuclear fuel for Russian designed VVER reactors operating in the EU by diversification of fuel sources. An ESSANUF's Licensing Workshop was held in Prague in June 2016. The project is expected to be finalised in 2017.

Reprocessing and recycling

One of the most important features of nuclear energy is that used fuel can be reprocessed to recover fissile and fertile materials to provide fresh fuel for existing and future nuclear power plants. Several EU countries, Russia and Japan have long had a policy to reprocess used nuclear fuel, while many other countries continue to see used fuel as waste rather than a resource. The recovery of uranium and plutonium through reprocessing of spent fuel is currently carried out in France, the United Kingdom and Russia. Further use of the recovered material requires dedicated conversion, enrichment and fabrication facilities.

According to WNA, by the end of 2016, some 90 000 tonnes of used fuel from commercial power reactors (of 290 000 tonnes discharged) had been reprocessed. Annual reprocessing capacity is now at about 4 500 tonnes per year for normal oxide fuels, but not all of it is operational.

It is anticipated that the use of reprocessed uranium (as ERU fuel assemblies) and plutonium (in MOX fuel) will still play a role in meeting the demand for nuclear fuel, as a replacement for fresh LEU in the supply mix of European, Russian and Japanese utilities, and will save more than 1 700 tU per year after 2017. To date, there are significant stocks of plutonium worldwide, and countries like Russia, Japan and China are consid-

(32) http://www.essanuf.eu/ .

ering additional fabrication capacity for MOX fuel. Due to the complex nature of the required upstream reprocessing of used nuclear fuel, the latest industry estimates indicate that, over the 2015-2035 period, MOX and ERU will contribute around 2 million SWU per year to total SWU supply worldwide33.

China National Nuclear Corp. and Areva have stated their intention to build a Chinese nuclear reprocessing plant based on Areva's existing La Hague plant in France. Work to select a site for the plant in China, however, has been suspended. Work on Japan's spent fuel reprocessing facility in Rokkasho is still on hold.

Following analysis of the budget proposal for the 2017 fiscal year, the US DOE decided that work on the MOX Fuel Fabrication Facility in South Carolina, which is 70 % constructed and is administered by DOE's National Nuclear Security Administration, would be terminated in two years.

(33) WNA, The Nuclear Fuel Report — Global Scenarios for Demand and Supply Availability 2015-2035.

3. Supply of and demand for nuclear fuels in the EU

This overview of nuclear fuel supply and demand in the EU is based on information provided by the utilities or their procurement organisations in an annual survey of acquisition prices for natural uranium, the amounts of fuel loaded into reactors, estimates of future fuel requirements, quantities and origins of natural uranium and separative work, and future contracted deliveries and inventories. At the end of 2016, there were 128 commercial nuclear power reactors operating in the EU, located in 14 Member States and managed by 18 nuclear utilities. There were four reactors under construction in France, Slovakia and Finland. According to the latest available data published by the European Commission, the gross electricity generation from nuclear plants within the EU-28 Member States in 2015 was 857.1 TWh, which accounted for 26.5 % of total EU-28 production [34].

Fuel loaded into reactors

In 2016, 2 086 tU of fresh fuel was loaded into commercial reactors in the EU-28. It was produced using 14 856 tU of natural uranium and 525 tU of reprocessed uranium as feed, enriched with 11 120 tSW. The quantity of fresh fuel loaded decreased by 6 % (i.e. 144 tU less than in 2015). In 2016, the fuel loaded into EU reactors had an average enrichment assay of 3.99 %, 85 % falling between 3.43 % and 4.54 %. The average tails assay was 0.23 %, more than 90 % falling between 0.22 % and 0.25 %.

In 2016, MOX fuel was used in a number of reactors in France and the Netherlands. MOX fuel loaded into NPPs in the EU contained 9 012 kg Pu in 2016, a 16 % decrease over the 10 780 kg Pu used in 2015. Use of MOX resulted in estimated savings of 807tU and 567 tSW (see Annex 5).

The total amount of natural uranium included in fuel loaded into the EU reactors in 2016, including natural uranium feed, reprocessed uranium and savings from MOX fuel, was 16 188 tU. The quantity of natural uranium originating in the EU accounted for approximately 220 tU per year, which together with savings in natural uranium resulting from the use of MOX fuel and reprocessed uranium gives the amount of feed material coming from indigenous and secondary sources. All this provided for about 10 % of the EU's annual natural uranium requirements.

[34] Eurostat Energy Statistics, 2015.

Table 5. Natural uranium included in fuel loaded by source in 2016

Source	Quantities (tU)	Share (%)
Uranium originating outside the EU	14 636	90.4
Uranium originating in the EU (approximate annual production)	220	1.4
Reprocessed uranium	525	3.2
Savings from MOX fuel	807	5.0
Total annual requirements	16 188	100

Future reactor requirements (2017-2036)

EU utilities have estimated their gross reactor needs for natural uranium and enrichment services over the next 20 years, taking into account possible changes in national policies or regulatory requirements resulting in the construction of new units (only projects at an advanced stage of construction), lifetime extensions, the early retirement of reactors, phasing-out or decommissioning. Net requirements are calculated based on gross reactor requirements, less savings resulting from planned uranium/plutonium recycling and inventory usage.

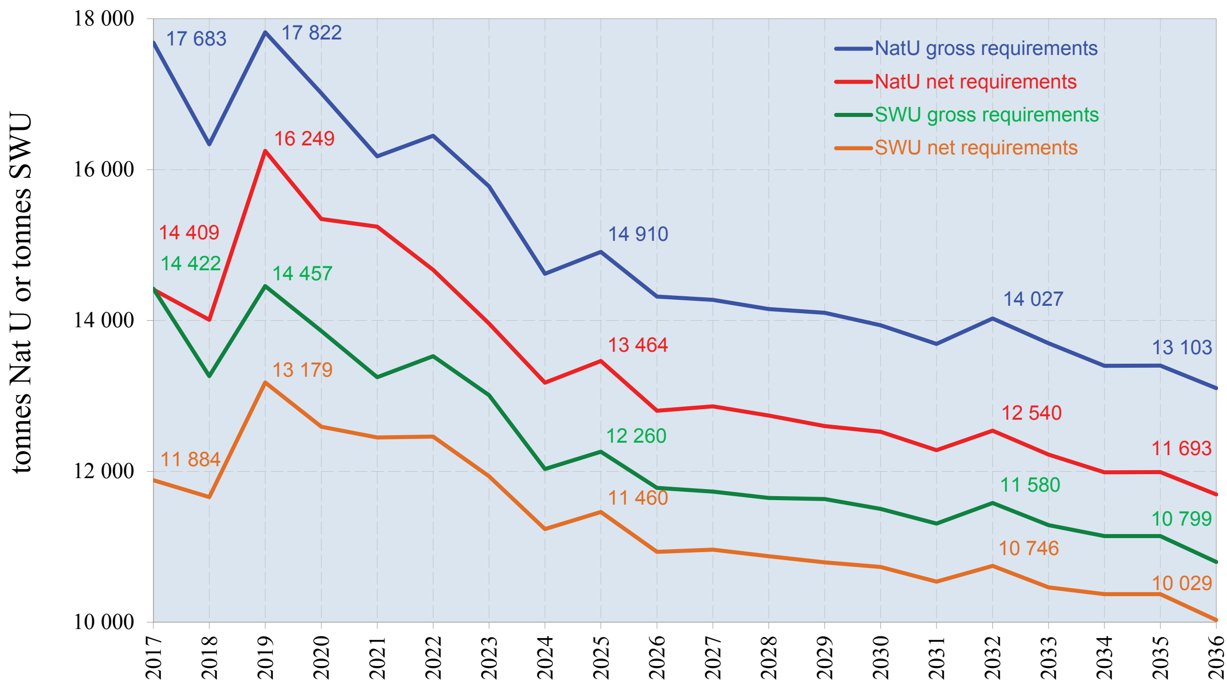
Natural uranium — average reactor requirements		
2017-2026	16 110 tU/year (gross)	14 333 tU/year (net)
2027-2036	13 778 tU/year (gross)	12 344 tU/year (net)

Enrichment services — average reactor requirements		
2017-2026	13 186 tSW/year (gross)	11 979 tSW/year (net)
2027-2036	11 377 tSW/year (gross)	10 588 tSW/year (net)

Estimates of future reactor requirements for uranium and separative work, based on data supplied by all EU utilities, are shown in Figure 4 (see Annex 1 for more detailed figures).

Compared with last year's annual survey, future aggregate requirements declared by the utilities have decreased for both decades. For the period 2017-2026, forecasts of average gross requirements for natural uranium have fallen by 4 % (-634 tU) and for separative work by 3 % (-471 tSW). For 2027-2036, the drop in demand for gross natural uranium is calculated at 6 % (-810 tU) and for enrichment services at 4 % (-475 tSW).

Figure 4. Reactor requirements for uranium and separative work in the EU-28 (in tonnes NatU or SWU)



Supply of natural uranium

Conclusion of contracts

In 2016, ESA processed a total of 107 contracts and amendments, of which 67 (63 %) were newly concluded contracts. Out of 57 new purchase/sale contracts, 30 % involved EU utilities and the remainder were signed by intermediaries. Table 6 gives further details on the kinds of supply, terms and parties involved.

Table 6. Natural uranium contracts concluded by or notified to ESA (including feed contained in EUP purchases)

Type of contract	Number of contracts concluded in 2016	Number of contracts concluded in 2015
Purchase/sale by an EU utility/user	**17**	**23**
— multiannual ([1])	12	9
— spot ([1])	5	14
Purchase/sale by intermediaries	**40**	**39**
— between intermediaries ([2]) (multiannual)	8	3
— between intermediaries ([2]) (spot)	32	36
Exchanges and loans ([3])	**10**	**26**
Amendments	**40**	**27**
Total ([4])	**107**	**115**

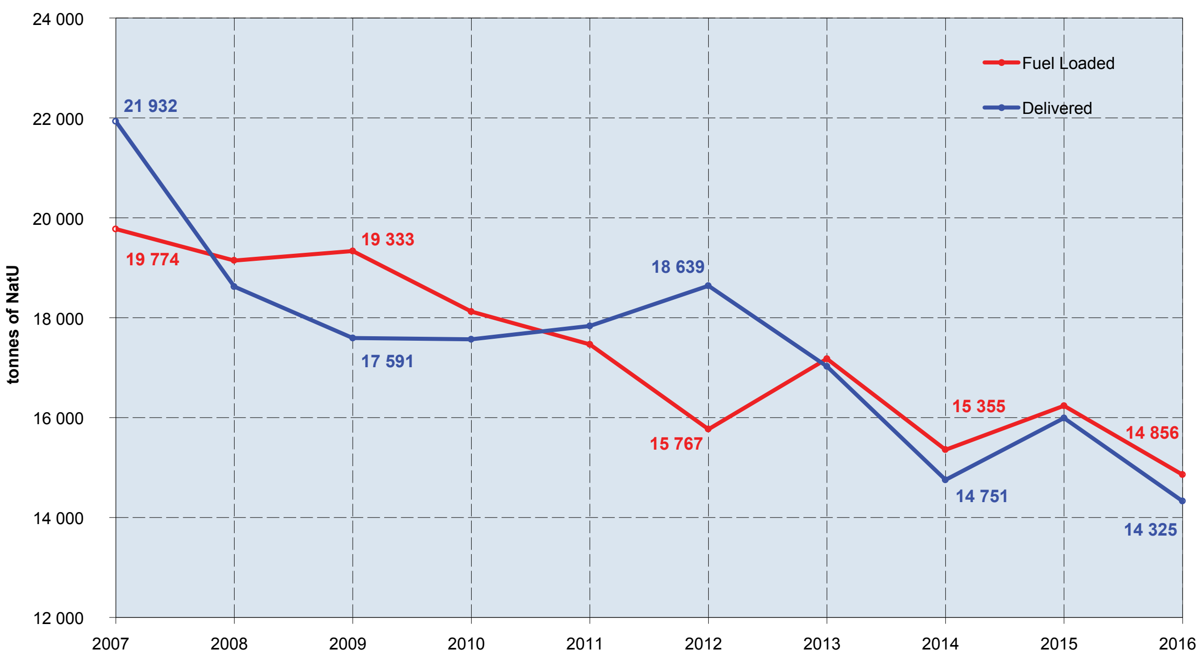
([1]) Multiannual contracts are contracts providing for deliveries extending over more than 12 months, whereas spot contracts provide either for only one delivery or for deliveries over a maximum of 12 months, whatever the time between conclusion of the contract and the first delivery.

([2]) Purchase/sale contracts between intermediaries — neither the buyers nor the sellers are EU utilities/end-users.

([3]) This category includes exchanges of ownership and exchanges of U_3O_8 against UF_6. Exchanges of safeguard obligation codes and international exchanges of safeguard obligations are not included.

([4]) Transactions for small quantities (as under Article 74 of the Euratom Treaty) are not included.

Figure 5. Natural uranium feed contained in fuel loaded into EU reactors and natural uranium delivered to utilities under purchasing contracts (tonnes NatU)



Volume of deliveries

The deliveries taken into account are those to EU utilities or their procurement organisations in 2016, excluding research reactors. Also taken into account is the natural uranium equivalent contained in enriched uranium purchases, when stated.

In 2016, demand for natural uranium in the EU represented approximately one quarter of global uranium requirements. EU utilities purchased a total of 14 325 tU in 138 deliveries under long-term and spot contracts, which is 1 664 tU or 11.6 % less than in 2015. As in previous years, long-term supplies constituted the main source for meeting demand in the EU. Deliveries of natural uranium to EU utilities under long-term contracts accounted for 13 876 tU (of which 13 061 tU with reported prices) or 97 % of total deliveries, whereas the remaining 3 % (449 tU) was purchased under spot contracts. On average, the quantity of natural uranium delivered was 107 tU per delivery under long-term contracts and 56 tU per delivery under spot contracts.

Natural uranium contained in the fuel loaded into reactors in 2016 totalled 14 856 tU. Quantities of natural uranium feed contained in fuel loaded into EU reactors and natural uranium delivered to utilities under purchasing contracts are shown in Figure 5 (see Annex 2 for the corresponding table for 1980-2016).

Average delivery prices

In order to enhance market transparency, each year ESA publishes three EU natural uranium price indices, which are based only on deliveries made to EU utilities or their procurement organisations under natural uranium and enriched uranium purchasing contracts in which the price is stated.

The natural uranium delivery price stated in purchase contracts concluded in recent years (mainly for new multiannual contracts but also for a non-negligible percentage of the spot contracts) is generally agreed using price formulae based on uranium price and inflation indices.

