Report on
Nuclear Fuel
Security of Supply

Euratom Supply Agency
Advisory Committee WG Report
REPORT

of the Advisory Committee to the Euratom Supply Agency
on the Analysis of Nuclear Fuel Availability
at EU Level from a Security of Supply Perspective

June 2015

This report has been elaborated by the Members of the Advisory Committee Working Group on Prices and Security of Supply and the Euratom Supply Agency and has been endorsed by the Euratom Supply Agency’s Advisory Committee at its meeting held on 28 April 2015 in Luxembourg.
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1. Executive summary

Nuclear energy remains a key source of low-carbon electricity generation in the European Union (EU). This report identifies threats and restrictions which could potentially jeopardise availability of nuclear fuel and provision of electricity at affordable prices to all EU consumers.

The most common way for utilities to secure their supply of nuclear fuel is to have a diversified portfolio of suppliers at every step of the nuclear fuel cycle (natural uranium, conversion, enrichment and fabrication). However, some utilities still have only one single supplier for all four stages, delivering the fabricated fuel to the reactor sites. From a security of supply point of view, ideally there should always be at least two alternative fuel designs from two different suppliers qualified for each reactor. If individual delivery is disrupted, it is in most cases possible to buy uranium, conversion and enrichment on the spot markets. But it takes time to qualify an alternative fuel design and this is therefore an important condition for increasing security of supply. As an intermediate measure one could also consider having a diversified portfolio before the fabrication step and maintain a strategic stock of (enriched) uranium. Another possible mitigating measure is to have a store of fresh fuel bundles at the reactor site that can be used in case of delivery disturbance (at least temporarily).

A reduction in market demand, especially in some specific segments of the nuclear fuel market, also creates a risk of reduction in qualified fuel fabrication capacity, as nuclear fuel vendors, under pressure to reconsider their product portfolio to concentrate on the most in-demand products, are driven to restructure. Consequently there is a potential for loss of power generation due to the limited availability of stocks to cover transitional periods between two plants and/or vendors.

A new risk identified in this report was not mentioned in the 2005 study. It is related to potential fuel failure during operation in the reactor core. Reliability is a key factor because the fuel is expected to operate without failure for an operating time of at least five years. Fuel failures could be of a generic nature and affect multiple nuclear power plants (NPPs). At worst they could lead to plant shutdown or extended outage times.

As with other commodities, strong concentration of production or services in a specific area could increase vulnerability to any kind of access restriction. A balanced diversified fuel supply and a strategic inventory of material would help to reduce the risk.

Another factor influencing the nuclear industry is financial or business environment instability, which lessens the expected profitability of new projects and puts development at risk and increases the price of electricity generation. Being a capital-intensive industry demanding long periods of development, nuclear energy requires financial and regulatory stability.

Lack of investment in new mines due to postponement or cancellation, as well as reduction of production from existing uranium mining operations could lead globally to a mismatch between demand and supply, particularly in terms of quantities, but also in terms of required regional diversification and/or producers’ diversity in utilities’ supply portfolios. This may limit procurement strategies in terms of a ‘healthy’ supply mix for utilities or could lead to a more conservative commercial approach by producers. This makes diversification more difficult to maintain, puts pressure on prices and may result in shortage of nuclear material. An appropriate level of strategic inventory of nuclear fuel material held by utilities can help; the appropriateness of supplier country, volume, form and location should be reviewed regularly in terms of sufficiently diversified fuel supply, and early warnings by EU institutions and concerted industry action can be supportive.

While the mining and enrichment industries have seen ups and downs when it comes to market prices, the conversion industry tends to suffer for most of the time from low spot prices and limited long-term contracting activity as a result of secondary supplies and large stockpiles. As a consequence there is no incentive for the producers to invest in capacity expansion to overcome regional imbalances and some facilities have recently been de-

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1. Quantity of nuclear material (including fuel assemblies) defined by an entity as necessary to mitigate its individual supply risks.
commissioned without replacement. Up to now, technical or strike-related interruptions of production could be managed with the help of inventories and loans/swaps and this is likely to be the case also in the near future. Nevertheless, continuous postponement of investments can have a long-term impact on supply. Strategic inventories are a proven instrument to mitigate symptoms of supply failure but they cannot heal the root cause of it. Utilities may be well advised to consider sharing the risk and value with the converters for the sustainability of the smallest but important step in the fuel chain.

Another aspect which influences the nuclear industry is vertical and horizontal concentration of the business, which in general lessens competition, limits diversification options and may lead to a dominant position being obtained by a single provider. This in consequence may lead to an increase in prices.

In assessing the security of supply of nuclear fuel one has to look carefully at transport issues. Cross-border transport of radioactive materials is becoming increasingly complex and time-consuming due to different approaches of regulators in each country. Although the transport regulations are based on the same international references, the complex system of national reporting and authorisation procedures relating to carriers of radioactive materials hinder business operations. The main effects are interruption of and delays to consignments and, in extreme cases, shipment denials. This in turn causes administrative burdens and increases costs.

It is important to make different stakeholders aware of the excellent safety record of the transport of radioactive materials. It is recommended to develop a harmonised pan-European arrangement for handling cross-border transport package approvals which would be valid in each country involved. Impact of delays in transport can be mitigated by diversifying fuel supply and developing different transport routes. Strategic inventories of materials and fuel further mitigate the impact of delays.
<table>
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<th>ACTOR</th>
<th>PROPOSALS FOR ACTION</th>
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<tr>
<td>UTILITY</td>
<td>- Perform risk analysis</td>
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<td></td>
<td>- Diversification</td>
</tr>
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<td></td>
<td>- Appropriate inventory, specified in level and in form resulting from risk analysis and on-going monitoring</td>
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<td></td>
<td>- Advance delivery of fabricated fuel</td>
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<td>- Qualification of alternative fuel designs, fabrication plants or vendors</td>
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<td></td>
<td>- Long-term and flexible contracts</td>
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<td></td>
<td>- Sharing risks and benefits with converters under e.g. long-term conversion contracts</td>
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<td></td>
<td>- Information exchange between utilities on fuel design operating experience</td>
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<tr>
<td>SUPPLIER</td>
<td>- Continuous endeavour in proving its reliability and improving transparency</td>
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<td></td>
<td>- Greater openness to support on-going monitoring of the market risks</td>
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<td></td>
<td>- Proactive licensing by fuel vendors in potential market areas</td>
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<tr>
<td>REGULATOR</td>
<td>- Harmonisation of regulations</td>
</tr>
<tr>
<td></td>
<td>- Monitoring whether vendors and utilities will abuse their dominant position if applicable</td>
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<td></td>
<td>- Appropriate antitrust measures</td>
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<tr>
<td>MEMBER STATE</td>
<td>- Securing a fair electricity market and conditions for all sources of electricity generation</td>
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<td></td>
<td>- Consider and treat nuclear generation as the strategic sector of energy supply</td>
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<td>- Accept a pan-European arrangement for package approvals for cross-border transport</td>
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<tr>
<td>EU/ESA</td>
<td>- Ongoing monitoring of the market and early warnings</td>
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<td></td>
<td>- Perform risk analysis</td>
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<td></td>
<td>- Consider, treat and promote nuclear generation as the strategic sector of energy supply</td>
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<tr>
<td></td>
<td>- Monitor any appearance of possible supply risks and their probability and recommend mitigation measures</td>
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<td></td>
<td>- Create a pan-European arrangement for handling cross-border transport package approvals and mutual recognition of registered carriers</td>
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1.1. Risks and proposals

