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Analysis of the Nuclear Fuel Availability at EU Level from a Security of Supply Perspective

Euratom Supply Agency – Advisory Committee Task Force on Security of Supply

Final Report of the Task Force

June 2005[1]

[1] The analysis was undertaken in 2003 and early 2004 (before the EU enlargement on 1 May 2004), and therefore focuses on the EU-15. Due to rapidly changing market conditions, it was not possible to include the latest market developments in the analysis.

TABLE OF CONTENTS

THE MEMBERS OF THE TASK FORCE:

Mr. Ali Etemad (Chairman)	Vattenfall, Sweden
Mr. Thierry Arnold	EDF, France
Mr. Georges Capus	Cogema, France
Mr. Germán García-Calderón	ENUSA, Spain
Mr. Arthur Max	RWE Nukem, Germany
Mr. Gérard Pauluis	Synatom, Belgium
Mr. Bahi Sivalingam	Rio Tinto, U.K.
Mrs. Dorothy Seed (during 2003)	BNFL, U.K.

ESA SECRETARIAT:

Mr. Patrick Vankerckhoven (until June 2004)

Mr. Jussi Vihanta

The work was performed under the umbrella and according to the recommendations of the ESA Head of Unit, Ms. Dolores Carrillo-Dorado (until the transfer of ESA to Luxembourg in June 2004).

INTRODUCTION

1.1. General Context of the Work

"The purpose of an EU energy supply security policy is to secure, for the EU, the immediate and longer-term availability of a diverse range of energy products at a price which is affordable to all consumers (domestic and industrial) while respecting environmental requirements."[2]

A stable system of electricity supply is essential for the European citizens and for the economy. Nuclear reactors are a key element in the electricity supply, and their nuclear fuel supply is important for the future of nuclear power in the EU.

- Nuclear power is the largest single source of electricity in the EU (21% of installed capacity and 33% of electricity production).
- In case of a disturbance in oil or gas supplies to a conventional power plant, the plant has to be shut down as soon as there is no supply and no fuel inventories at the plant. These inventories are usually not larger than for one to three months' forward demand. In most EU countries, strategic oil stocks correspond to 90 days' forward requirements. In the case of nuclear power, nuclear reactors operate without refueling for 12 to 18 months (thus securing months of electricity supply before halting), and if delivery of fresh fuel is delayed, a reactor can still be operated for 2-6 months beyond its scheduled shut down, at gradually lower power. As operators of nuclear power plants usually receive their full fuel reloads several months in advance of refueling, and the fuel supply inventories of material in process within the procurement chain amount to months of requirements, this mode of electricity production provides an autonomy many times longer than for electricity generated by conventional combustion means (coal, oil or gas).
- For the most part, nuclear fuel used in the EU is locally produced (part of conversion and major parts of enrichment and fuel fabrication), but natural uranium is almost totally imported. However, due to geopolitical conditions, uranium imports are much less vulnerable than imports of oil and gas.

Therefore, nuclear fuel security of supply (later often mentioned by the acronym S.o.S) provides a unique service and is essential for the EU at large, for geopolitical reasons of autonomy, but also to the utilities for their direct business success and for the adequate electricity supply to society.

With appropriate measures, nuclear fuel supply can be assured within the EU for years. However, this situation has to be monitored over time by a dedicated entity. So far, this is part of the mission of the Euratom Supply Agency (ESA) (see chapter 3).

[2] Green Paper "Towards a European strategy for the security of energy supply", 2001, annex I.

1.1.1. Factors influencing the nuclear fuel security of supply

Security of supply concerns in the nuclear fuel cycle result from the fact that primary production of natural uranium covers only some 60% of world demand, while the remaining part comes from historical production (inventories and weapons dismantling) and from the re-enrichment of tails of depleted uranium resulting from the enrichment process.

The opening and liberalisation of electricity markets have a potentially negative influence on security of supply because utilities are under an increasing pressure to cut costs. As a consequence, there is a decrease of stocks in many countries as part of this reduction of operational costs for utilities. The appropriate level of stocks and the entire fuel procurement policy depends on the size and electricity generation pattern of each utility. Until now, there are no official EU requirements on nuclear material stocks (to the contrary of oil and gas for which stocks are mandatory, yet of only three months for oil and gas).

As background to the current situation, it can be recalled that for several decades the uranium market was characterised by a build-up of inventories. Until the mid 1980's, primary production was above consumption, but after the scaling back of new nuclear power programmes (especially after the Chernobyl accident), investments in mining were also curtailed and a steady reduction of inventories followed. The break-down of the Soviet Union and the recycling of former weapon material as well as the liberalisation of electricity markets have encouraged this inventory reduction at the expense of new investment in the fuel supply chain, especially in uranium mining and conversion. As a result the nuclear fuel infrastructure is aging and in some instances prone to operational problems. Also production has now been concentrated in a limited number of facilities, and opening new mines or processing facilities involves years of environmental and safety assessments, which mean that new supply cannot quickly respond to an increase in demand.

Transport is an essential part of the nuclear fuel supply chain, in particular for conversion and enrichment due to the geographical imbalances of their production between Europe and North America. New transport regulations and the reluctance of many ports and carriers to accept nuclear materials as cargo put a threat on these necessary movements of nuclear materials.

1.1.2. Mandate and objective for the Task Force's work

During its meeting of 25 March 2003, the ESA Advisory Committee accepted the proposal made by the Agency 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 14th February 2002 entitled "the Future Role of the Euratom Supply Agency and its Advisory Committee".