ESA's price calculation method is based on currency conversion of the original contract prices, using the average annual exchange rates published by the European Central Bank, into EUR per kg uranium (kgU) in the chemical form U_3O_8. The average prices are then calculated after weighting the prices paid according to the quantities delivered under each contract. A detailed analysis is presented in Annex 8.

Since uranium is priced in US dollars, fluctuation of the EUR/USD exchange rate influences the level of the price indices calculated. The annual average ECB EUR/USD rate in 2016 stood at 1.11 which was the same level as in the previous year.

In order to calculate a natural uranium price excluding the conversion cost whenever the latter was included but not specified, ESA applied a rigorously calculated average conversion price based on reported conversion prices under long-term contracts for natural uranium.

1. ESA spot U_3O_8 price: the weighted average of U_3O_8 prices paid by EU utilities for uranium delivered under spot contracts in 2016 was calculated as:	
EUR 88.56/kgU contained in U_3O_8	**(EUR 88.73/kgU in 2015)**
USD 37.71/lb U_3O_8	**(USD 37.87/lb U_3O_8 in 2015)**

2. ESA long-term U_3O_8 price: the weighted average of U_3O_8 prices paid by EU utilities for uranium delivered under multiannual contracts in 2016 was calculated as:	
EUR 86.62/kgU contained in U_3O_8	**(9 % down from EUR 94.30/kgU in 2015)**
USD 36.88/lb U_3O_8	**(10 % down from USD 40.24/lb U_3O_8 in 2015)**

3. ESA 'MAC-3' new multiannual U_3O_8 price: the weighted average of U_3O_8 prices paid by EU utilities, only for multiannual contracts which were concluded or for which the pricing method was amended in the past 3 years and under which deliveries were made in 2016, was calculated as:	
EUR 87.11/kgU contained in U_3O_8	**(3 % down from EUR 88.53/kgU in 2015)**
USD 37.09/lb U_3O_8	**(3 % down from USD 37.78/lb U_3O_8 in 2015)**

The ESA U_3O_8 spot price reflects the latest developments on the uranium market, as it is calculated from contracts providing either for a single delivery or for a number of deliveries over a maximum of 12 months. In 2016, the ESA U_3O_8 spot price was EUR 88.56/kgU (or USD 37.71/lb U_3O_8), 17 Euro cents lower than in 2015. Prices varied widely, 90 % falling within the range of EUR 82.04 to EUR 101.20/kgU (USD 34.93 to USD 43.09/lb U_3O_8).

The ESA long-term U_3O_8 price was EUR 86.62/kgU U_3O_8 (USD 36.88/lb U_3O_8). Long-term prices paid varied widely, with approximately 75 % (assuming a normal distribution) falling within the range of EUR 68.01 to EUR 111.82/kgU (USD 38.28 to USD 47.61/lb U_3O_8). Usually, long-term prices trade at a premium to spot prices as buyers are willing to pay a risk premium to lock in future prices. However, the ESA long-term U_3O_8 price is not forward-looking. It is based on historical prices contracted under multiannual contracts, which are either fixed or calculated based on formulae indexing mainly uranium spot prices. Spot prices are the most widely indexed prices in long-term contracts. On average, the multiannual contracts which led to deliveries in 2016 were signed 8 years earlier. The ESA long-term U_3O_8 price paid for uranium originating in the Commonwealth of Independent States (CIS - Russia, Kazakhstan and Uzbekistan) was 16 % lower than the price for uranium of non-CIS origin.

The ESA MAC-3 multiannual U_3O_8 price, published in 2009 for the first time, was EUR 87.11/kgU U_3O_8 (USD 37.09/lb U_3O_8). The data were spread across a wide range, with approximately 80 % of prices reported as falling between EUR 67.02 and EUR 105.58/kgU (USD 28.53 to USD 44.95/lb U_3O_8). The ESA MAC-3 index takes into account only long-term contracts signed recently (2014-2016) or older long-term contracts for which the uranium pricing method was amended during the same period, thus incorporating current market conditions and providing insights into the future of the nuclear market.

The ESA MAC-3 multiannual U_3O_8 price paid for uranium originating in CIS countries was 9 % lower than the price for uranium of non-CIS origin.

Figures 6a and 6b show the ESA average prices for natural uranium since 2007. The corresponding data are presented in Annex 3.

Figure 6a. Average prices for natural uranium delivered under spot and multiannual contracts, 2007-2016 (EUR/kgU)

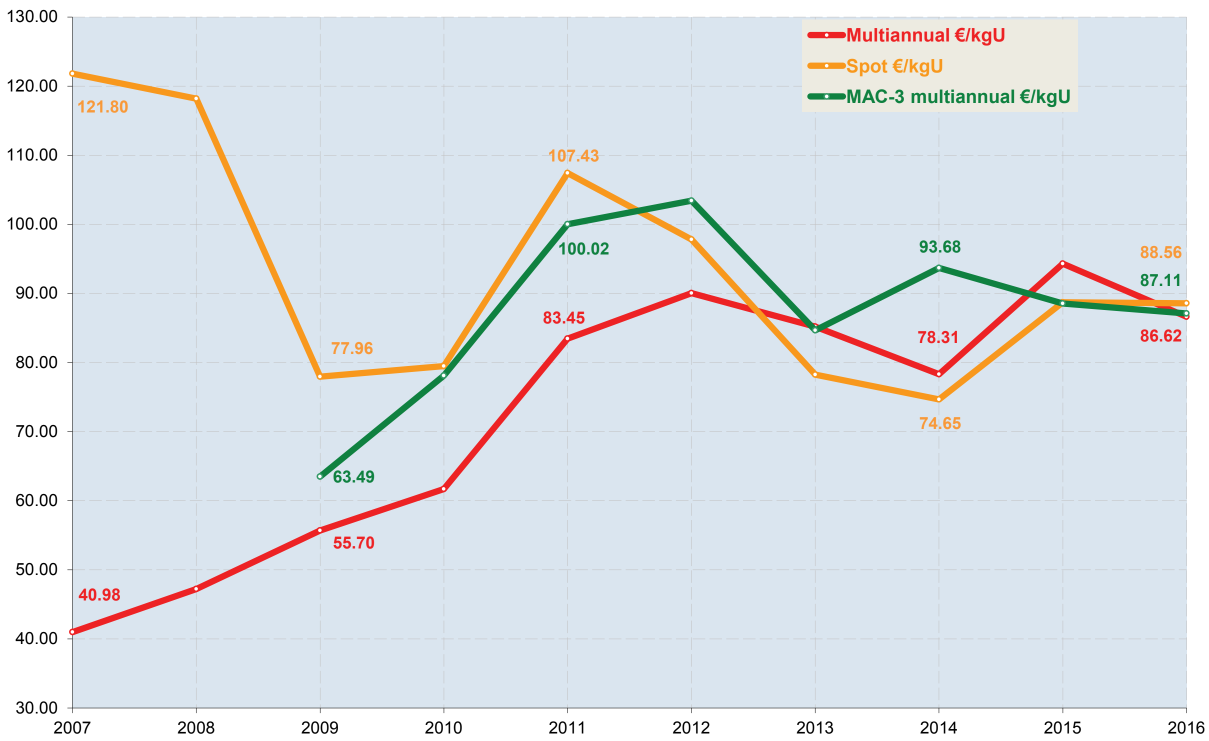
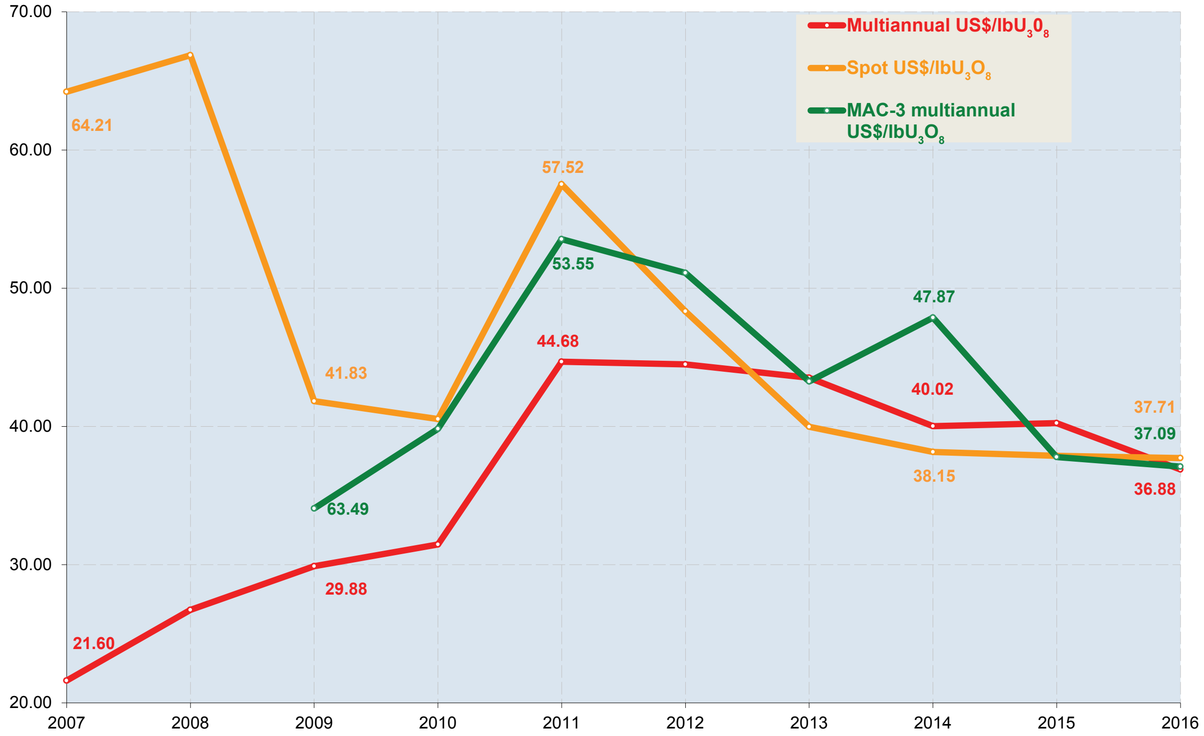


Figure 6b. **Average prices for natural uranium delivered under spot and multiannual contracts, 2007-2016 (USD/lb U_3O_8)**



Origins

In 2016, natural uranium supplies to the EU continued to come from diverse sources. In general, the origins of natural uranium supplied to EU utilities have remained unchanged since 2015.

Table 7. **Origins of uranium delivered to EU utilities in 2015 (in tonnes)**

Mining origin	Quantity (tU)	Share (%)	Change in quantities 2015/2014 (%)
Niger	3 152	22.0	45.2
Canada	2 946	20.6	58.8
Russia	2 765	19.3	4.4
Kazakhstan	2 261	15.8	-42.6
Australia	1 896	13.2	-4.9
Namibia	504	3.5	55.0
EU	220	1.5	-44.6
Re-enriched tails	212	1.5	-
Other	130	0.9	-56.5
United States	125	0.9	-78.7
Uzbekistan	115	0.8	-68.4
Total	14 325	100.0	-2.9

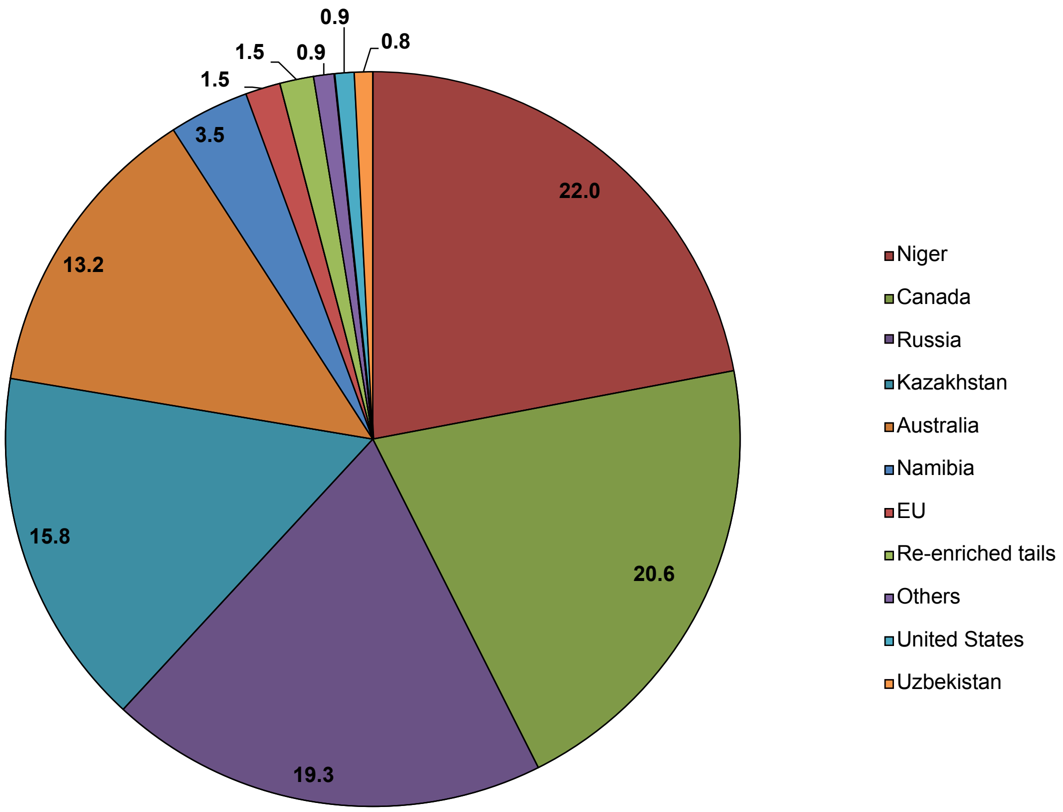
Niger and Canada were the top two countries delivering natural uranium to the EU in 2016, providing 42.6 % of the total, of which uranium originating in Niger represented 22 % and in Canada 20.6 % of total deliveries. In third place, uranium mined in Russia (including purchases of natural uranium contained in EUP) amounted to 19.3 %. Kazakhstan and Australia accounted for 15.8 % and 13.2 % in 2016 respectively. The five big producing countries together provided 91 % of the natural uranium delivered to the EU.

Natural uranium produced in CIS countries accounted for 5 353 tU, or 37.4 % of all natural uranium delivered to EU utilities, a 23 % decrease from the year before.

Deliveries of uranium from Africa increased by 38 %, up to 3 656 tU from 2 641 tU in 2015. Uranium mined in Africa originated in two countries, Niger and Namibia, with Niger representing 86 % of African-origin deliveries.