Current slowdown on the nuclear market accompanied by low profitability and price volatility do not provide favourable conditions for prospective investments in plants and exploration. This in turn might influence future security of supply of nuclear fuel to EU utilities. Several mining projects have been halted during the last few years, among them Trekkopje in Namibia, Imouraren in Niger and Millennium in Canada. Nevertheless producers in many regions claim to be able to develop new production if only market conditions would turn more advantageous. Some projects are moving ahead e.g. Cigar Lake in Canada, ISL in the US and the ‘non-market’ based Husab project in Namibia. The situation is a consequence of the Fukushima Daiichi accident in March 2011 and revision of nuclear strategies around the world, mainly postponement of investments in new nuclear power plants. The current market situation tends to reflect the supply/demand balance with obvious surplus of the former and is not taking fully into account production costs and capital investment needs of producers.

For some time now, not only natural uranium prices but also the conversion prices have been falling in the EU and US and the conversion industry is faced with low profitability which cannot support investments. In the course of 2014 Cameco prematurely ended the conversion agreement with the Springfields plant in the UK, which was set to run till 2016.

Enrichment service prices have also fallen over the last three years, which encourages underfeeding by enrichers. On the one hand this removes surplus of enrichment capacity from the market but on the other hand contributes to surplus of natural uranium.

For utilities it is strongly recommended to maintain diversified contracts with manifold producers and to keep appropriate levels of stocks. The inventory should include nuclear fuel material in different stages of the fuel cycle providing diversification in each stage. It should be reviewed constantly in the light of political and market developments. Nevertheless world aggregated inventories of utilities should not be unreasonably high, though it may induce uranium suppliers to defer even more their investment decisions in relation to new mines.

Utilities should have a choice of alternative fuel fabricators and ongoing monitoring of market developments is also desirable.

Risks related to access restrictions stemming from a political situation or market protection policies can be reduced by implementing measures similar to those mentioned above. Additionally, EU institutions are perceived as a watchdog of ongoing processes and changes:

- Strategic inventory of nuclear material. The appropriateness of volume and form and location should be reviewed from time to time to incorporate recent political developments.
- Diversified fuel supply (supplier country, location, transport route, volumes and form) to utilities reduces the risks.
- Early warnings by EU institutions and concerted industry action may alleviate any impact.

Strong support for harmonisation of attitudes to fuel design evolution and thus discouragement to increase numbers of technical market segments that lead to greater market fragmentation and exacerbate the risk.

In the transport of nuclear material there are political risks at national, regional and municipal levels, especially in regions where shipment and rail freight is a monopoly of one single company or is the single route.

Further work leading to adoption of the 2011 proposal for a Council Regulation establishing a European system for mutual recognition of registered carriers of radioactive materials should be continued.

© CEZ’s stockpile of U-concentrate from production of DIAMO, s.p.
1.2. ESA objectives and resources

In carrying out the tasks entrusted to it by the Euratom Treaty, ESA processes more than 150 transactions, including contracts, amendments and notifications of front-end activities, on an annual basis. Under the Euratom Treaty, ESA is endowed with a right of option on ores, source materials and special fissile materials produced in the territories of Member States and has an exclusive right to conclude contracts relating to the supply of ores, source materials and special fissile materials coming from inside the Community or from outside.

To increase market transparency ESA conducts an annual market survey and gives its detailed analysis of the EU nuclear fuel market, as well as its vision of the global nuclear fuel market. It identifies market trends that could affect security of the European Union’s supply of nuclear materials and services and provides EU stakeholders with expertise and advice.

ESA together with its Advisory Committee forms a unique mix of precise knowledge of the EU nuclear market and experience. It is required to use these assets for drawing up proposals, recommendations and decisions influencing the nuclear market not only when possible supply problems may occur but far in advance, before any difficulties could harm the European market.

The expertise of ESA offering early warning should be used together with concentrated industry action. The ESA annual survey should be of utmost importance in monitoring the EU market.

In order to accomplish its mission and maintain its position in a changing environment, ESA should have at its disposal staff with a high level of expertise in administering contracts submitted by the European nuclear operators for ESA’s agreement, and collecting and analysing data from the industry.

In order to maintain ESA’s role in evaluating the market, advising and making recommendations, ESA should sustain its balanced cooperation with other international bodies and organisations e.g. IAEA, NEA WNA, WNFM. ESA should also continue to contribute to international reports, reviews and specialised publications and enhance its international recognition and visibility.
European energy security has recently again become the number one priority in the EU. In response, the European Commission adopted the European Energy Security Strategy on 28 May 2014, based on an in-depth study of Member States’ energy dependence. A European internal market for energy is seen as a key factor in energy security and is the delivery mechanism for achieving it in a cost-effective way. Government interventions that affect this market framework, such as national decisions on renewable energy or efficiency targets, decisions to support investment in (or decommissioning of) nuclear generation, or decisions to support key infrastructure projects (such as NordStream, SouthStream, TAP or a Baltic LNG Terminal) need to be discussed at European and/or regional level to ensure that decisions in one Member State do not undermine security of supply in another Member State. Various tools exist at EU level to implement such projects in a coordinated manner (internal market legislation, TEN-E guidelines, state aid control). A real European Energy Security Strategy requires that enforcement tools be preceded by a strategic discussion at EU level, not just at national level.