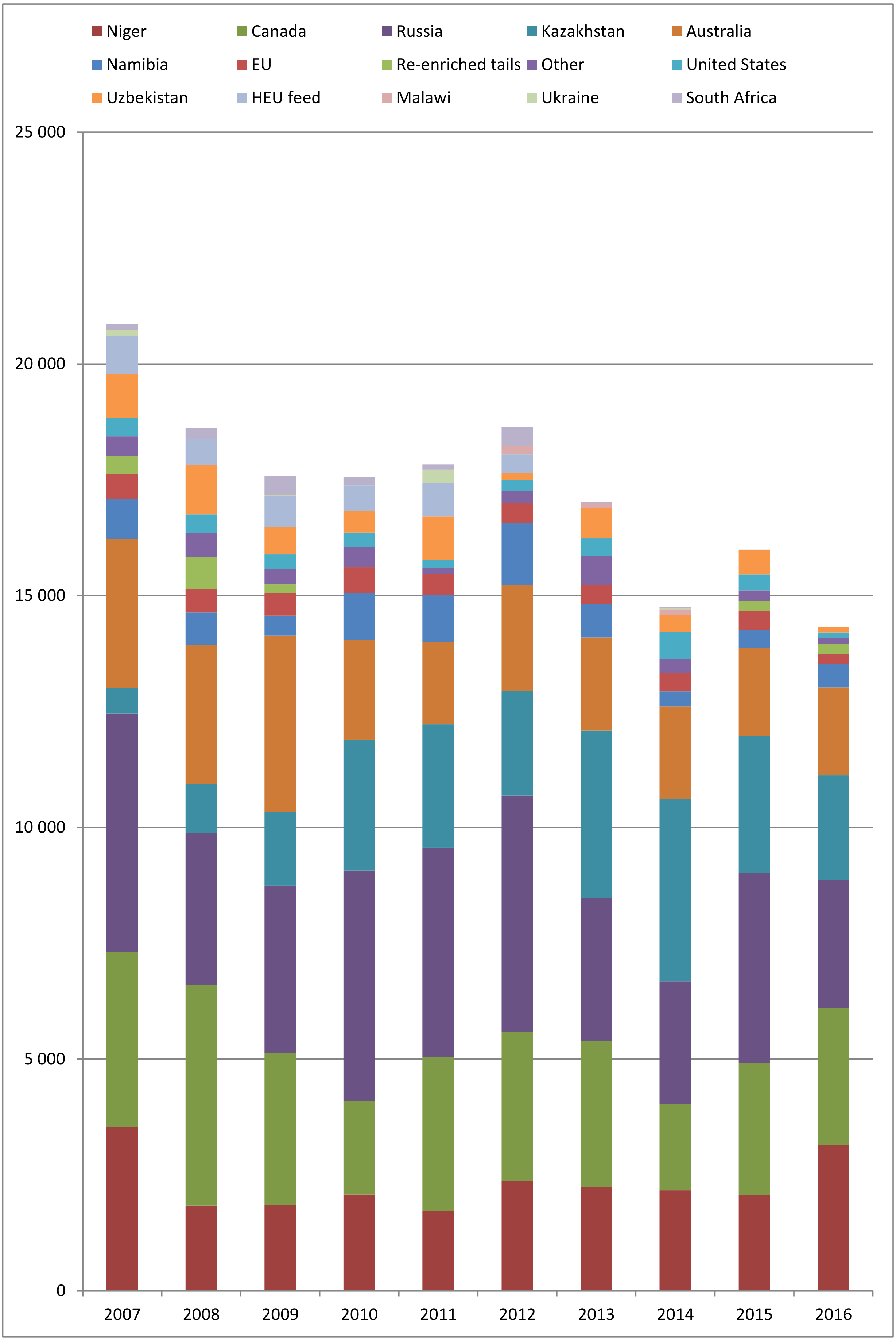
European uranium delivered to EU utilities originated in the Czech Republic covered approximately 1.5 % of the EU's total requirements (a total of 220 tU).

Figure 7. Origins of uranium delivered to EU utilities in 2016 (% share)



Totals may not add up due to rounding.

Figure 8. Purchases of natural uranium by EU utilities, by origin, 2007-2016 (tU)



Conversion services

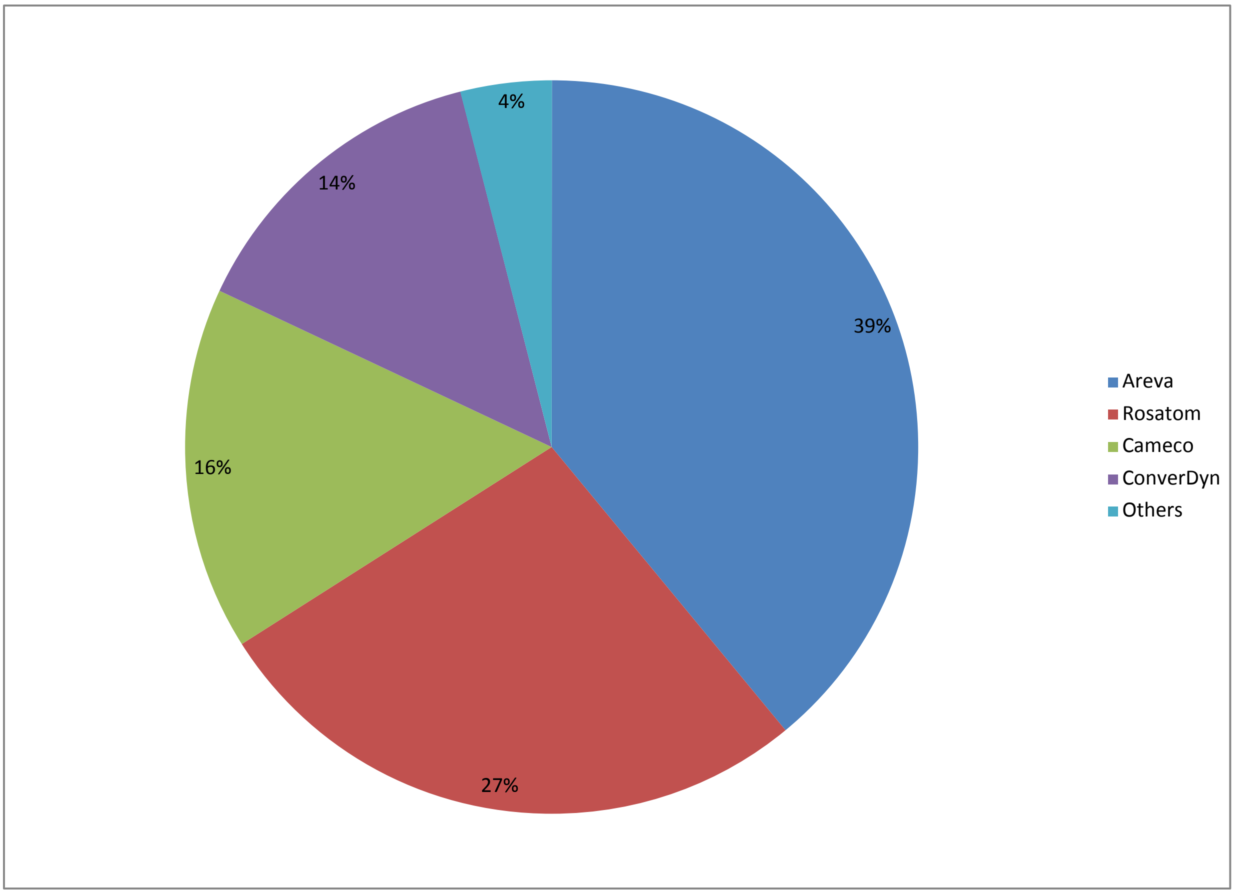
To ensure comprehensive market monitoring, ESA included for the first time conversion services in its Annual Report. In 2016, 9 152 tU were converted under separate conversion contracts, which accounted for 64 % of all conversion services deliveries to EU utilities. The remaining 36 %, or 5 117 tU, were delivered under contracts other than conversion contracts (purchases of natural UF6, EUP, bundled contracts for fuel assemblies). As regards the providers of conversion services, 39 % of EU requirements were delivered by AREVA / Comurhex, followed by Rosatom (27 %), Cameco (16 %) and ConverDyn (14 %).

Table 8. Supply of conversion services to EU utilities under separate conversion contracts

Converter	Quantity (tU)	%
Areva	**5 490**	**39**
Rosatom	**3 848**	**27**
Cameco	**2 265**	**16**
ConverDyn	**2 031**	**14**
Others	**636**	**4**
Total	**14 269**	**100**

Totals may not add up due to rounding.

Figure 9. Supply of conversion services to EU utilities by provider, 2016 (% share)



Special fissile materials

Conclusion of contracts

Table 9 shows the aggregate number of contracts, notifications and amendments ([35]) relating to special fissile materials (enrichment services, enriched uranium and plutonium) handled in 2015 and 2016 in accordance with ESA's procedures.

Deliveries of low-enriched uranium

In 2016, the enrichment services (separative work) supplied to EU utilities totalled 10 775 tSW, delivered in 1 724 tonnes of low-enriched uranium (tLEU) which contained the equivalent of 13 481 tonnes of natural uranium feed. In 2016, enrichment service deliveries to EU utilities decreased by 16 % as compared with 2015, with NPP operators opting for an average enrichment assay of 4.09 % and an average tails assay of 0.24 %.

Table 9. Special fissile material contracts concluded by or notified to ESA

Type of contract	Number of contracts concluded/notifications acknowledged in 2016	Number of contracts concluded/notifications acknowledged in 2015
A. Special fissile materials		
New contracts	41	33
Purchase (by an EU utility/user)	15	7
Sale (by an EU utility/user)	5	7
Purchase/sale (between two EU utilities/end users)	3	4
Purchase/sale (intermediaries)	14	7
Exchanges	4	6
Loans	0	2
Contract amendments	19	23
Total (1)	60	56
B. Enrichment notifications (2)		
New notifications	11	17
Notifications of amendments	20	12
Total	31	29

(1) In addition, there were transactions for small quantities (as under Article 74 of the Euratom Treaty) which are not included here.

(2) Contracts with primary enrichers only.

Table 10. Providers of enrichment services delivered to EU utilities

Enricher	Quantities in 2016 (tSW)	Share in 2016 (%)	Quantities in 2015 (tSW)	Share in 2015 (%)	Change in quantities 2016/2015 (%)
AREVA/GBII and Urenco (EU)	7 579	70	7 538	60	1
Tenex/TVEL (Russia)	2 966	28	4 145	33	-28
Russian blended (1)	119	1	610	5	-80
USEC(United States)	110	1	200	2	-45
Total (2)	10 775	100	12 493	100	-16

(1) Including enriched reprocessed uranium.

(2) Totals may not add up due to rounding.

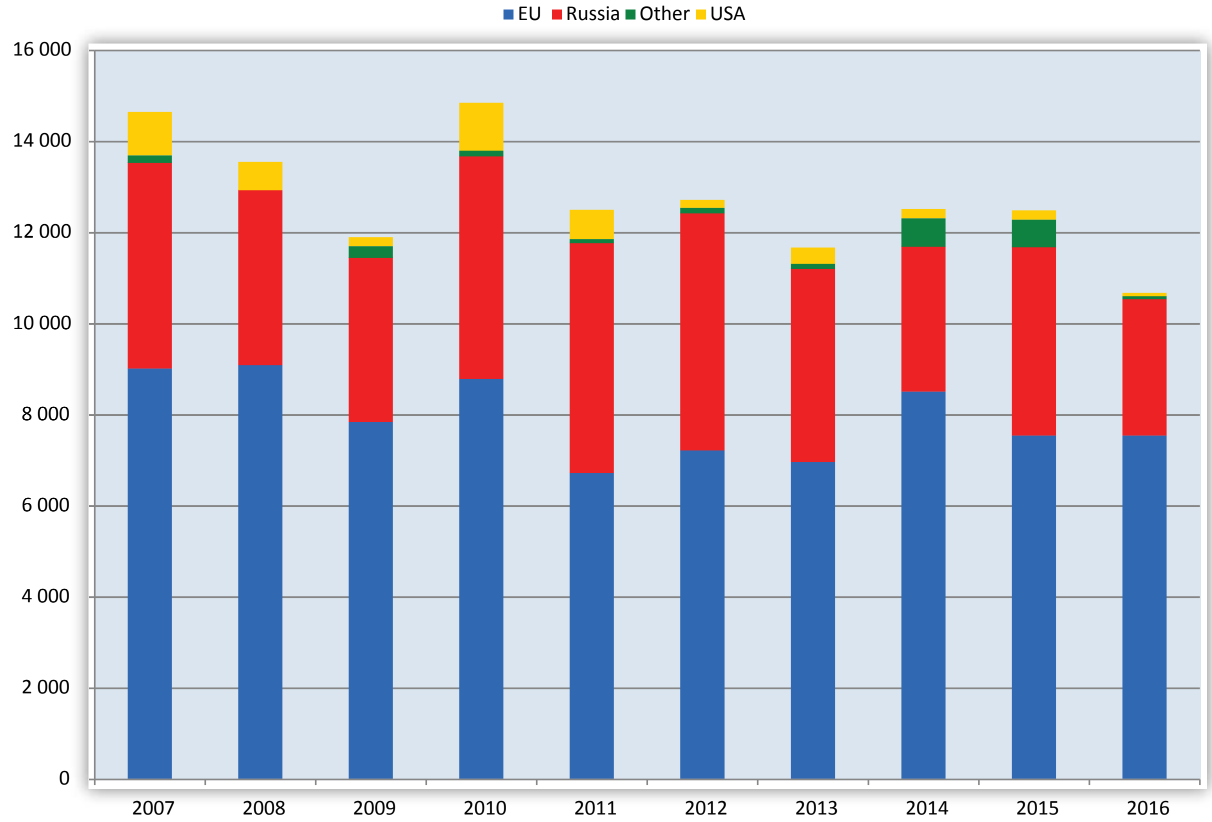
([35]) The aggregate number of amendments includes all the amendments to existing contracts processed by ESA, including technical amendments that do not necessarily lead to substantial changes in the terms of existing agreements.

As regards the providers of enrichment services, 70 % of EU requirements were met by the two European enrichers (AREVA-GBII and Urenco), totalling 7 579 tSW, an increase of 1 percentage point in year-on-year comparison.

Deliveries of separative work from Russia (Tenex and TVEL) to EU utilities under purchasing contracts totalled 2 966 tSW, which accounts for 28 % of total deliveries, a 28 % decrease from the year before. The aggregate total includes SWUs delivered under contracts concluded before accession to the EU ('grandfathered' under Article 105 of the Euratom Treaty), and covered 5.6 % of total EU requirements. Russian enrichment services delivered under other contracts accounted for 22.4 % of total requirements.

Enrichment services provided by USEC decreased by 45 % compared with 2015, totalling 119 tSW and accounting for 1 % of total enrichment services supplied to EU utilities.