Electricity produced from nuclear power plants constitutes a reliable base load of emission-free supply and plays an important role in energy security. The relative value of nuclear fuel is marginal in relation to the total production cost of electricity compared to gas or coal-fired plants. The worldwide uranium supply market is stable and well diversified but the EU is nonetheless completely dependent on external supplies. There are only a few entities in the world that are able to transform uranium into fuel for nuclear reactors, but the EU industry has technological leadership on the whole chain, including conversion, enrichment, fabrication, reprocessing and recycling.

The supply and demand situation for nuclear fuels in the EU could change radically by 2030. Having regard to the nuclear phase-out strategy in Germany and Belgium, and the energy transition announced by the French government, the four on-going new build reactor projects in three Member States and a couple of new projects, which will be commissioned in the near future, could not compensate for all possible shutdowns.
Facts and figures on EU nuclear fuel market

There are 131 commercial nuclear power reactors operating in the EU, located in 14 Member States and managed by 18 nuclear utilities.

✈ EU nuclear gross electricity generation accounts for about 26% of total EU-28 production.

✈ Demand for uranium in the EU constitutes about 30% of world uranium demand.

✈ More than 95% of natural uranium delivered to the EU on an annual basis comes from diversified sources outside Europe; nevertheless the EU has substantial resources of uranium, exploitation of which in the prevailing conditions cannot be economically justified.

✈ About 40% of enrichment services comes from outside the EU, mostly Russia.

✈ Supply of natural uranium is fully guaranteed from 2014 to 2018 with a contractual coverage rate of over 90%. In the long term, the uranium coverage rate remains above 70% from 2019 to 2020 and drops sharply to 40% for the period 2020-21.

✈ Enrichment services supply is well secured for the whole period 2014–20, with contractual coverage steadily above 90% and over 80% between 2021 and 2022.

✈ EU industry has technological leadership on the whole fuel supply chain, including enrichment and reprocessing.

✈ In general, deliveries to EU utilities are well diversified with regard to the whole nuclear fuel cycle, but four countries, namely Bulgaria, Czech Republic, Hungary and Slovakia operating exclusively VVER reactors are dependent on deliveries of fuel assemblies from one fabricator to the countries’ nuclear reactor fleets (additionally, in Finland, two out of the four operating reactors are VVER-type, which represents 10% of the country’s electricity production).

✈ EU utilities’ uranium inventories have increased substantially since 2008 and can fuel nuclear power reactors, on average, for 3 years.

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3. Legal background and principles of security of supply

3.1. EURATOM Treaty

The fundamental objectives of the European Atomic Energy Community (EURATOM) Treaty are to contribute to raising the standard of living in the Member States and the development of relations with other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries. To this end, it is necessary to ensure that all users in the European Union receive a regular and equitable supply of ores and nuclear fuels.

A common nuclear market was created by the EURATOM Treaty, Article 52 of which established the EURATOM Supply Agency (ESA) to ensure a regular and equitable supply of nuclear fuels to EU users in line with the objectives of Article 2(d). To perform this task, ESA applies a supply policy based on the principle of equal access of all users to ores and nuclear fuel.

In this context, ESA focuses on enhancing the security of supply of users located in the European Union and shares responsibility for the viability of the EU nuclear industry. In particular, it recommends that EU utilities operating nuclear power plants maintain stocks of nuclear materials and cover their needs by entering into long-term contracts with diversification of their sources of supply. ESA’s mandate is, therefore, to exercise its powers and, as required by its Statutes, to monitor the market to make sure that the activities of individual users reflect the values set out above.

Article 52 of the Euratom Treaty requires ESA to conclude supply contracts for nuclear material (ores, source material and special fissile material) in accordance with the relevant provisions. Contracting parties are utilities, operators of research reactors in the EU or producers/intermediaries selling nuclear material (imports into or exports from the EU, as well as intra-EU transfers). When concluding supply contracts, ESA implements the EU supply policy for nuclear materials. ESA also has a right of option to purchase nuclear materials produced in the Member States.

On the basis of the Euratom Treaty, ESA also monitors transactions involving services in the nuclear fuel cycle (enrichment, conversion and fuel fabrication). Operators are required to submit notifications giving details of their commitments. ESA verifies and acknowledges these notifications.

The Euratom Treaty also provides, in its Article 70, the possibility for the Commission to make recommendations to Member States on the development of prospecting for and exploitation of mineral deposits. Even financial support for uranium exploration within the territory of the Member States is seen as a possibility. To forestall any supply shortage, Article 72 allows ESA or the Commission to build up necessary stocks.
3.2. ESA status

As the nuclear fuel market is becoming increasingly complex, the remit of the Agency was strengthened by a Council Decision of 12 February 2008 establishing ESA’s Statutes, which entrusted the Agency with the creation of a nuclear market observatory in order to:

- provide expertise, information and advice on any subjects connected with the operation of the market in nuclear materials and services,
- monitor the market and identify trends that could affect security of the European Union’s supply of nuclear materials and services.

The observatory role of ESA has been extended to cover aspects of the supply of medical radioisotopes in the EU, reflecting, on the one hand, Council Conclusions ‘Towards the Secure Supply of Radioisotopes for Medical Use in the EU’ (2010 and 2012) prepared in response to increasing fragility of the current production chain, which relies on an unsustainably low number of ageing research reactors, and, on the other hand, efforts to obtain the necessary supplies of nuclear material for enriched uranium targets used for radioisotope production.

The Advisory Committee, created to act as a link between ESA and both producers and users in the nuclear industry, also operates on the basis of the Statutes for the Euratom Supply Agency.

The Committee assists ESA in performing its tasks by giving opinions and providing analysis and information. Assistance also extends to the preparation of reports, surveys and analysis.

The Committee members are appointed by the EU Member States on the basis of their relevant experience and expertise in regard to nuclear issues. The number of Committee members each Member State can appoint is laid down in the Statutes. The term of office is for three years with the possibility of renewal. The Committee has to appoint a Chairperson and two Vice-Chairpersons from among its members. The Committee is convened when it is considered necessary and usually meets twice a year.