Figure 10. Supply of enrichment to EU utilities by provider, 2007-2016 (tSW)



Plutonium and MOX fuel

MOX fuel is produced by mixing uranium and plutonium recovered from spent fuel. Use of MOX fuel has an impact on reactor performance and safety requirements. Reactors have to be adapted for this kind of fuel and must obtain a special licence before using it. MOX fuel behaves similarly (though not identically) to the enriched uranium-based fuel used in most reactors. The main reasons for using MOX fuel are the possibility of using plutonium recovered from spent fuel, non-proliferation concerns, and economic considerations. It is widely recognised that reprocessing spent fuel and recycling recovered plutonium together with uranium in MOX fuel increase the availability of nuclear material, replace enrichment services, and contribute to the security of supply. The quantity of MOX fuel loaded into NPPs in the EU totalled 9 012 kg Pu in 2016, a 16 % decrease over the 10 780 kg Pu used in 2015.

Inventories

At the end of 2016, uranium inventories owned by EU utilities totalled 51 513 tU, a decrease of 1 % from the end of 2015 and an increase of 9 % compared to the level at the end of 2011. The inventories represent uranium at different stages of the nuclear fuel cycle (natural uranium, in-process for conversion, enrichment or fuel fabrication), stored at EU or other nuclear facilities.

Figure 11. Total uranium inventories owned by EU utilities at the end of the year, 2011-2016 (in tonnes)

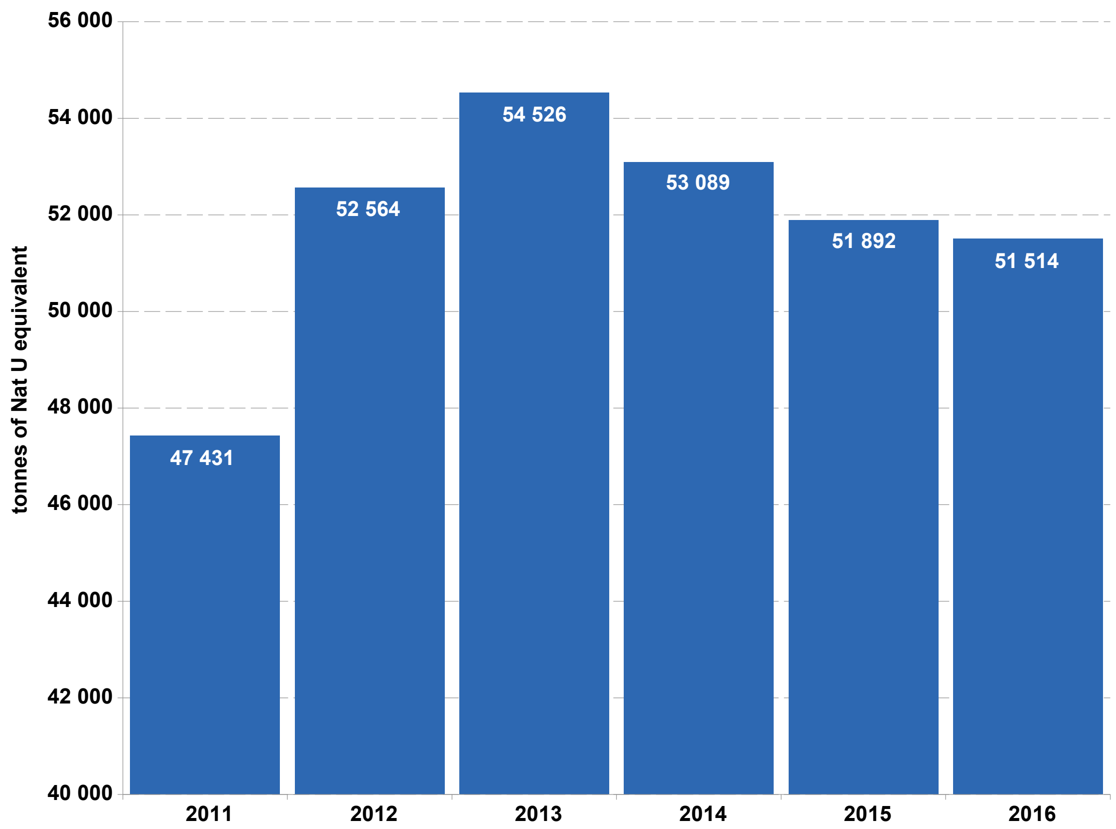


Figure 11 shows the level of total uranium inventories owned by EU utilities at the end of the year, expressed as natural uranium equivalents.

The changes of the aggregate natural uranium inventories do not necessarily reflect the difference between the total natural uranium equivalent loaded into reactors and uranium delivered to EU utilities, as the level of inventories is subject to movements of loaned material, sales of uranium to third parties and one-off national transfers of material.

Based on average annual EU gross uranium reactor requirements (approximately 16 000 tU per year), uranium inventories can fuel EU utilities' nuclear power reactors for 3 years on average. However, the average conceals a wide range, although most utilities keep a sufficient quantity of inventories for at least one reload.

Future contractual coverage rate

EU utilities' aggregate contractual coverage rate for a given year is calculated by dividing the maximum contracted deliveries in that year — under already-signed contracts — by the utilities' estimated future net reactor requirements in the same year. The result is expressed as a percentage. Figure 11 shows the contractual coverage rate for natural uranium and SWUs, and figure 12 shows the contractual coverage rate for conversion services for EU utilities.

$$\text{Contractual coverage rate of year X} = 100 \text{ X } \frac{\text{Maximum contracted deliveries in the year X}}{\text{Net reactor requirements in the year X}}$$

As regards net reactor requirements (the denominator), a distinction is made between demand for natural uranium and demand for enrichment services. Average net reactor requirements for 2017-2026 are 14 300 tU and 12 000 tSW per year, respectively (see table on page 25). ESA assumes the same quantity of requirements for conversion services as for the natural uranium. A distinction is made between demand for conversion services covered under separate conversion contracts and other contracts which include deliveries of natural UF6, EUP or bundled contracts for fuel assemblies.

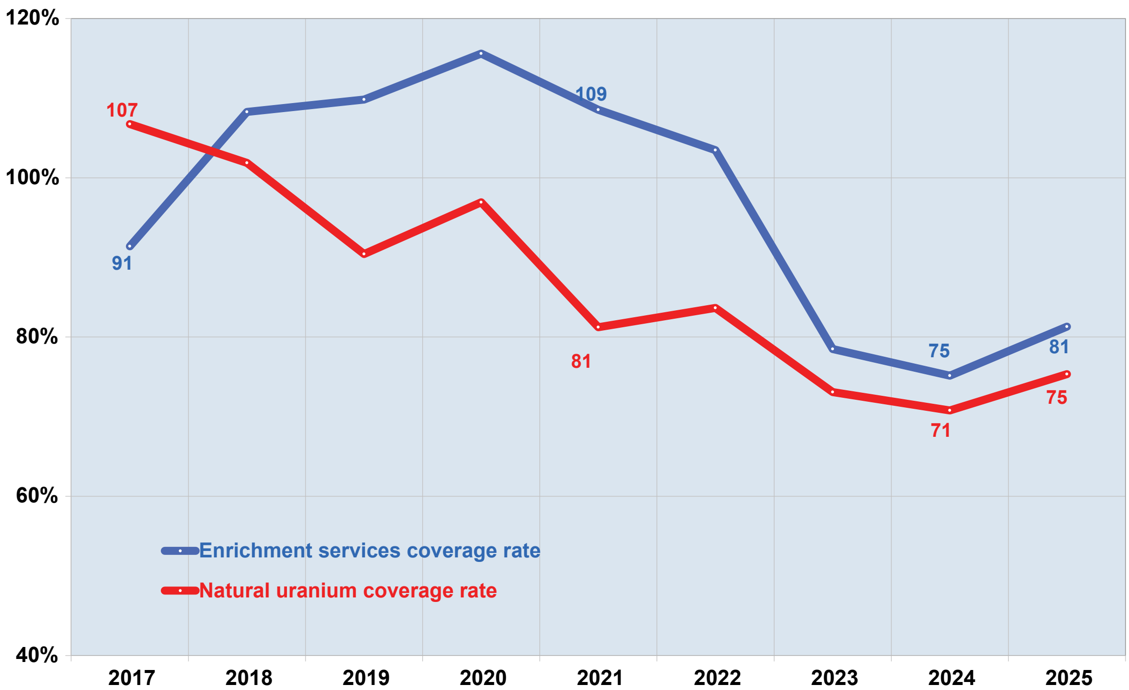
Quantitative analysis shows that EU utilities are covered well above their estimated net reactor requirements (90 % and more) until 2020, in terms of both natural uranium and enrichment services, under existing contracts.

For natural uranium, supply is well secured during 2017-2020 with a contractual coverage rate of over 100 % in 2017 and 2018 and slightly under 100 % in 2019 and 2020. In the long term, the uranium coverage rate will remain above 70 % until 2025.

Enrichment service supply is well secured until 2022, with contractual coverage ranging from 91 % in 2017 to 116 % in 2020, staying above 100 % from 2018 until 2022 and above 70 % from 2023 until the end of the analysed period in 2025.

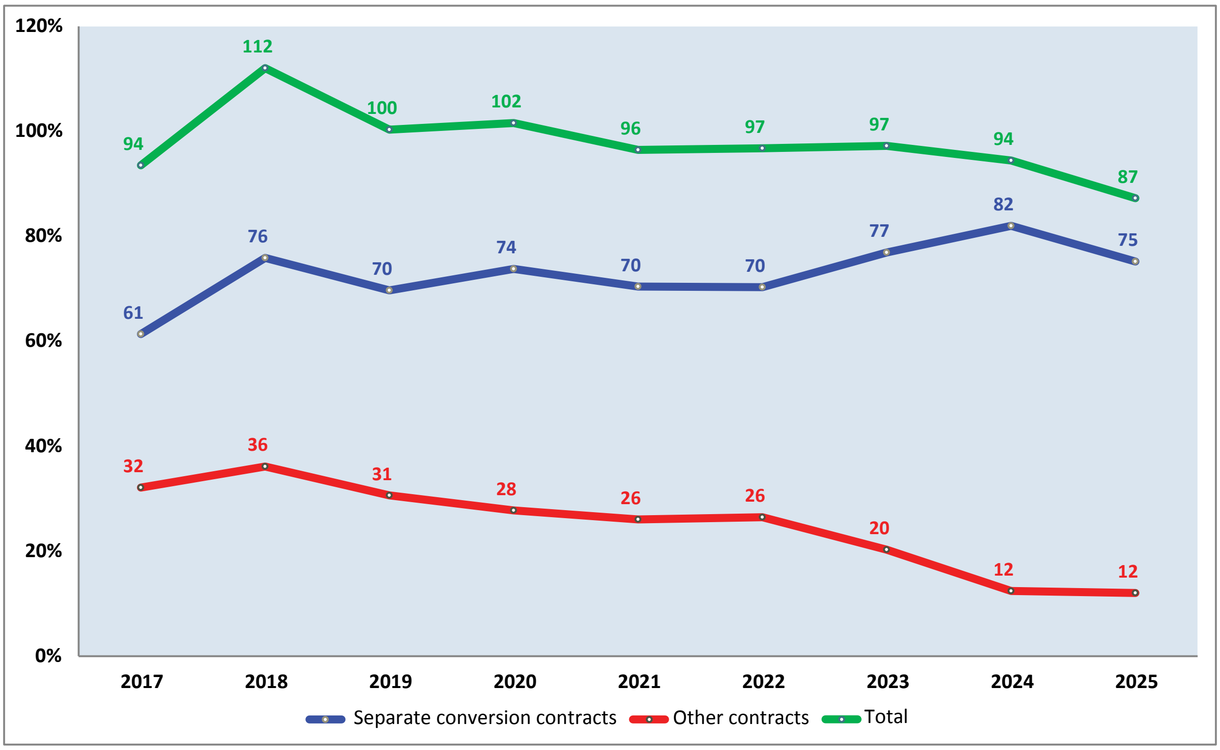
In general, EU utilities' reactor requirements for both natural uranium and enrichment services are sufficiently covered in the short and medium term.

Figure 12. Coverage rate for natural uranium and enrichment services, 2017-2025 (%)



Quantitative analysis of conversion services shows that EU utilities are covered between 93 % and 112 % of their net reactor requirements until 2020 under existing contracts. Supply is well secured during the whole analysed period with a contractual coverage rate accounting for almost 90 % until 2025.

Figure 13. Coverage rate for conversion services, 2017-2025 (%)



ESA findings, recommendations and diversification policy

Each year ESA continues to monitor the market for nuclear fuel to ensure that EU utilities have diverse sources of supply and do not become over-dependent on any single source. It does this by exercising its right to sign contracts and by compiling comprehensive statistical reports on trends in the nuclear market. One key goal for long-term security of supply is to maintain the viability of the EU industry at every stage of the fuel cycle.

ESA recommends that utilities cover most of their current and future requirements under long-term contracts from diverse sources of supply. In line with this recommendation, deliveries of natural uranium to the EU under long-term contracts accounted for 97 % of total deliveries in 2016. As regards mining origin, the relative shares of individual producer countries changed in comparison with the previous year, with Niger, Canada, Russia, Kazakhstan and Australia together providing 91 % of the natural uranium delivered to the EU. In 2016, deliveries of uranium from Africa and North America increased by 38 % and 26 % respectively. Instead deliveries of uranium from the CIS and Australia were down 23 % and 5 % respectively, while EU-origin deliveries dropped by 45 % compared with the previous year. Overall the deliveries of natural uranium to EU utilities are well diversified, but there are a number of utilities buying their natural uranium from only one supplier.

On the diversification of sources of supply of enriched uranium to EU utilities, 70 % of the SWUs delivered in 2016 were provided by the two European enrichment companies, AREVA-GBII and Urenco. The remaining services were delivered mostly by Russia's Tenex/TVEL (28 %), and by the American company USEC (1 %), which currently operates as an intermediary after its reorganisation in 2013.

In 2016, deliveries of enrichment services decreased by 16 %. However, the two European enrichers increased their relative share in the EU market as deliveries of enrichment services provided by them remained almost at the same level as in the previous year. Out of the 28 % of SWUs of Russian-origin, contracts 'grandfathered' under Article 105 of the Euratom Treaty accounted for 5.6 % of total deliveries. In practice, due to their 'grandfathered' contracts, certain EU utilities are still dependent on a single external external supplier ([36]).