3.3. Mandate and objectives of the ESA Working Group on Prices and Security of Supply

The aim of the Working Group on Prices and Security of Supply is to support the Euratom Supply Agency in the assessment of possible shortcomings in security of nuclear material supply and the application of appropriate market monitoring tools. The Working Group helps the Agency to carry out its tasks by giving opinions and providing analyses and information. That assistance may also extend to the preparation of reports, surveys and analyses. The results of the activities undertaken by the group are reported to the Advisory Committee during its meetings.

The mandate of the Working Group (WG) dates back to 2003, when during its meeting of 25 March 2003 the ESA Advisory Committee accepted the Agency’s proposal to create a joint task force to assess ‘the impact of all steps of the fuel cycle from the security of supply perspective’. This proposal was in line with the recommendations made by the Advisory Committee in its paper adopted on 14 February 2002 entitled ‘the Future Role of the Euratom Supply Agency and its Advisory Committee’. In 2012, after some of the members of the WG were replaced due to expiry of their term of office in the Advisory Committee, the WG drew up its work plan for 2013 and 2014 and decided that one of its major tasks would be to update the security report issued in 2005.

Members of the WG are either members of the Advisory Committee or experienced representatives of the nuclear industry, including service providers and utilities, delegated by them. The WG’s assistance to ESA in technical assessment is expected in the following areas:

- Methodology for calculating uranium price indices and ensuring the highest quality of the statistical tools for data processing,
- Risk monitoring and analysis for the security of supply of nuclear fuel in the EU,
- Long-term scenarios for EU uranium demand,
- Long-term scenarios for uranium supply,
- Evaluation of the EU situation from a worldwide perspective, including reports and analysis published by different bodies and agencies.
4. Risk analysis for security of supply in the nuclear fuel cycle

4.1. Methodology

The members of the WG met several times during 2013 and 2014 in Luxembourg, Paris and Brussels and discussed in detail risks which have potential to influence the security of supply of nuclear fuel in Europe. A comprehensive list of risks, called root causes, influencing security of supply in the nuclear fuel cycle, was developed.

Each root cause was assessed by WG members with regard to its probability of occurrence and consequences scale. In the consequences scale a distinction was made between risks occurring in the short term and long term. The assessments were done independently by 11 WG members in March and April 2014.

The two tables below include the definitions applied in the analysis for the categories of consequences and probability of occurrence.
1. Short term (up to one year)
Temporary impact. Likely to be compensated through market adjustments, industry flexibilities and existing inventories. In principle no NPP shut down. Extended outages possible for over-exposed / poorly diversified buyers.

2. Mid-term (one to five years)
Multi-year impact. Exceeds the short term adjustment potential of both market and industry. Leads to a severe depletion of fuel cycle inventories at all steps. Triggers a multi-year industry adaptation. Limited and temporary NPP shutdowns within the most affected geographic areas.

3. Long term (over five years)
Durable impact. Generalised supply chain disruption. Requires massive industry adaptation. Many temporary NPP shutdowns, potentially 100% in the most severely impacted areas. Permanent local shutdowns possible due to induced replacement of nuclear power by other forms of power generation.

Table 1: Consequences Scale

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>IMPACT ON SUPPLY</th>
<th>IMPACT ON NPP</th>
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<tbody>
<tr>
<td>1. Short term (up to one year)</td>
<td>Temporary impact. Likely to be compensated through market adjustments, industry flexibilities and existing inventories.</td>
<td>In principle no NPP shut down. Extended outages possible for over-exposed / poorly diversified buyers.</td>
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<td>2. Mid-term (one to five years)</td>
<td>Multi-year impact. Exceeds the short term adjustment potential of both market and industry. Leads to a severe depletion of fuel cycle inventories at all steps. Triggers a multi-year industry adaptation.</td>
<td>Limited and temporary NPP shutdowns within the most affected geographic areas.</td>
</tr>
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<td>3. Long term (over five years)</td>
<td>Durable impact. Generalised supply chain disruption. Requires massive industry adaptation.</td>
<td>Many temporary NPP shutdowns, potentially 100% in the most severely impacted areas. Permanent local shutdowns possible due to induced replacement of nuclear power by other forms of power generation.</td>
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Table 2: Probability Scale

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<tr>
<th>CATEGORY</th>
<th>PROBABILITY OF OCCURRENCE</th>
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</table>
| 1 | Very unlikely
Has never happened or is very unusual.

| 2 | Less Likely to happen
Seen in the industry history, or seen as less likely for documented reasons.

| 3 | More Likely to happen
Seen several times in the industry history, or seen as more likely for documented reasons.

| 4 | Rather frequent
Seen several times during the past ten years, or made almost inevitable for documented reasons.
4.2. Listing and classifying the risks

The risks were grouped into three categories representing threats in supply and demand balance, commercial and technical causes and political and regulatory causes.

A. Supply / demand balance threats

✓ Temporary suspension of production, or shortages in uranium mines
✓ Temporary suspension of production, or short lages
✓ Lack of sea ports open to nuclear transport
✓ Concentration of nuclear transport companies
✓ Reduction of production and withdrawal from uranium mining developments
✓ Lack of investment in new mines
✓ Postponement of new investments in conversion facilities
✓ Postponement of new investments in enrichment facilities
✓ Uncertain availability of secondary supplies of uranium
✓ Uncertain availability of secondary supplies of conversion
✓ Uncertain availability of secondary supplies of enrichment
✓ Major industrial accidents in uranium mining industry
✓ Major industrial accidents in conversion industry
✓ Major industrial accidents in enrichment industry
✓ Natural disasters
✓ Increase of demand in the emerging markets leading to reduced supply in Europe

B. Commercial and technical causes

✓ Overdependence on a single source of supply
✓ Horizontal and vertical concentration of the business vs competition and technological development, lessening of competition
✓ Major technological or technical failures in uranium industry
✓ Major technological or technical failures in conversion industry
✓ Major technological or technical failures in enrichment industry
✓ Major technological or technical failures in fuel fabrication industry
✓ Reduction in qualified fuel fabrication capacity
✓ Fuel fabrication issues related to licensing, fuel design
✓ New financial players on the market (brokers and traders)
✓ Shrinking market power of European utilities