ESA welcomes the use of reprocessed uranium, either by blending it with HEU to produce power reactor-grade fuel or by having it re-enriched, on the basis that such practices increase security of supply. Furthermore, blending reprocessed uranium with HEU of military origin is conducive to nuclear

([36]) he significant differences in supply patterns and, therefore, in the diversification of sources of supply are due to the fact that utilities with western technology traditionally obtain uranium and services (e.g. enrichment) under separate contracts from diverse sources. On the other hand, utilities using Russian technology usually purchase fabricated fuel assemblies from a single supplier under the same contract (including supply of uranium and enrichment).

disarmament and the non-proliferation of nuclear materials. ESA therefore takes account of these positive aspects of reprocessed fuel use when implementing its diversification policy. HEU blended with reprocessed uranium and re-enriched reprocessed uranium fuel accounted for the equivalent of approximately 1 % of the total enrichment services delivered in 2016. This was lower than in the previous year, when it amounted to 5 % of total enrichment services delivered.

ESA also recommends that EU utilities maintain adequate strategic inventories and use market opportunities to increase their stocks, depending on their individual circumstances. The aggregate stock level at the end of 2016 totalled 51 513 tU, which could fuel EU utilities' nuclear power reactors, on average, for 3 years. However, the average conceals a wide range, and some utilities would be wise to consider increasing their stocks.

On the supply side, ESA monitors the situation of EU producers which export nuclear material mined in the EU, as it has option rights over such material under Article 52 of the Euratom Treaty. Where the material is exported from the EU under long-term contracts, ESA may require the contracting parties to accept certain conditions relating to the security of supply on the EU market.

Following an analysis of the information gathered from EU utilities in the annual survey at the end of 2016, ESA concludes that, in the short and medium term, the needs of EU utilities for both natural uranium and enrichment services are well covered. However, the 100 % reliance on one single supplier for VVER fuel fabrication remains a matter of concern.

4. Security of supply

Introduction

Six years after the Fukushima Daiichi accident, the nuclear industry has not recovered. Most of the Japanese reactors remain closed, and some other countries continue to pursue phase-out policies or plan to reduce the share of nuclear energy. In the longer term, significant growth in global nuclear energy generation is still expected, in particular in Asia. But for the time being all segments of the nuclear fuel market remain over-supplied, and during 2016 spot prices for uranium reached their lowest point in more than a decade. Suppliers are taking measures to reduce output and are hoping for a recovery, which is constantly delayed.

In these circumstances some utilities may consider that security of supply is not an issue, at least not for the foreseeable future. In some cases, in particular for countries phasing out nuclear energy, the focus has turned to managing existing stocks. However, for those with a longer term perspective, and in particular companies and countries planning to build new reactors, security of supply should be of utmost importance, regardless of current market conditions. As a new reactor is expected to operate for 60 years, and many of the existing ones are seeking extensions of 10 or 20 years, it would be unrealistic to expect the market to remain over-supplied for such long periods.

Security of supply and ESA's diversification policy

For NPP operators, the main issue after nuclear safety is to ensure the continuous availability of fuel and the prevention of supply disruptions. Since nuclear energy still provides close to 30 % of the EU's electricity, and in France, Hungary and Slovakia more than 50 %, securing its supply is very important. Diversification is a key pillar of security of supply, for nuclear as well as for other energy sources.

ESA continues to monitor the market to ensure that EU utilities have diverse supply sources and do not become over-dependent on any single external source, as this could jeopardise the security of supply in the medium and long term. It does this by exercising its right to sign contracts and by compiling comprehensive statistical reports on trends on the nuclear market. One key goal for long-term security of supply is to maintain the viability of the EU industry at every stage of the fuel cycle.

In addition to the overall EU dependence level, it is important to note that some individual EU utilities remain 100 % dependent on one external supplier. In such cases, the overall risk for a stable electricity supply needs to be evaluated, taking into account a number of factors: the share of nuclear in the energy mix of the Member State in which the utility is located, possible reserve capacities, the Member State's potential electricity exports to neighbouring Member States, and its capacity to import electricity in case of need.

In its market-monitoring role, ESA is responsible for the early identification of market trends likely to affect the medium- and long-term security of supply of nuclear materials and services in the EU, both at aggregate EU level and for individual utilities.

ESA must make use of its powers under Chapter 6 of the Treaty if:

- the situation in the market suddenly deteriorates and requires a quick reaction (in particular, if external dependence increases significantly in a short period of time or if imports risk distorting competition within the EU internal market);
- a user fails to diversify their supply sources or to implement remedial measures.

Supply side — assessment of the global situation

Natural uranium production has increased in recent years, and although primary production does not cover worldwide reactor requirements, there is clear over-supply on the market because of other sources such as HEU down blending, RepU and Pu use in MOX fuel, underfeeding, tails re-enrichment and inventory draw-down. In 2016 and early 2017, some reductions of current production were announced by several primary producers, but these reductions remain modest. Many major producers are government-controlled entities which are not guided only by financial considerations.

At some stage, global uranium production will need to increase to meet demand from Asia and other emerging nuclear countries. The industry is likely to meet this challenge. According to the latest NEA-IAEA Red Book ([37]), identified global uranium resources are sufficient to cover current demand for at least 135 years, and many so far unexplored areas of the world may hold very significant additional resources.

In the short term, further production cuts appear necessary to support prices and guarantee that exploration and future mine development work can continue in view of the next upcycle. For the time being, plentiful inventories of uranium in the EU, Japan and China provide a buffer against an increase in prices similar to what occurred in 2005-2007.

All front-end fuel cycle services — conversion, enrichment and fuel fabrication — continue to suffer from world-wide over-capacity and low prices which are starting to put increasing pressure on the financial situation of many producers. As there are only a few players in each of these segments, all of them are needed to ensure long-term security of supply and a minimum of competition.

In particular for conversion, utilities may be well advised to consider sharing the risk and some of the costs with converters, for the economic sustainability of the smallest but important step in the fuel chain.

For enrichment, the current global commercial nameplate capacity of over 59 000 tSW is more than sufficient to cover demand at least until 2020.

Although there is currently over-capacity for conversion and enrichment services, the closure of one of the few conversion facilities for economic reasons could quickly change the situation and create a bottleneck in the supply chain. Also, the capacity of the industry to invest in the future is seriously hampered by the current market environment.

The existing fuel fabrication capacity, ensured by several reliable PWR/BWR/CANDU-type fuel fabricators, is considered more than sufficient to meet current demand, including projected first core loads, well into the 2020s. However, with regard to VVER-type reactors, very limited competition in this market segment raises concerns for security of supply.

Transport remains an issue which could lead to a short-term supply disruption. Cross-border transport of radioactive materials has become increasingly complex and time-consuming due to the different approaches of national regulators, port authorities and shipping companies. The main effects are interruption of and delays to consignments and, in extreme cases, shipment denials. Therefore, many companies are trying to develop alternative shipping routes or adopt different means of shipment for specific deliveries. In addition to a diversified supply chain, strategic inventories of nuclear materials or even ready-made fuel assemblies is the best defence against delays caused by transport.

Supply side — assessment of the EU situation

On the supply side, EU industry is active in all areas of the nuclear fuel supply chain. While uranium production in the EU is limited, there are signs of possible new production, in particular in Spain. EU-based industry is active in mining operations in several major producer countries. Resources of natural uranium located in different Member States could be considered a potential source of supply, at least from a long-term perspective.

In addition, in case of significantly higher prices and scarcity of uranium, there is considerable potential for increasing the use of RepU and plutonium in the EU. As an additional reserve, significant quantities of depleted uranium are stockpiled in the EU and could either be re-enriched or used together with plutonium as MOX fuel. Currently, 10 % of the nuclear material used in fuel loaded into EU reactors comes from indigenous sources in various forms (see Table 5).

For other parts of the fuel cycle (conversion, enrichment, fuel fabrication and spent fuel reprocessing), EU industry can cover most or all of the EU utilities' needs. It would be possible to expand capacity based on demand, usually faster than it is to build new reactors, which gives a certain reassurance on supply security. The main challenge is to ensure the EU industry's continued viability so that the current industrial capacity and technological level are at least maintained and do not diminish as a result of short-term economic considerations.

The capacity to produce fuel and components for VVER reactors in the EU is an important aspect which still needs attention. Production capacity has been re-established for VVER-1000 fuel produced in Sweden and used in Ukraine, and consideration is being given to re-establishing such capacity also for VVER-440 fuel manufacturing in the EU, as indicated in Chapter 2.

([37]) Uranium 2016: Resources, Production and Demand, https://www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf.

Demand side — assessment of the EU situation

Demand for nuclear materials and services in the EU is decreasing for the time being (see Chapter 3 for details). However, these current estimates provided by utilities are conservative and based on firm current commitments. Therefore, they do not include potential new NPPs which are being planned but not yet in construction. Several NPPs are in the planning stages in Finland, Hungary, Romania and the UK, but those are not yet included in the estimated requirements.

For the moment, the EU is still the biggest regional nuclear fuel market in the world and remains an attractive business base for many intermediary companies, which in turn add liquidity to the market and contribute to the maintenance of physical stocks of uranium within EU-based facilities.

Natural uranium supplies to the EU are well diversified (see Table 7 in Chapter 3). Furthermore, a number of key supplier countries are politically stable and have cooperation agreements with the EU. The situation does not raise shortage concerns in the medium term.

For conversion and enrichment services, the main three or four suppliers in the world are also well represented as suppliers to EU utilities. As long as all of them are in operation, there should be no shortage of supply of these services. However, a prolonged closure of any of these facilities could create problems, including for EU customers.

For fuel fabrication, the situation is different since fuel assemblies are reactor specific and dependent on reactor design. While operators with western-design reactors usually have the choice between two or even three different fuel fabricators, four EU countries, namely Bulgaria, the Czech Republic, Hungary and Slovakia, operating exclusively VVER reactors, are currently 100 % dependent on Russian suppliers of fuel assemblies. Additionally, two out of the four operating reactors in Finland are of the VVER-type, which represents 36 % of the country's nuclear electricity production. The dependence on one single supplier constitutes a significant risk, since qualifying an alternative supplier could take several years due to licensing and testing requirements.

Future contractual coverage rate

As detailed in Chapter 3, and taking into account EU utilities' contractual coverage for the coming years and their inventories, EU reactor requirements for both natural uranium and enrichment services are sufficiently covered in the short and medium term.

Inventories

Most EU utilities have inventories to cover 1 or 2 years of operation, in different forms (natural or enriched uranium, fabricated fuel assemblies). Some utilities are covered for more than 4 years, others only for a few months. In the current situation, the most vulnerable utilities in terms of security of supply remain those that depend on Russian fabricated fuel assemblies (VVER reactors), which cannot be quickly replaced by fuel assemblies from other manufacturers.

Compared to the previous year, the global level of inventories in the EU decreased slightly in 2016 as utilities have been adjusting downwards their uranium deliveries under contract flexibilities, or in some cases even selling what may previously have been excessive inventories.

The process of building up inventories of different chemical forms of nuclear material, and their appropriate level, should take into account the lead times for various steps of the fuel cycle. One possible guideline is that the inventory level should cover at least the lead time for a reload, i.e. 18 months of operation in the case of an 18-month reloading cycle.

Sustainability of supply

This year, ESA wishes to highlight the issue of sustainability of uranium production, both in terms of environmental and social responsibility. An increasing number of EU utilities are including in their purchase contracts clauses on sustainability, and some are following up with audits to check that these clauses are being observed.

As nuclear energy generation often comes under criticism, it is very important for all parts of the industry to take sustainability seriously. It is important not only for the overall acceptability of nuclear energy but also for creating a level playing field and for ensuring resource availability in the future. In order to develop new mines, which will be needed to fuel reactors in the coming decades, it is essential to demonstrate that uranium is produced in a sustainable manner.

The EU, through its Instrument for Nuclear Safety Cooperation ([38]), has in recent years financed remediation activities at uranium mining legacy sites in Central Asia. For new mining projects anywhere in the world, it is necessary to ensure that remediation is planned and sufficient financial provisions for this are made already before production starts. While this is nowadays standard practice in most producer countries, emerging producers should not neglect this aspect, which can have a critical impact on the reputation of the whole industry.

ESA findings and recommendations

Following thorough analysis of the information gathered from EU utilities at the end of 2016 (as discussed in Chapter 3), in the short and medium term, the needs of EU utilities for both

([38]) Council Regulation (Euratom) No 237/2014 establishing a new Instrument for Nuclear Safety Cooperation, OJ L 77, 15.3.2014, p. 109-116.

natural uranium and enrichment services remain well covered on average. In the case of natural uranium, some EU utilities are even over covered and may look into reducing their inventories further, although this is mostly driven by financial considerations and may not be the best strategy should uranium prices increase substantially after 2020.

In general, ESA recommends that utilities cover most of their current and future requirements for natural uranium and fuel cycle services under long-term contracts (6 to 10 years) from diverse sources of supply. ESA also notes that intermediaries and low interest rates have changed the nature of the mid-term market, with deliveries in 2 to 5 years. In addition to intermediaries, underfeeding by enrichers has become a substantial source of natural uranium sold in the market. Both these phenomena are putting pressure on traditional long-term contracting with primary producers and are contributing to the low prices, which could jeopardise investments in new primary production in the longer term.

ESA continues to recommend that EU utilities maintain adequate strategic inventories of nuclear materials and use market opportunities to increase their stocks, depending on their individual circumstances. In order to forestall risks of shortages in the nuclear fuel supply chain, appropriate inventory levels should be maintained, not only by EU utilities but also by producers.

As regards fuel fabrication, there has been no change in the 100 % reliance on one single supplier of VVER reactors in the EU, which is against the EU's security of supply policy (see Figure 14). Currently the only VVER operator having two different suppliers of fuel fabrication services is the Ukrainian operator Energoatom. In contrast, most European operators have two and some even three different fabricators.