C. Political / Regulatory causes

✓ Lack of harmonisation and overregulation in transport authorisation
✓ Delays and increased uncertainty of new projects in each part of the fuel cycle, due to licensing/environmental regulations
✓ Supply disruption resulting from political instability
✓ Instability of taxation or regulatory or political interference (royalties)
✓ Reduced diversification of sources due to European trend to apply sustainability standards
✓ Unharmonised non-proliferation issues e.g. obligation codes
✓ Access restrictions to nuclear material and related services e.g. temporary ban, bilateral restrictions
✓ Security of supply of fresh fuel in light of the current political situation

4.3. Risk evaluation

All the causes listed above were evaluated independently by the Working Group members. Each individual cause received a rating according to the Consequences Scale (see Table 1) and the Probability Scale (see Table 2). An average score, produced from the two ratings, was computed for each, as well as a range of scores. All the significant discrepancies were discussed and then generally reduced through consistent appraisal of the listed risks, according to recorded experiences. As a result of the scoring exercise a Top 10 Risks ranking list was established.

The Top 10 Risks according to the importance of their consequences and impact, their probability of occurrence, and short or long-term horizon are presented in Table 3. Probability of occurrence of the root causes classified in the Top 10 Risks list ranges between 2.54 and 3.27, which indicates high probability. Marks for impact on supply and impact on NPP range from 1.2 to 1.85, which indicates an impact in the short and medium term.
Table 3: Top 10 Risks

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<tr>
<th>Nr</th>
<th>Root causes</th>
<th>Probability of occurrence</th>
<th>Impact on supply</th>
<th>Impact on NPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lack of investment in new mines</td>
<td>3.27</td>
<td>1.55</td>
<td>1.25</td>
</tr>
<tr>
<td>2</td>
<td>Overdependence on a single source of supply</td>
<td>2.7</td>
<td>1.33</td>
<td>1.85</td>
</tr>
<tr>
<td>3</td>
<td>Lack of harmonisation and over-regulation in transport authorisation</td>
<td>3</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td>4</td>
<td>Reduction of production and withdrawal from uranium mining developments</td>
<td>2.8</td>
<td>1.77</td>
<td>1.25</td>
</tr>
<tr>
<td>5</td>
<td>Restrictions on access to nuclear material and related services e.g. temporary ban, bilateral restrictions, geopolitical factors</td>
<td>2.54</td>
<td>1.62</td>
<td>1.62</td>
</tr>
<tr>
<td>6</td>
<td>Reduction in qualified fuel fabrication capacity</td>
<td>2.63</td>
<td>1.5</td>
<td>1.57</td>
</tr>
<tr>
<td>7</td>
<td>Fuel fabrication issues related to licensing, fuel design</td>
<td>2.54</td>
<td>1.37</td>
<td>1.75</td>
</tr>
<tr>
<td>8</td>
<td>Suspension of production, or shortages in conversion</td>
<td>3</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>Horizontal and vertical concentration of the business vs competition and technological development, lessening of competition</td>
<td>2.72</td>
<td>1.25</td>
<td>1.42</td>
</tr>
<tr>
<td>10</td>
<td>Instability of taxation or regulatory or economic interference (royalties)</td>
<td>2.63</td>
<td>1.33</td>
<td>1.42</td>
</tr>
</tbody>
</table>
4.4. Summary of the main risks

Risk 1 Lack of investment in new mines

Lack of investment in new mines means that the contribution of new mines, perceived as needed for future market supply, is not sufficient to ensure adequacy between demand and supply in terms of volumes but also in terms of desired regional diversification, or producer diversity which itself may lead to reduced scope of contracting practices or modes. This is the case when a decision to invest in a new mining project development is postponed and therefore the timing of its actual contribution to the supply mix is not known, leading to more limited procurement strategies for utilities or a more conservative commercial approach by the producer. Reasons can be manifold due to a combination of issues hampering investment decisions. Investment decisions are usually taken once the mining investment tollgate review has given the green light to five major items, namely technical and environmental feasibility of the project, its economics, its legal and regulatory aspects, the agreements with major stakeholders, and financing. In today's situation, the economics can be challenging not only because of prevailing price benchmarks for long-term commitments but also due to lack of clarity on actual demand for very large or lengthy projects.

<table>
<thead>
<tr>
<th>Impact</th>
<th>May lead to higher exposure to country or supplier risk as diversification is more difficult to maintain. Potential price increase and shortage of nuclear material due to lead time necessary for putting new production in place.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of occurrence</td>
<td>3.27</td>
</tr>
<tr>
<td>Impact on supply</td>
<td>1.55</td>
</tr>
<tr>
<td>Impact on NPP</td>
<td>1.25</td>
</tr>
<tr>
<td>Risk mitigation</td>
<td>A strategic inventory of material(s) held by utilities can help bridge unplanned non-availability of fuel. The appropriateness of volume and form and location should be reviewed from time to time to take account of recent political developments. If world aggregated inventories of utilities are too high though, it may induce mining companies' suppliers to take quite different investment decisions in new mines. Diversified fuel supply (supplier country, location, volumes and form) to utilities further reduces the risk. Early warnings by EU institutions and concerted industry action may alleviate the impact.</td>
</tr>
</tbody>
</table>
Risk 2 Overdependence on a single source of supply

A utility (or nuclear power plant) which remains dependent upon a single source of supply for all nuclear materials and services is at greater risk of supply interruption. Most utilities have a diversified supply chain for nuclear materials and services. This enhances both short-term and long-term security of supply as well as levels of competition amongst suppliers, driving cost efficiency.

Diversification can cut across a number of suppliers at each stage of the front end of the nuclear fuel cycle — uranium mining, conversion, enrichment and fabrication. Due to the technical specifications of fuel fabrication it can be more difficult to establish alternative suppliers, but even in cases where a nuclear power plant has a single qualified fuel fabricator, supply diversification is common practice at earlier stages of the fuel cycle. Diversification also reduces risk exposure to a particular transport route.

| Impact | May lead to unavailability of materials or services due to a variety of factors, including political risk and transport logistics. |
| Probability of occurrence | 2.7 |
| Impact on supply | 1.33 |
| Impact on NPP | 1.85 |

Risk mitigation

A strategic inventory of material(s) held by utilities and suppliers can help bridge unplanned non-availability of fuel. The appropriateness of volume and form and location should be reviewed from time to time to take account of recent political developments. Diversified fuel supply (supplier country, location, transport route, volumes and form) to utilities can reduce the risk. Early warnings by EU institutions and concerted industry action may alleviate the impact.
Risk 3 Lack of harmonisation and overregulation in transport authorisation

Lack of harmonisation and overregulation cause difficulties in regard to nuclear transport, especially across borders.

The reason for this is that regulators have different approaches in each country, which could make freight scheduling a difficult and complex issue. There are references in place like the ‘Orange Book’ of the UN (‘Recommendations on the Transport of Dangerous Goods’), which deals with transport of nuclear material, and organisations facilitating nuclear transport like the European Association of Competent Authorities, which currently consists of 22 European authorities. Nevertheless, a complex system of national reporting and authorisation procedures relating to carriers of radioactive materials and lack of a single pan-European arrangement for transport package approvals hampers operations.

<table>
<thead>
<tr>
<th>Impact</th>
<th>May lead to interruptions and consignment delays and even shipment denials. This in turn increases costs of operations. It is a potential source of administrative burden.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of occurrence</td>
<td>3</td>
</tr>
<tr>
<td>Impact on supply</td>
<td>1.42</td>
</tr>
<tr>
<td>Impact on NPP</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Risk mitigation

Simplification of procedures and reduction of administrative burdens would result in time and resource savings. Different stakeholders have to be made aware of the excellent safety record in the transport of radioactive materials. Creating one pan-European arrangement for transport package approvals would contribute to improving conditions for services, especially with regard to cross-border transport. Diversified fuel supply (supplier country, location, volumes and form) to utilities further reduces the risk. A strategic inventory of material(s) held by utilities and suppliers can help bridge unplanned non-availability of fuel.
Risk 4 Reduction of production and withdrawal from existing uranium mining operations

Reduction of existing uranium mining operations happens either by accident or under economic constraints. When market conditions are unfavourable, the mining company may contemplate three remedial steps in order to adjust costs accordingly. First, the operator may act in a more selective manner, e.g. taking the best part of the ore body and leaving aside lower grade or deeper ore. Second, although fixed cost components account for a major part of the cost structure, the mine operator may decide to reduce production when new accessible sales prices are below cash costs. Third, if market conditions keep deteriorating, the mining operator may decide to put the mine under maintenance and care mode or shut it down for good. Withdrawal from existing uranium mining operations happens for two main reasons: impossibility of adjusting to market conditions or decision to refocus on other more profitable industrial or mining activities. There is usually no successor in the first case as the best part of the ore body has been mined out. In today’s situation, the reduction of production can only be a temporary solution for a mining company if its position on the merit curve is badly ranked.

Impact

May lead to higher exposure to producer or supplier country as diversification is more difficult to maintain. World reserves are partially or fully reduced, thus potentially impacting on overall mid-term market supply. Mid-term prices can increase.

Probability of occurrence

2.8

Impact on supply

1.77

Impact on NPP

1.25

Risk mitigation

A strategic inventory of material(s) held by utilities can help bridge unplanned non-availability of fuel. The appropriateness of volume and form and location should be reviewed from time to time to take account of recent political developments. Diversified fuel supply (supplier country, location, volumes and form) to utilities further reduces the risk.
## Risk 5 Restrictions on access to nuclear material and related services, e.g. temporary ban, bilateral restrictions, geopolitical factors

Like in many other industries, access to nuclear materials and services may be temporarily or indefinitely restricted for political reasons. For example, an exporting nation or one or more importing countries may decide to impose quotas on quantities or values or completely suspend the sale, purchase, transport, storage or processing of nuclear materials in any form and of any origin. Reasons can be manifold and may be factual such as preferential supply of domestic needs in case of scarce resources, avoidance of excessive dependency on a single supply source, protection of domestic nuclear industry, anti-dumping actions or sustainability issues. Restrictions, however, may also be driven by reasons that are completely outside the nuclear industry’s sphere such as trade conflicts or political disturbances between nations or regions developments.

### Impact

<table>
<thead>
<tr>
<th>Probability of occurrence</th>
<th>2.54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on supply</td>
<td>1.62</td>
</tr>
<tr>
<td>Impact on NPP</td>
<td>1.62</td>
</tr>
</tbody>
</table>

### Risk mitigation

A strategic inventory of material(s) held by utilities and suppliers can help bridge unplanned non-availability of fuel. The appropriateness of volume and form and location should be reviewed from time to time to take account of recent political developments. Diversified fuel supply (supplier country, location, volumes and form) to utilities further reduces the risk. Early warnings by EU institutions and concerted industry action may alleviate the impact.
**Risk 6 Reduction in qualified fuel fabrication capacity**

Fuels used in civil NPPs range from unique designs supplied by dedicated single fabrication plants to those for globally established reactor classes where utilities are ostensibly able to choose from a range of vendors, many with several plants. Whilst the risks for the former are binary and clear, for the more common reactor classes the requirements for a fuel vendor's design to achieve national generic licensing and specific reactor use regulatory approval, as well as fabrication plant quality assurance qualification, result in the apparent freedom of these utilities being restricted to purchasing from only those fabrication plants that are qualified to their particular requirements and hence fabricated fuel will not be a fungible commodity. This situation prevails against a market backdrop of overcapacity as the few Western fabricators face geographic shifts away from traditional markets, a dip in global demand, increasing challenges from new entrants (as developing markets seek indigenous capability), and penetration across traditional western/eastern European boundaries. As a result there is a risk of reduction in qualified fabrication capacity as established fabrication plants become uneconomic and fabricators come under increasing pressure to restructure. Where fabricators reduce the number of plants, their ability to offer alternative plants that could most readily be qualified to produce the required design is commensurately reduced.

**Impact**

May lead to loss of generation where NPPs lack stocks sufficient to cover the transitional period needed to qualify an alternative plant and/or vendor. Reduced numbers of plants may result in rising fuel costs due to less competition. Opportunities for diversification will be similarly reduced.