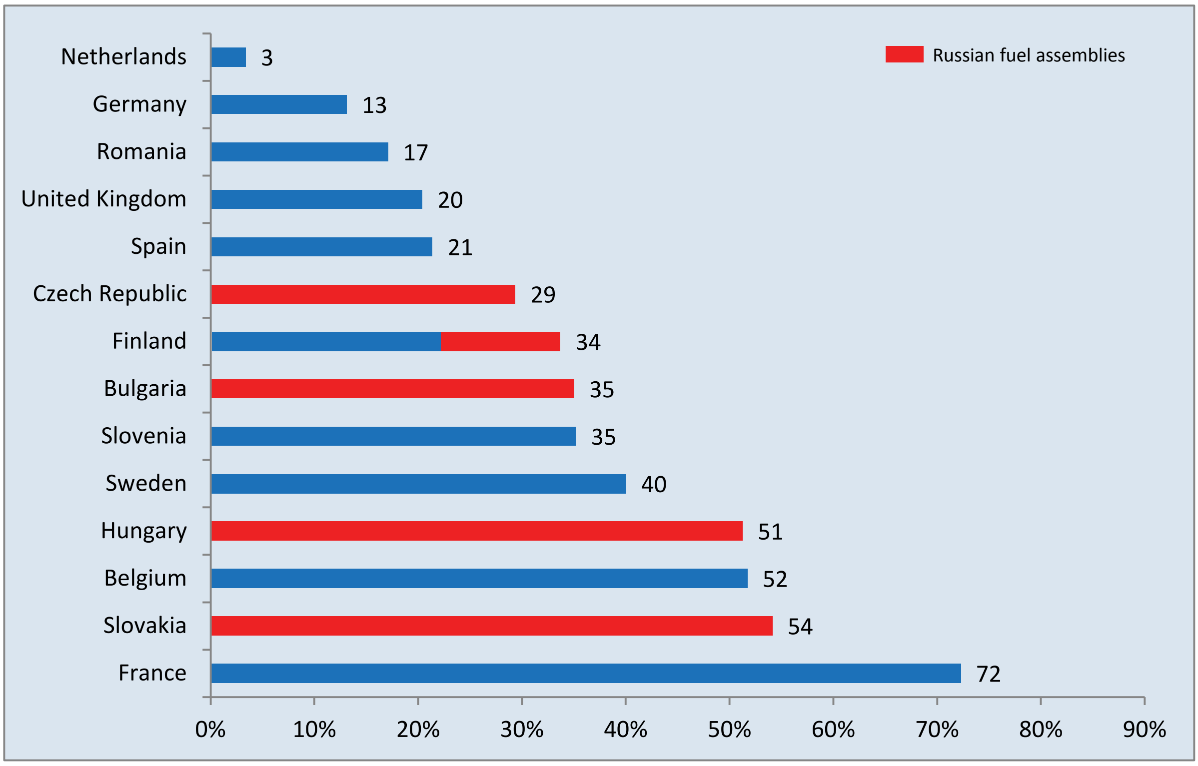
From a security-of-supply point of view, there should always be at least two alternative suppliers for each stage of the fuel cycle. The second best option is to have a diversified portfolio up to the fabrication stage and maintain a strategic stock of fabricated fuel. Ideally, all utilities should hold one or two reloads of fabricated fuel assemblies for each reactor, depending on the size of their reactor fleet and other electricity generation assets.

Operators should ensure that fuel supply diversification is possible for their reactors at all stages of the fuel cycle. Contracts for bundled sales of fuel assemblies (i.e. including nuclear material, conversion, enrichment and fuel fabrication) must allow the operator to provide natural or enriched uranium from an alternative supplier. In particular for new reactors, the contract must enable the use of fuel assemblies produced by different fabricators by providing for the disclosure of fuel compatibility data and for the testing of alternative fuel assemblies.

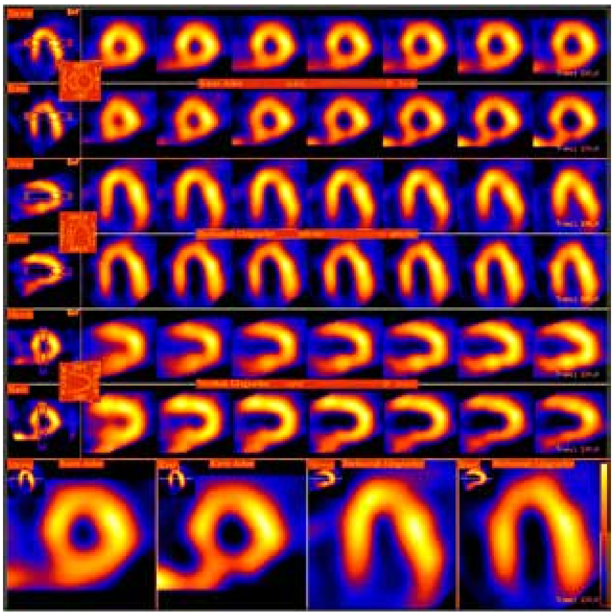
If an alternative fuel fabricator is not yet available, operators should establish contacts with potential fabricators interested in developing the required fuel. Both operators and national regulators of countries operating VVER reactors could benefit from mutual cooperation in the development, testing and licensing of alternative fuel.

Although the above ESA recommendations are targeted mainly at utilities, it is clear that for long-term security of supply, EU producers should also maintain a skilled workforce, further develop their technology and continue to invest in their production facilities to the extent possible under the prevailing market conditions.

Figure 14. Nuclear power share of total electricity production in the EU, 2016 (%)



5. Supply of medical radioisotopes



Radioisotopes are used in medicine for the diagnosis and treatment of various diseases, including some of the most important ones, like cancers, or cardiovascular and brain diseases. Over 10 000 hospitals worldwide use radioisotopes for the *in vivo* diagnosis or treatment of about 30 million patients every year, including 7 million in Europe. The majority of today's nuclear medicine procedures are for diagnosis, with about 100 different imaging procedures available. Imaging using radioisotopes is often indispensable, for instance due to its ability to identify various disease processes early, long before other diagnostic tests. Technetium-99 m (Tc-99 m) is the most widely used (diagnostic) radioisotope. The production of Tc-99 m is a complex process which includes irradiation of uranium targets in nuclear research reactors to produce Molybdenum-99 (Mo-99), extraction of Mo-99 from targets in specialised processing facilities, production of Tc-99 m generators and shipment to hospitals. Due to their short decay times, Mo-99 and Tc-99 m cannot be stockpiled and must be produced continuously and delivered to hospitals weekly. Any supply disruption can have negative and sometimes life-threatening consequences for patients.

ESA involvement

In the light of the Council Conclusions 'Towards the secure supply of radioisotopes for medical use in the EU' dated 2010 ([39]) and 2012 ([40]), ESA's observatory role was widened in 2013 to cover aspects of the supply of medical radioisotopes in the EU.

In 2016, ESA continued to coordinate activities undertaken to improve the security of supply of Mo-99/Tc-99 m — the most vital medical radioisotope, and chaired the European Observatory on the supply of medical radioisotopes ([41]).

European Observatory on the supply of medical radioisotopes

The Observatory, set up in 2012, seeks to gather all relevant information to assist the decision-makers of the EU institutions and national governments in defining strategies, and the policies for their implementation. It is composed of representatives of the EU institutions and various industry stakeholders, most of which are grouped within the AIPES (Association of Imaging Producers and Equipment Suppliers) ([42]). The Observatory carries out its work in four working groups:

1 — Global reactor scheduling and Mo-99 supply monitoring;

2 — Full-cost recovery mechanisms;

3 — Management of HEU-LEU conversion and target production;

4 — Capacity and infrastructure development.

In 2016, the Observatory held two plenary meetings in Luxembourg, in April and in October.

([39]) http://ec.europa.eu/euratom/docs/118234.pdf .
([40]) http://ec.europa.eu/euratom/docs/2012_council_radioisotopes.pdf.
([41]) http://ec.europa.eu/euratom/observatory_radioisotopes.html.
([42]) http://www.aipes-eeig.org .

Working Group 1 — Global reactor scheduling and Mo-99 supply monitoring

Working Group 1 (WG1), with its core member AIPES, ensures effective coordination of reactor schedules to avoid and mitigate Mo-99 supply disruptions. The continuous week-by-week follow-up by AIPES makes it possible to identify potential Mo-99 shortages and to define mitigation action plans involving all stakeholders. As a result, there were no significant supply disruptions in 2016 despite it being a rather challenging year in terms of supply. Such challenges included the extended shutdown of the BR2 reactor in Belgium for the replacement of its beryllium matrix (February 2015 to June 2016), the definitive shutdown of the OSIRIS reactor in France (December 2015) and cessation of routine Mo-99 production at the NRU reactor in Canada (November 2016).

In order to deal with severe supply shortages, the WG1 has established two mechanisms: 1) an emergency response team (ERT), composed of representatives of research reactors, Mo-99 processors and Mo-99/Tc-99 m generator manufacturers, to be activated to monitor in detail Mo-99 production and to define all possible short-term mitigation actions, and, 2) a joint communication team (JCT) to promptly communicate with government representatives.

Working Group 2 — Full-cost recovery mechanisms

One of the key principles of the policy approach of the OECD/NEA High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) is that all Mo-99/Tc-99 m supply chain participants should implement full-cost recovery (FCR). This would provide the economic incentives to develop Mo-99 related infrastructure and to fully finance operating costs. FCR has to be achieved throughout the supply chain, and sufficient reimbursement should be made available to ensure sustainability of the Mo-99 supply. In a follow-up to the Agency's report to the European Commission on medical radioisotopes, published in 2015 ([43]), the Dutch Presidency of the Council of the European Union addressed in the first half of 2016 the security of supply of medical radioisotopes and FCR in a position paper submitted to the energy ministers at the Energy Council meeting of June 2016 ([44]). The Presidency was of the view that the underlying cause of previous supply disruptions was and still is the unsustainable economic structure of the medical radioisotopes production chain. To ensure a secure supply of medical radioisotopes in the medium and long term, a system of FCR must be implemented. In this context, the Presidency note suggested various measures that should be undertaken at EU level. This has resulted in a research project that will be carried out in 2017 by the European Commission (Directorate-General for Joint Research Centre). The study will, among other aspects, investigate the medical radioisotope reimbursement systems in the EU Member States. It should be noted that the Presidency also welcomed the European Commission's (Directorate-General for Energy) planned comprehensive review of the medical, industrial and research applications of nuclear and radiation technology (SAMIRA) ([45]). The review is to be presented in 2018 and will, among other aspects, address the long-term security of supply of medical radioisotopes.

Working Group 3 — Management of HEU-LEU conversion and target production

All countries currently producing radioisotopes have agreed to the principle of converting targets for Mo-99 production from HEU to LEU, implementing the work plan of the 2010 Washington Nuclear Security Summit.

At the beginning of its mandate, Working Group 3 (WG3) carried out a study of the risks that could occur during the HEU-LEU conversion of targets used for radioisotope production. The ensuing report determined potential mitigating actions and gave recommendations for the radiopharmaceutical industry and policy-makers ([46]).

As follow-up to these recommendations, WG3 liaised with the European Medicines Agency (EMA) ([47]) on the subject of regulatory approval of Mo-99.

Another important subject, relating to the recommendations given in the WG3 report, was the transport of the bulk raw Mo-99 and uranium targets used to produce Mo-99. The Observatory addressed a letter to the Association of Heads of the European Radiological Protection Competent Authorities (HERCA) ([48]) and the European Association of Competent Authorities for the Safe Transport of Radioactive Material

([43]) http://ec.europa.eu/euratom/docs/ESA-MEP-web_final%20 14.09.2015.pdf .

([44]) http://data.consilium.europa.eu/doc/document/ST-8403-2016-INIT/en/pdf .

([45]) https://ec.europa.eu/energy/en/news/commission-launches-call-tender-study-nuclear-and-radiation-technology .

([46]) http://ec.europa.eu/euratom/docs/WG3 %20report.pdf .

([47]) http://www.ema.europa.eu/ema .

([48]) http://www.herca.org/ .

(EACA) ([49]). In 2016 some concerns were raised about the potential reclassification of the packages used for the transport of irradiated targets, which could impact transport of irradiated uranium targets through Germany. The Observatory coordinated the actions taken in this regard by the stakeholders and took contact with the German ministry for environment, nature conservation, building and nuclear safety.

Also as a follow-up to its report, WG3 asked the processors based in the EU to provide updates to the Observatory at its plenary meetings on their schedules of conversion to non-HEU processes. Such information is essential to the monitoring of overall progress on HEU-LEU conversion and to defining European needs for HEU/LEU material. The importance of the conversion was highlighted in the Council Conclusions adopted in 2012, which called upon the European Commission to identify the needs of research that might be supported by the Euratom research and training programme. As a result, a research and innovation action grant was awarded to the HERACLES-CP ([50]) project, which kicked-off in December 2015. This project, aimed 'towards the conversion of high performance research reactors in Europe', is coordinated by the Technical University of Munich and involves five partners, three of which are or will be producers of medical radioisotopes. The project's progress was discussed at the European Research Reactor Conference held in Berlin in March 2016 ([51]). Successful developments in manufacturing technology and new data were presented. To further support such research two new Euratom calls for the research reactors were opened in 2016: NFRP-10 'Support for the optimised use of European research reactors' and NFRP-11 'Support for the EU security of supply of nuclear fuel for research reactors'.

It remains very important to scrutinise the potential risks to the security of supply of HEU and LEU and to strive to obtain sufficient supplies of them, as neither HEU nor LEU (enriched to 19.75 %) is currently produced in the EU (the US and the Russian Federation are the only suppliers).

To that end, in close cooperation with the Member States concerned, ESA continued to facilitate the supply of HEU to users who still need it, in compliance with international nuclear security commitments. In 2016 ESA arranged for meetings to discuss the implementation of the Memorandum of Understanding signed with the US DoE-NNSA in 2014 on the exchange of HEU needed for the supply of European research reactors and radioisotope production facilities. An important development in this context was the drawing up of a list of materials eligible for exchange under the Memorandum of Understanding and the release of a Joint Statement on EU-US HEU exchange ([52]) at the 2016 Nuclear Security Summit in Washington. The overall balance of HEU quantities to be requested by Euratom Member States and HEU quantities to be shipped to the United States for downblending or to be recycled and downblended in Europe has been achieved, as envisaged by the Memorandum, and a significant proportion of the materials identified has already been shipped to the US.

The current HEU supply situation raises the question of availability of LEU. LEU will be needed to supply research reactors with appropriate fuel and radioisotope producers with material for the production of irradiation targets, when their conversion is finalised. At the Observatory October meeting, ESA presented a report on Securing the European Supply of 19.75 % Enriched Uranium Fuel, drafted in 2012 by a working group of its Advisory Committee. The purpose of this report was to evaluate the feasibility and opportunity to build a European capacity for the production of metallic LEU, at 19.75 % enrichment, to cover the needs of European research reactors after their conversion. The working group's strategic, technical and economic study was endorsed by the Agency's Advisory Committee in 2013. The adoption and publication of the European Commission Communication on the European Energy Security Strategy in May 2014 gave new impetus to the Agency's mission in support of security of supply ([53]). As a result, ESA published a paper version of the report in 2016. Two of its major contributors, URENCO and AREVA, working separately, reviewed and confirmed at the beginning of 2016 that the information they had provided in 2013 was still valid. The report remains therefore relevant to the international discussion on metallic LEU supply and can provide a useful input to any cooperative initiative in this area, including with interested countries outside the EU.

Working Group 4 — Capacity and infrastructure development

The main objective of Working Group 4 (WG4) is to examine Mo-99 production capacity and infrastructure developments for both reactors and processing facilities.

In line with its revised mandate, in 2016, WG4 continued to monitor the radioisotope market. The analyses focused mainly on the forecast of radioisotope demand and current and future Mo-99/Tc-99 m production capacity in the EU. A possible scope of further work of WG4 was agreed, including: strengths and weaknesses of the supply chain, technologies, installed production capacities and sustainability of the business models.

At its April meeting the Observatory discussed possible future alternative methods of Mo-99/Tc-99 m production. A representative from the European Organisation for Nuclear Research (CERN) ([54]) gave a presentation on R&D towards Mo-99/Tc-99 m production at the isotope mass separator ISOL-

([49]) http://www.euraca.eu/ .
([50]) http://heracles-consortium.eu/ .
([51]) https://www.euronuclear.org/meetings/rrfm2016/index.htm .
([52]) http://www.nss2016.org/document-center-docs/2016/4/1/joint-statement-on-eu-us-heu-exchange .
([53]) http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&qid=1407855611566 .
([54]) https://home.cern/ .

DE ([55]). It is a facility dedicated to the production of a large variety of radioactive ion beams for many different experiments in the fields of nuclear and atomic physics, solid-state physics, materials and life sciences. The facility is located at the Proton-Synchrotron Booster at CERN. In the Mo-99/Tc-99 m mass separation, U-238 is fissioned by fast neutrons to produce Mo-99. The progress of research on various aspects of this method was presented. This research is part of MEDICIS-PROMED ([56]), a Marie Skłodowska-Curie Innovative Training Network of the Horizon 2020 research programme.

During its October meeting the Observatory discussed the results of the Delphi study on the future supply initiatives of Tc-99 m, commissioned by the Foundation Preparation PALLAS Reactor ([57]). The goal of the study was to obtain expert consensus on the feasibility of current and future Tc-99 m production initiatives. The study analysed 26 initiatives worldwide of six types, from the point of view of success probability, supply capacity, financial and contextual competitiveness. The five most promising initiatives have been identified.

In 2016 the Observatory liaised closely with the European Association of Nuclear Medicine (EANM) ([58]). The Observatory took part in the 2016 EANM Congress, held in Barcelona in October. The EANM Annual Congresses are the biggest events for the European nuclear medicine community, gathering more than 6 000 participants and industry exhibitors. The Observatory had its booth at the EANM expo and organised a special focus session on 'Sustainability of supply of medical radioisotopes in the EU'. In addition to that, the Observatory representatives had a meeting with the EANM Board, including the EANM President and EANM Congress Chair, to discuss further cooperation, namely in the light of the forthcoming European Commission projects on medical radioisotopes.

([55]) http://isolde.web.cern.ch/ .
([56]) http://medicis-promed.web.cern.ch/.
([57]) http://www.pallasreactor.com.
([58]) http://www.eanm.org/.

6. ESA's Work Programme for 2017

In line with the Agency's remit, as defined in Chapter 6 of the Euratom Treaty and its Statutes, ESA's work programme for 2017 is built around five specific objectives.

1. **Exercise ESA's exclusive rights and powers in order to maintain a regular and equitable supply of ores and nuclear fuels in the European Atomic Energy Community**

Diversifying sources of supply to prevent excessive dependence on any single external supplier is of paramount importance for the medium and long-term security of nuclear fuel supply to EU utilities. ESA will continue to work for the security of supply by evaluating supply contracts submitted to it for conclusion and by acknowledging transactions duly notified to it covering provision of services in the entire nuclear fuel cycle. It will do this, taking due account of the Commission Communication of 28 May 2014 on the European Energy Security Strategy [59], The Agency will keep focusing on the supplies of HEU and, increasingly, on the future supplies of LEU required for producing medical radioisotopes and fuelling research reactors.

2. **Observe developments on security of supply in the nuclear fuel market**

ESA will continue to seek advice from its Advisory Committee on further development of its Nuclear Market Observatory, including assessments of information tools created by the Agency. In this regard, ESA will continue to support the activities of the Advisory Committee's working groups.

3. **Cooperate with international organisations and non-EU countries**

To efficiently carry out the Nuclear Market Observatory's tasks and contribute to security of supply, ESA will actively pursue its relations with international bodies. Following up the Memorandum of Understanding signed in December 2014 with the US DoE/NNSA, the Agency will, as in the previous years, ensure its implementation, coordinating with the Member States concerned where necessary.

4. **Monitor relevant R & D activities for their potential impact on ESA's policy for security of supply**

ESA will continue to follow nuclear technology developments to anticipate changes likely to affect the state of the nuclear fuel market.

5. **Make ESA's internal organisation and operations more effective**

To further improve the management of the contracts it receives and the operations of its Nuclear Market Observatory, ESA will continue to review its procedures. In line with commitments taken in the previous years, the Agency has carried out revision of its Rules determining the manner in which demand is to be balanced against the supply of ores, source materials and special fissile materials. Following consultations with all parties concerned, a unanimous favourable opinion on the new Rules was delivered by the Advisory Committee at its meeting of 13 May 2016. A Commission decision approving the new Rules (in accordance with Article 60, paragraph 6 of the Euratom Treaty) is still pending.

1. Exercise ESA's exclusive rights and powers in order to maintain a regular and equitable supply of ores and nuclear fuels in the European Atomic Energy Community

Since its inception, the Agency's main task has been to apply the principle of equal access to supplies of nuclear materials for all users in the EU Member States. It pays particular attention to the diversification of sources of supply, which has been, and remains, a key priority of EU energy policy.

ESA monitors the diversification of sources by evaluating contracts submitted to it for conclusion, which pertain to supply of ores, source materials and special fissile materials coming from inside or outside the EU (Article 52 of the Euratom Treaty). Notification to ESA of contracts on the processing, conversion or shaping of materials (Article 75 of the Treaty) and notification of transactions involving transfer, import or export of small quantities of materials (Article 74) also help to update the Agency both on the needs and the industrial capacity of undertakings in the EU.

[59] COM(2014) 330, final.

In accordance with Article 105 of the Euratom Treaty, supply contracts concluded before the EU accession of the Member States concerned are exempted from the diversification requirement until they expire or are modified. New supply contracts for the same utilities are being assessed in the light of the diversification policy.

ESA will continue to encourage the emergence of alternative sources of nuclear fuel/services supply where such sources are presently not available; notably, as regards fuel for VVER power reactors.

ESA will continue to scrutinise potential risks to the security of supply of the HEU and LEU (19.75 %), which are required to produce medical radioisotopes (Mo-99/Tc-99 m) and to fuel research reactors. Neither HEU nor such LEU is currently produced in the EU. As we are in a transition period from HEU to LEU targets and in some cases from HEU to LEU fuel, it is very important to succeed in obtaining the necessary supplies in order to prevent any shortage in the production of medical radioisotopes. ESA will continue to be actively involved in monitoring requirements for these fissile materials and striving to ensure their supply.

Regarding LEU, the Report 'Securing the European Supply of 19.75 % enriched Uranium Fuel' has been published It was produced by a dedicated working group of ESA's Advisory Committee, then endorsed and approved by the latter at its meeting of 14 November 2013. The decision to publish was authorised by the Advisory Committee at its meeting of 13 May 2016. ESA will continue to take due account of the recommendations of the said Report.

Specific objective No 1

1. Exercise ESA's exclusive rights to conclude nuclear fuel supply contracts, pursuant to Article 52 of the Euratom Treaty, in line with the EU supply/diversification policy and within the statutory deadline.

2. Acknowledge notifications of transactions on provision of services in the nuclear fuel cycle, pursuant to Article 75 of the Euratom Treaty, in the light of the EU supply/diversification policy.

3. Acknowledge notifications of transactions involving small quantities, pursuant to Article 74 of the Euratom Treaty.

4. Encourage the emergence of alternative sources of nuclear fuel/services supply where such sources are presently not available; liaise in this respect with the operators concerned, including by convening a meeting with them.

5. Continue to monitor the needs for HEU and LEU which are required to produce medical radioisotopes and to fuel research reactors; strive to ensure supply of the materials in question. To that end, continue to liaise with both suppliers and users, including non-EU ones.

6. Support the European Commission's nuclear materials accountancy staff, on request, in verification of contract data contained in prior notifications of movements of nuclear materials.

7. Verify, on request, the conformity of draft bilateral agreements between the EU Member States and non-EU countries with the requirements of Chapter 6 of the Euratom Treaty.

8. Contribute, on request, to the preparation of European Commission proposals on broader nuclear energy or general EU energy issues.

2. Observe developments on security of supply in the nuclear fuel market

Acting as the secretariat of the Advisory Committee's Working Group on security of supply scenarios, ESA will continue to facilitate the Group's activities to increase the transparency of the nuclear fuel cycle market in the EU. Likewise, as in the previous years, the Agency will provide support to all the working groups set up by the Advisory Committee, as necessary.

ESA will continue to fine-tune its market-monitoring capacity to better respond to operators' expectations.

These activities lay the foundations for building up comprehensive overviews of the current state and emerging trends of the nuclear fuel cycle market. ESA's Annual Report, Quarterly Uranium Market Report and weekly Nuclear News Digest, circulated within the Commission, will remain the main way to present the Nuclear Market Observatory's analyses. ESA's website will still be regularly updated by the Nuclear Observatory, thus offering direct access to information about market developments.

ESA's Nuclear Market Observatory will continue to cooperate with the European Commission's Directorate-General for Energy in the context of the energy market analysis.

ESA will continue to chair the European Observatory on the supply of medical radioisotopes set up in 2012 and to coordinate actions undertaken by various services involved to increase the security of supply of Mo-99/Tc-99 m — the most vital medical radioisotope. It will do this in line with the mission entrusted to its Nuclear Market Observatory to cover aspects of the supply of medical radioisotopes in the EU.

Specific objective No 2

To deliver on its market-monitoring responsibilities, ESA will:

1. continue to support the activities of the ESA Advisory Committee's Working Group on security of supply scenarios;

2. regularly update information published by the Nuclear Market Observatory, in particular through the regular pub-

lication of Quarterly Uranium Market Reports, the Nuclear Digest and ad hoc studies;

3. publish its Annual Report, including market analyses, by July 2017;

4. continue to publish yearly natural uranium price indices: long-term, medium-term, spot and quarterly price indices;

5. chair and lead the activities of the European Observatory on the supply of medical radioisotopes;

6. update regularly the medical radioisotope section on ESA's website, offering direct access to recent information on this subject;

7. provide support to the activities of the ESA Advisory Committee's working groups as necessary.

3. Cooperate with international organisations and non-EU countries

Due to their quality and neutrality, ESA's analyses of the nuclear fuel cycle market are increasingly sought by groups of international experts. To raise the profile of its activities as a Nuclear Market Observatory and to carry out its other tasks efficiently, ESA will maintain regular contact not only with international nuclear organisations such as the IAEA and the NEA, but also with a number of international players on the nuclear fuel market. It will continue its membership of the World Nuclear Association (WNA) and the World Nuclear Fuel Market (WNFM).

To ensure regular HEU supplies for as long as necessary, ESA will pursue its cooperation with the US DoE/NNSA, which was formally initiated through the 2014 MoU and complemented by the establishment of a list of materials eligible for exchange. A relevant Joint Statement was released at the margins of the 2016 Nuclear Security Summit in Washington.

Specific objective No 3

1. Pursue contacts with international authorities, companies and nuclear organisations.

2. Participate in the negotiation of Euratom cooperation agreements with non-EU countries and monitor their implementation as regards trade in nuclear fuel.

3. Take part in the dialogue with Russia (as soon as this becomes politically feasible) on nuclear energy matters.

4. Maintain contacts with the US for the sake of supply of HEU, currently still required for the production of medical radioisotopes; follow up, in this context, the 2014 MoU.

5. Resume contacts with the US with a view to securing LEU (19.75 %) supply, required for the production of medical radioisotopes.

6. Seek appropriate political support to establish the conditions for setting up a European LEU facility to cover needs in a larger number of (EU and non-EU) countries, as suggested in the dedicated Report of the Agency's Advisory Committee.

4. Monitor relevant R & D activities for their potential impact on ESA's policy for security of supply

ESA will keep on monitoring R & D activities which are likely to have an impact on diversification or on nuclear fuel cycle management. It will do this in EU and international research and development (R & D) forums both for electricity generation and for medical radioisotopes' production (e.g. reprocessing waste, reducing the volume of waste, improving reactor efficiency) and thus, influence directly the nuclear fuel market.

The outcome of the following ongoing projects may be of interest for the Agency:

- HERACLES-CP, which is a Horizon 2020 project supported by the European Commission and a central pillar of the programme for the development and qualification of high-density LEU fuel to be used in research reactors and processes, presently fuelled with HEU, after their conversion.

- ESSANUF, i.e. the project 'European Supply of Safe Nuclear Fuel', which aims at the qualification of nuclear fuel, produced by alternative suppliers, for VVER-designed power reactors operating in the EU.

Specific objective No 4

1. Continuously monitor technological developments on the nuclear fuel cycle management, with a view to adapting the Agency's security of supply policy as appropriate.

2. Review the latest technological developments on diversification or fuel cycle management in Advisory Committee meetings or at specifically organised events, where appropriate.

5. Make ESA's internal organisation and operations more effective

The objective is to make ESA more effective and efficient. This is particularly important in the light of the Agency's restricted resources.

Specific objective No 5

1. Implement the Agency's new Rules determining the manner in which demand is to be balanced against the supply of ores, source materials and special fissile materials. (A Commission decision approving the said Rules is presently still pending).

2. Continue to review the Agency's work practices as well as its internal control standards and update them to the extent appropriate; continue to update the manual of procedures for the Contract Management and Nuclear Market Observatory sectors.

3. Continue to ensure sound financial and budgetary management.

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This report and its previous editions are available on ESA's website:
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A limited number of paper copies of this report may be obtained, subject to availability, from the above address.

Further information

Additional information can be found on the EUROPA website:
http://europa.eu/index_en.htm.

EUROPA provides access to the websites of all European institutions and other bodies.

More information on the Commission's Directorate-General for Energy can be found at:
http://ec.europa.eu/energy/index_en.html.

This website contains information on areas such as security of energy supply, energy-related research, nuclear safety, and liberalisation of the electricity and gas markets.