**Probability of occurrence**

2.63

**Impact on supply**

1.5

**Impact on NPP**

1.57

**Risk mitigation**

A strategic inventory of fabricated fuel can insulate utilities against removal of fabrication capacity from a previously used plant, but where the only alternatives are different designs (such as from another vendor) then the stocks need to be large enough to cover the extended periods necessary for safety case preparation by the utility as well as national generic licensing and specific reactor use approval as well as the qualification of the alternative plant. Utilities can reduce the potential transitional period by progressing the various stages up to and including qualification of alternative plants. Ultimately they can remove the risk by taking this to the point of operation with cores of mixed fuel designs or where they have multiple plants of the same design, having a diversified supply policy for fabricated fuel. Ongoing monitoring of the fabrication market by utilities, preferably supported by greater openness of fabricators, will allow the utilities to judge more accurately the extent of the risk and encourage early mitigation. The costs of taking a design/plant through to qualification are considerable. These (and hence the impact of the risk) could be reduced through greater regulatory harmonisation for fuel design licensing and by proactive licensing by fuel vendors in potential market areas. Information exchange between utilities on fuel design operating experience would support a more harmonised approach to fuel design evolution and thus discourage any increase in the number of technical market segments that would lead to greater market fragmentation and exacerbate the risk.
Risk 7 Fuel fabrication issues related to licensing, fuel design

This risk was not identified in the first study (2005). It indicates the importance of fuel fabrication although this is not the most expensive component of the total fuel cost. Its importance is related to the residence time of fuel assemblies in a reactor core, which is at least five years. Reliability is very important since fuel is expected to operate during that period without failure.

Fuel design or licensing-related problems have a generic character and observed design failures can affect multiple clients. They can lead to temporary shutdown of a plant, extended outages or reduction of the plant’s output level. They can require extensive fuel inspection programmes which also influence the outage length. Fuel that is prematurely discarded and unable to attain its design burnup is more costly. Design is specific to the reactor type and therefore an alternative fuel fabricator is not always available.

Impact

May lead to loss of generation where NPPs lack stocks sufficient to cover the transitional period needed to qualify an alternative plant and/or vendor. Reduced numbers of plants may result in rising fuel costs due to less competition. Opportunities for diversification will be similarly reduced.

<table>
<thead>
<tr>
<th>Probability of occurrence</th>
<th>2.54</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on supply</td>
<td>1.37</td>
</tr>
<tr>
<td>Impact on NPP</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Risk mitigation

Only load fuel designs qualified through adequate lead test programmes performed on representative reactor types. If possible, qualify alternative fuel designs, plants or vendors.
Risk 8 Suspension of production, or shortages in conversion

Suspension of production or shortages in conversion could be the result of either an unplanned conversion disruption (for example an accident or changes in regulatory requirements) or postponement of investment in conversion facilities.

Impact

Unplanned conversion disruptions are likely to have a limited and short-term impact for utilities. Currently, the conversion facilities do not utilise their full capacity and there are large inventories of UF6 available on the market. Therefore, the industry would most likely be able to handle such short-term impacts. However, delay or postponement of investments in conversion facilities could have a long-term impact on supply. Such lack of investment would most likely stem from an expectation of low profitability even though there could be other reasons. For quite some time now, the conversion industry has been pointing out that profitability is low and that today’s spot prices are too low to support investments. In the course of 2014, Cameco fast-tracked the premature ending of the conversion agreement with the Springfields plant in the UK, which had been scheduled to run until 2016. There are only four companies that provide the vast majority of the conversion supply to EU utilities. In a worst case scenario, if one of these four suppliers were to exit the conversion business it could have a serious impact on the nuclear fuel supply chain. It is most likely that none of these four companies will exit the market, but postponement of investments in new conversion capacity combined with an increase in demand could result in a shortage of conversion sometime in the next decade.

Probability of occurrence

Impact on supply

Impact on NPP

Risk mitigation

Strategic inventory of converted material and long-term diversified conversion supply are the most obvious mitigation activities. All stakeholders should also think about sustainability in the conversion industry. Holding a large strategic inventory to mitigate risk in the conversion stage could actually end up being more expensive than sharing some risk and value with conversion suppliers in order to maintain a viable supply chain.
Risk 9 Horizontal and vertical concentration of the business vs competition and technological development, lessening of competition

In the nuclear fuel business horizontal concentration means that one company has a dominant market position or market power in one or more sectors of the nuclear fuel supply chain. Such a company then has a strong influence on prices in that (those) sector(s). Vertical concentration means that one company owns several parts of the supply chain needed in producing nuclear fuel. This makes one-stop shopping possible but concurrently it may restrict customers’ options for optimisation and diversification.

Impact

Horizontal concentration lessens competition and may lead to higher prices, depending on the level of dominance. Strong market position may also lessen (or even stop) technological development and make diversification more difficult. Vertical concentration increases a supplier’s market power and, depending on the market share, may also lead to higher prices and fewer diversification options.

| Probability of occurrence | 2.72 |
| Impact on supply          | 1.25 |
| Impact on NPP            | 1.42 |

Risk mitigation

Where there is horizontal concentration, a strategic inventory of material(s) or fabricated assemblies, as the case may be, held by utilities reduces the risk of fuel shortage. Diversified fuel supply (supplier country, location, volumes and form) to utilities further reduces the risk.

In the case of vertical concentration, a large strategic inventory of fabricated assemblies held by utilities reduces the risk of fuel shortage. A licensed second supplier and diversified supply chain further reduces the risk. These measures should be implemented in due time according to risk analysis and anticipation of the time frame for any changes on the market.
Risk 10 Instability of taxation or regulatory or economic interference

Instability or unpredictability of business environment leading to industrial or investment adjustments or deferral.

In the mining industry, instability of taxation means any unexpected increase of taxes, duties or royalties applied to mines in operation or mining developments. For nuclear fuel cycle companies, instability of regulatory environment means evolving requirements imposed by safety or administrative authorities. For nuclear reactor operators, economic interference means, for example, sudden and nuclear specific taxation.

Impact

Higher taxation or risk thereof in a uranium-producing country may deter investors from investing in or financing a new mining project because the rate of return on investment is difficult to appraise and secure, thus leading to the use of high WACC and eventually deferral of investment. If the tax instability occurs during operations, any required adjustment of production costs may lead to more selective operations (reduction of stripping ratio) and associated reserves reduction. In the nuclear fuel cycle, regulatory change may lead to delays in constructions needed to meet market demand in a timely manner. When dealing with transport and storage of materials, suboptimal flows due to newly imposed regulatory constraints may disturb the smoothness of just-in-time operations and potentially impact on delivery schedules of nuclear materials and fuel. Penalties imposed on nuclear fuel may generate specific sourcing and inventory strategies less focused on security of supply.