Annexes

Annex 1
EU-28 gross and net requirements (quantities in tU and tSW)

(A) 2017-2026

Year	Natural uranium		Separative work	
	Gross requirements	Net requirements	Gross requirements	Net requirements
2017	17 683	14 409	14 422	11 884
2018	16 336	14 010	13 262	11 660
2019	17 822	16 249	14 457	13 179
2020	17 014	15 346	13 861	12 593
2021	16 176	15 244	13 247	12 449
2022	16 449	14 670	13 528	12 460
2023	15 779	13 961	13 011	11 935
2024	14 618	13 175	12 032	11 234
2025	14 910	13 464	12 260	11 460
2026	14 318	12 804	11 780	10 932
Total	**161 105**	**143 332**	**131 860**	**119 787**
Average	**16 110**	**14 333**	**13 186**	**11 979**

(B) Extended forecast 2027-2036

Year	Natural uranium		Separative work	
	Gross requirements	Net requirements	Gross requirements	Net requirements
2027	14 273	12 863	11 732	10 962
2028	14 152	12 739	11 647	10 875
2029	14 102	12 599	11 633	10 794
2030	13 935	12 525	11 503	10 733
2031	13 689	12 279	11 308	10 538
2032	14 027	12 540	11 580	10 746
2033	13 698	12 222	11 286	10 461
2034	13 398	11 988	11 140	10 370
2035	13 401	11 991	11 142	10 372
2036	13 103	11 693	10 799	10 029
Total	**137 778**	**123 439**	**113 770**	**105 880**
Average	**13 778**	**12 344**	**11 377**	**10 588**

Annex 2
Fuel loaded into EU-28 reactors and deliveries of fresh fuel under purchasing contracts

Year	Fuel loaded			Deliveries		
	LEU (tU)	Feed equivalent (tU)	Enrichment equivalent (tSW)	Natural U (tU)	% spot	Enrichment (tSW)
1980		9 600		8 600	(*)	
1981		9 000		13 000	10.0	
1982		10 400		12 500	< 10.0	
1983		9 100		13 500	< 10.0	
1984		11 900		11 000	< 10.0	
1985		11 300		11 000	11.5	
1986		13 200		12 000	9.5	
1987		14 300		14 000	17.0	
1988		12 900		12 500	4.5	
1989		15 400		13 500	11.5	
1990		15 000		12 800	16.7	
1991		15 000	9 200	12 900	13.3	10 000
1992		15 200	9 200	11 700	13.7	10 900
1993		15 600	9 300	12 100	11.3	9 100
1994	2 520	15 400	9 100	14 000	21.0	9 800
1995	3 040	18 700	10 400	16 000	18.1	9 600
1996	2 920	18 400	11 100	15 900	4.4	11 700
1997	2 900	18 200	11 000	15 600	12.0	10 100
1998	2 830	18 400	10 400	16 100	6.0	9 200
1999	2 860	19 400	10 800	14 800	8.0	9 700
2000	2 500	17 400	9 800	15 800	12.0	9 700
2001	2 800	20 300	11 100	13 900	4.0	9 100
2002	2 900	20 900	11 600	16 900	8.0	9 500
2003	2 800	20 700	11 500	16 400	18.0	11 000
2004	2 600	19 300	10 900	14 600	4.0	10 500
2005	2 500	21 100	12 000	17 600	5.0	11 400
2006	2 700	21 000	12 700	21 400	7.8	11 400
2007 (**)	2 809	19 774	13 051	21 932	2.4	14 756
2008 (**)	2 749	19 146	13 061	18 622	2.9	13 560
2009 (**)	2 807	19 333	13 754	17 591	5.2	11 905
2010 (**)	2 712	18 122	13 043	17 566	4.1	14 855
2011 (**)	2 583	17 465	13 091	17 832	3.7	12 507
2012 (**)	2 271	15 767	11 803	18 639	3.8	12 724
2013 (**)	2 343	17 175	12 617	17 023	7.1	11 559
2014 (**)	2 165	15 355	11 434	14 751	3.5	12 524
2015 (**)	2 231	16 235	11 851	15 990	5.0	12 493
2016 (**)	**2 086**	**14 856**	**11 120**	**14 325**	**3.1**	**10 775**

(*) Data not available.

(**) The LEU fuel loaded and feed equivalent contain Candu fuel.

Annex 3
ESA average prices for natural uranium

Year	Multiannual contracts		Spot contracts		New multiannual contracts		Exchange rate
	EUR/kgU	USD/ lb U_3O_8	EUR/kgU	USD/ lb U_3O_8	EUR/kgU	USD/lb U_3O_8	EUR/USD
1980	67.20	36.00	65.34	35.00			1.39
1981	77.45	33.25	65.22	28.00			1.12
1982	84.86	32.00	63.65	24.00			0.98
1983	90.51	31.00	67.89	23.25			0.89
1984	98.00	29.75	63.41	19.25			0.79
1985	99.77	29.00	51.09	15.00			0.76
1986	81.89	31.00	46.89	17.75			0.98
1987	73.50	32.50	39.00	17.25			1.15
1988	70.00	31.82	35.50	16.13			1.18
1989	69.25	29.35	28.75	12.19			1.10
1990	60.00	29.39	19.75	9.68			1.27
1991	54.75	26.09	19.00	9.05			1.24
1992	49.50	24.71	19.25	9.61			1.30
1993	47.00	21.17	20.50	9.23			1.17
1994	44.25	20.25	18.75	8.58			1.19
1995	34.75	17.48	15.25	7.67			1.31
1996	32.00	15.63	17.75	8.67			1.27
1997	34.75	15.16	30.00	13.09			1.13
1998	34.00	14.66	25.00	10.78			1.12
1999	34.75	14.25	24.75	10.15			1.07
2000	37.00	13.12	22.75	8.07			0.92
2001	38.25	13.18	(*) 21.00	(*) 7.23			0.90
2002	34.00	12.37	25.50	9.27			0.95
2003	30.50	13.27	21.75	9.46			1.13
2004	29.20	13.97	26.14	12.51			1.24
2005	33.56	16.06	44.27	21.19			1.24
2006	38.41	18.38	53.73	25.95			1.26
2007	40.98	21.60	121.80	64.21			1.37
2008	47.23	26.72	118.19	66.86			1.47
2009	55.70	29.88	77.96	41.83	(**) 63.49	(**) 34.06	1.39
2010	61.68	31.45	79.48	40.53	78.11	39.83	1.33
2011	83.45	44.68	107.43	57.52	100.02	53.55	1.39
2012	90.03	44.49	97.80	48.33	103.42	51.11	1.28
2013	85.19	43.52	78.24	39.97	84.66	43.25	1.33
2014	78.31	40.02	74.65	38.15	93.68	47.87	1.33
2015	94.30	40.24	88.73	37.87	88.53	37.78	1.11
2016	**86.62**	**36.88**	**88.56**	**37.71**	**87.11**	**37.09**	**1.11**

(*) The spot price for 2001 was calculated based on an exceptionally low total volume of only 330 tU covered by four transactions.

(**) ESA's price method took account of the ESA 'MAC-3' new multiannual U_3O_8 price, which includes amended contracts from 2009 onwards.

Annex 4
Purchases of natural uranium by EU utilities, by origin, 2007-2016 (tU)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Niger	3 351	1 845	1 845	2 082	1 726	2 376	2 235	2 171	2 077	3 152
Canada	3 786	4 757	3 286	2 012	3 318	3 212	3 156	1 855	2 845	2 946
Russia	5 144	3 272	3 599	4 979	4 524	5 102	3 084	2 649	4 097	2 765
Kazakhstan	557	1 072	1 596	2 816	2 659	2 254	3 612	3 941	2 949	2 261
Australia	3 209	2 992	3 801	2 153	1 777	2 280	2 011	1 994	1 910	1 896
Namibia	865	696	435	1 017	1 011	1 350	716	325	385	504
EU	526	515	480	556	455	421	421	397	412	220
Re-enriched tails	388	688	193	0	0	0	0	0	212	212
Other	432	520	329	432	128	256	621	299	229	130
United States	402	398	318	320	180	241	381	586	343	125
Uzbekistan	938	1 070	589	459	929	159	653	365	526	115
HEU feed	825	550	675	550	731	395	0	0	0	0
Malawi	0	0	0	0	0	180	115	125	2	0
South Africa	137	247	426	190	113	412	17	20	1	0
Ukraine	123		10	0	284	0	0	23	0	0
Total	**20 864**	**18 622**	**17 591**	**17 566**	**17 832**	**18 639**	**17 023**	**14 751**	**15 990**	**14 325**

Annex 5
Use of plutonium in MOX in the EU-28 and estimated natural uranium and separative work savings

Year	kg Pu	Savings	
		tNatU	tSW
1996	4 050	490	320
1997	5 770	690	460
1998	9 210	1 110	740
1999	7 230	870	580
2000	9 130	1 100	730
2001	9 070	1 090	725
2002	9 890	1 190	790
2003	12 120	1 450	970
2004	10 730	1 290	860
2005	8 390	1 010	670
2006	10 210	1 225	815
2007	8 624	1 035	690
2008	16 430	1 972	1 314
2009	10 282	1 234	823
2010	10 636	1 276	851
2011	9 410	824	571
2012	10 334	897	622
2013	11 120	1 047	740
2014	11 603	1 156	825
2015	10 780	1 050	742
2016	**9 012**	**807**	**567**
Grand total	**204 031**	**22 813**	**14 405**

Annex 6
EU nuclear utilities that contributed to this report

ČEZ, a.s.
EDF and EDF Energy
EnBW Kernkraft GmbH
ENUSA Industrias Avanzadas, S.A.
EPZ
Fortum Power and Heat Oy
Ignalina NPP
Kozloduy NPP Plc
Nuklearna elektrarna Krško, d.o.o.
Magnox Ltd (UAM)
Oskarshamn NPP (OKG)
Paks NPP Ltd
PreussenElektra (formerly E.ON Kernkraft GmbH)
RWE Power AG
Slovenské elektrárne, a.s.
Societatea Nationala Nuclearelectrica S.A.
Synatom sa
Teollisuuden Voima Oyj (TVO)
Vattenfall Nuclear Fuel AB

Annex 7
Uranium suppliers to EU utilities

AREVA NC and AREVA NP (formerly Cogéma)
AREVA Mines
BHP Billiton (formerly WMC)
Cameco Inc. USA
Cominak
DIAMO
Itochu International Inc.
KazAtomProm
Macquarie Bank Limited, London Branch
NUKEM GmbH
Rio Tinto Marketing Pte Ltd
Tenex (JSC Techsnabexport)
Traxys North America LLC
TVEL
UEM
Uranium One
Urenco Ltd

Annex 8
Calculation method for ESA's average U_3O_8 prices

ESA price definitions

In order to provide reliable objective price information comparable with previous years, only deliveries made to EU utilities or their procurement organisations under purchasing contracts are taken into account for calculating the average prices.

To improve market transparency, ESA calculates three uranium price indices on an annual basis:

1. The ESA spot U_3O_8 price is a weighted average of U_3O_8 prices paid by EU utilities for uranium delivered under spot contracts during the reference year.

2. The ESA long-term U_3O_8 price is a weighted average of U_3O_8 prices paid by EU utilities for uranium delivered under multiannual contracts during the reference year.

3. The ESA 'MAC-3' multiannual U_3O_8 price is a weighted average of U_3O_8 prices paid by EU utilities, but only under multiannual contracts which were concluded or for which the pricing method was amended in the previous 3 years (i.e. between 1 January 2014 and 31 December 2016) and under which deliveries were made during the reference year. In this context, ESA regards amendments which have a direct impact on the prices paid as separate contracts.

To ensure statistical reliability (sufficient amounts) and safeguard the confidentiality of commercial data (i.e. ensure that details of individual contracts are not revealed), ESA price indices are calculated only if there are at least five relevant contracts.

In 2011, ESA introduced its quarterly spot U_3O_8 price, an indicator published on a quarterly basis if EU utilities have concluded at least three new spot contracts.

All price indices are expressed in US dollars per pound (USD/lb U_3O_8) and euros per kilogram (EUR/kgU).

Definition of spot vs long-term/multiannual contracts

The difference between spot and multiannual contracts is as follows:

- spot contracts provide either for one delivery only or for deliveries over a maximum of 12 months, whatever the time between conclusion of the contract and the first delivery;

- multiannual contracts provide for deliveries extending over more than 12 months.

The average spot-price index reflects the latest developments on the uranium market, whereas the average price index of uranium delivered under multiannual contracts reflects the average long-term price paid by European utilities.

Method

The methods applied have been discussed in the working group of the Advisory Committee.

Data collection tools

Prices are collected directly from utilities or via their procurement organisations on the basis of:

- contracts submitted to ESA;

- end-of-year questionnaires backed up, if necessary, by visits to the utilities.

Data requested on natural uranium deliveries during the year

The following details are requested: ESA contract reference number, quantity (kgU), delivery date, place of delivery, mining origin, obligation code, natural uranium price specifying the currency, unit of weight (kg, kgU or lb), chemical form (U_3O_8, UF_6 or UO_2), whether the price includes conversion and, if so, the price and currency of conversion, if known.

Deliveries taken into account

The deliveries taken into account are those made under natural uranium purchasing contracts to EU electricity utilities or their procurement organisations during the relevant year. They also include the natural uranium equivalent contained in enriched uranium purchases.

Other categories of contracts, e.g. those between intermediaries, for sales by utilities, purchases by non-utility industries or barter deals, are excluded. Deliveries for which it is not possible to reliably establish the price of the natural uranium component are also excluded from the price calculation (e.g. uranium out of specification or enriched uranium priced per kg EUP without separation of the feed and enrichment components).

Data quality assessment

ESA compares the deliveries and prices reported with the data collected at the time of conclusion of the contracts, taking into account any subsequent updates. In particular, it compares the actual deliveries with the 'maximum permitted deliveries' and options. Where there are discrepancies between maximum and actual deliveries, clarifications are sought from the organisations concerned.

Exchange rates

To calculate the average prices, the original contract prices are converted into euros per kgU contained in U_3O_8 using the average annual exchange rates published by the European Central Bank.

Prices which include conversion

For the few prices which include conversion but where the conversion price is not specified, given the relatively minor cost of conversion, ESA converts the UF_6 price into a U_3O_8 price using an average conversion value based on reported conversion prices under the natural uranium long-term contracts.

Independent verification

Two members of ESA's staff independently verify spreadsheets from the database.

Despite all the care taken, errors or omissions are discovered from time to time, mostly in the form of missing data (e.g. on deliveries under options) which were not reported. As a matter of policy, ESA never publishes a corrective figure.

Data protection

Confidentiality and the physical protection of commercial data are ensured by using stand-alone computers which are connected neither to the Commission intranet nor to the outside world (including the internet). Contracts and backups are kept in a secure room, with restricted key access.

Annex 9
Declaration of assurance

I, the undersigned, Marian O'Leary

Director-General of Euratom Supply Agency since 1 November 2016

In my capacity as authorising officer

Declare that the information contained in this report gives a true and fair view ([60]).

State that I have reasonable assurance that the resources assigned to the activities described in this report have been used for their intended purpose and in accordance with the principles of sound financial management, and that the control procedures put in place give the necessary guarantees concerning the legality and regularity of the underlying transactions.

This reasonable assurance is based on my own judgment and on the information at my disposal, such as the results and the lessons learnt from the reports of the Court of Auditors for years prior to the year of this declaration.

Confirm that I am not aware of anything not reported here which could harm the interests of the Euratom Supply Agency.

Luxembourg, 31 March 2017

Marian O'Leary

([60]) True and fair in this context means a reliable, complete and correct view on the state of affairs in the Agency.

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