<table>
<thead>
<tr>
<th>Probability of occurrence</th>
<th>2.63</th>
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</thead>
<tbody>
<tr>
<td>Impact on supply</td>
<td>1.33</td>
</tr>
<tr>
<td>Impact on NPP</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Risk mitigation

A diversified and flexible sourcing strategy can help to reduce the first impact of the risks associated with business environment instability on demand and supply sides.
5. Recommendations and measures to mitigate the risks

Risks analysed in this report have been classified according to their connection with a particular fuel cycle stage or related problems, namely mining, conversion, enrichment, fuel fabrication and licensing, access restrictions, transport and overdependence on a single source of supply. The mitigation measures indicated as remedies against all of the analysed risks seem to be underpinned by a universal principle that all utilities should avoid disruptions in supply. The two major measures are:
- maintaining an appropriate strategic inventory level, and
- diversifying the supply.

Concerning a strategic inventory of material(s), the appropriateness of volume, form and location should be reviewed from time to time to take account of recent (political) developments. The inventories should be available in different chemical forms and the volume and location should vary in time according to the perception of risks and anticipation of a changing global situation.

Diversified fuel supply with regard to supplier country, vendor of a product or service provider, location, transport route, volumes, fungibility and form should be maintained at an appropriate level at each stage of the nuclear fuel cycle. This will be the result of a specific risk analysis prepared by each utility.

Diversified fuel supply and an adequate inventory level — as described above — will enable flexible change from one supplier to another in the short term in order to overcome supply disruption.

With regard to mitigation measures against risks associated with uranics\(^3\) and access restrictions stemming from a political situation or market protection as well as fuel fabrication and fuel design licensing policies, the two major measures mentioned above should be applied by all utilities. With regard to fabricated fuel which cannot be replaced in the short term, particular emphasis should be placed on an appropriate level of the fabricated fuel assemblies. The adequacy of the inventory level should be evaluated by the utility in terms of its ability to withstand the period when security of supply could be jeopardised.

Risks related to fuel fabrication and fuel design licensing can also be reduced by providing greater regulatory harmonisation. This would reduce costs and timescale of qualification. Ultimately reactor operations with cores of mixed fuel designs could also contribute to reducing the exposure to risk.

Transport issues and associated lack of harmonisation and overregulation in transport authorisation should be mitigated in several ways. Regulators should be encouraged to simplify and harmonise regulations with regard to cross-border transport. Business stakeholders (ports, railways, authorities, etc.) should be made aware of the exemplary record of safety for transport of radioactive materials in order to facilitate their licence approvals.

Overdependence on a single source of supply should be avoided and diversified fuel supply encouraged to substantially reduce the risk of supply disruption. If diversification cannot be achieved, an appropriate level of inventories to overcome any period of disruption should be maintained.

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3. Uranium ore concentrate, converted and enriched product.
In general the security of supply of nuclear fuel to EU utilities is well maintained, but there are aspects which could be improved and the global market situation should be carefully monitored.

The goal of the working group was to provide an updated analysis of nuclear fuel availability at EU level from a security of supply perspective. Availability may easily be defined as ‘suitable, ready for use’, which also infers a required quality (specification) and location. Security of supply is more difficult to define since the context needs to be taken into account but it may be described from a utility perspective as ensuring that sufficient volume in appropriate form is obtainable in order to maintain electricity generation. This includes aspects which have been addressed in this report such as the supply source, transport logistics and inventory.

Nuclear power plants represent substantial investments. Mines and fuel cycle facilities are also significant investments. Both have payback periods of many years. Nuclear power plants are typically expected to have a generating lifetime of up to 60 years. Therefore long-term sustainability is an important consideration. Sustainability can be enhanced by actively encouraging the viability of domestic industry.

It is difficult to consider security of supply solely from an EU perspective, however, since the nuclear fuel market is a worldwide one. An interruption in the operation of a mine in Africa or Australia or a conversion plant in North America is equally likely to impact on supplies to a nuclear power plant in the EU. Although most of the costs comprise upfront capital unlike, for example gas power plants, the reliability of nuclear fuel supply in the long term is essential. Risks that threaten to undermine or disrupt stable supply need careful consideration and regular review to minimise the possibility of non-availability of fuel. The working group, which represents utilities, suppliers and intermediaries, has reviewed the current risks and impacts and identified mitigation measures. The approach described earlier has identified the top 10 risks and the principal mitigation measures (see section 5).

Bearing in mind challenges that the mining industry faces and an anticipated increase in demand for uranium in the next decade, the regional imbalance in the supply of and demand for services related to the nuclear power industry cannot be overlooked. The geographical comparison of worldwide UF6 demand on the one hand and the locations of existing conversion capacities on the other hand indicate that North America is the region with substantial oversupply of UF6 and Europe and Asia are regions with deficit (to a certain extent). The gap, which according to WNA Global fuel market report is going to widen in the current decade, will result in extension of transport needs.

In conclusion:

a) EU utilities should keep to their policy of concluding long-term supply contracts and should always maintain a decent level of diversification of suppliers. At present, natural uranium supplies to the EU are well diversified, and the same can be said about enrichment service deliveries, but final fuel assemblies are not, notably for Russian type reactors in several countries.

b) To prevent risks of shortages in nuclear fuel supply, appropriate levels of inventories should be maintained by EU utilities and producers. This could mitigate risks in the short term but long-term investments in new facilities are needed. Since building new infrastructure is capital-intensive, it requires stable and favourable market conditions or government incentives to guarantee a return on investment.

In addition, EU industry should maintain technological leadership on the whole nuclear fuel supply chain, including enrichment and reprocessing. Resources of natural uranium located in different Member States could be considered as a potential source of supply, at least from a long-term perspective.

It is recommended that ESA, through its established market observatory role and in regular dialogue with the Advisory Committee, review the identified risks on an annual basis and include references in its Annual Report so that all parties concerned can be made aware and take appropriate action to mitigate relevant risks.