The mandate of the Task Force "Security of Supply" is to help the ESA and provide technical assistance in the assessment, in particular in the following areas:

- Analysis of market data and review of the scenarios of supply and demand.
- Identification and monitoring of market trends.

- Assess the security of supply through the different stages of the fuel cycle, considering possible scenarios, and review the question of stocks of natural and enriched uranium as well as fabricated fuel.

The analysis of this Task Force encompasses the following items:

- Uranium supply from primary and secondary sources and related risks for S.o.S.
- Possible unbalance of supply and demand for conversion and enrichment.
- Effects of increased transport from/to the USA on prices and S.o.S.
- Inventories in a liberalised market.

1.2. EURATOM Treaty: Legal Background and Principles of Security of Supply

The fundamental objectives of the European Atomic Energy Community (Euratom) Treaty are to contribute to the raising of 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 in the Community. In order to perform this task, the Community shall ensure that all users in the Community receive a regular and equitable supply of ores and nuclear fuels.

The Euratom Supply Agency, operative since 1960, is the body established by the Euratom Treaty to ensure this supply by means of a *common supply policy* based on the principle of equal access to sources of supply (Chapter VI of the Treaty).

The Euratom Supply Agency's mission is to ensure, under the supervision of the European Commission, a regular and equitable supply of nuclear fuels for Community users. The Supply Agency and the Commission pursue the objective of long-term security of supply through diversification of supply sources and the avoidance of excessive dependency on any one supply source, and ensure that in a context of fair trade and liberalised electricity markets, the viability of the European industry is maintained.

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 has been foreseen as a possibility. In case of a pending supply shortage, Article 72 allows the Supply Agency or the Commission to build up necessary stocks. [3]

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[3] Article 70 of the Euratom Treaty:

Within the limits set by the budget of the Community, the Commission may, on such conditions as it shall determine, give financial support to prospecting programmes in the territories of Member States.

The Commission may make recommendations to the Member States with a view to the development of prospecting for and exploitation of mineral deposits.

The Member States shall submit annually to the Commission a report on the development of prospecting and production, on probable reserves and on investment in mining which has been made or is planned in their territories. The reports shall be submitted to the Council, together with an opinion from the

2. SUMMARY OF THE SUPPLY AND DEMAND ANALYSIS

Supply and demand of uranium, conversion, enrichment and fabrication (in less detail for the latter) has been analyzed by the Security of Supply Task Force for the Western Reactors until 2020. The analysis is based (to the extent relevant) on the findings of the World Nuclear Association Market Report published in September 2003.

For a full coverage of the analysis, refer to Annex 1 of this report.

Western Reactors in this study represents:

- All Western designed reactors; and
- all Russian designed reactors in the EU member states (in Finland and the new Member States) as well as Bulgaria.

Thus demands of the reactors in CIS countries and their sources of supply are excluded.

The results of the study are summarized hereafter:

- There is a **gap between the fuel requirements of the reactors and the primary supply of uranium and conversion services.**
- Secondary supplies have the potential to fill this gap **until 2008, for conversion, and until 2010, for uranium** (from HEU[4], re-enrichment of depleted uranium tails, inventories, etc.).
- **Beyond those dates new supplies** (primary or secondary) **are necessary** (the existing US-Russia HEU Agreement[5] expires in 2013).
- In the absence of sufficient additional uranium and conversion supplies (after 2008/2010), **the gap may be reduced by adjustment of the enrichment tails assay.**
- There exists enough current or foreseen capacity for the enrichment services through the period (assuming that Russian enrichment will replace the contribution of the US-Russia HEU Agreement after 2013).

Commission which shall state in particular what action has been taken by Member States on recommendations made to them under the preceding paragraph.

Article 72 of the Euratom Treaty:

The Agency may, from material available inside or outside the Community, build up the necessary commercial stocks to facilitate supplies to or normal deliveries by the Community.

The Commission may, where necessary, decide to build up emergency stocks. The method of financing such stocks shall be approved by the Council, acting by a qualified majority on a proposal from the Commission.

4 Down-blended highly enriched uranium from past military use (in Russia and the USA).

5 The US-Russia HEU agreement was concluded in 1993 for 20 years concerning the disarmament of nuclear weapons and the subsequent use of the military origin highly enriched uranium for commercial nuclear reactors.

- Reducing the tail assay as mentioned above **will increase the enrichment demand**. As a consequence,
  - **new capacities in the West will then be needed around 2013;**
  - **and/or the Russian capacities must be used more effectively.**
- **Enough fuel fabrication capacity exists** through the period but it is very concentrated.

3. RISK ANALYSIS FOR SECURITY OF SUPPLY IN THE NUCLEAR FUEL CYCLE

3.1. Methodology

Risks which could jeopardize the security of supply are identified and analyzed with respect to their:

- **Consequences**
  - Impact on the supply/demand balance
  - Impact on the performance of the nuclear power plants
- **Probability**
- **Root cause**
  - Accident
  - Social/political interferences
  - Regulations
  - Market

The most "important" risks are identified as a result of the joint examination of "probability" and "impact".

To illustrate the Task Force's findings, the product of probability and impact is used to give an indication of the "weight" that a certain risk may have relative to another. This 'product' should not be taken as an absolute measure.

The previously mentioned Green Paper retains three major classes of threats to a secure energy supply:

- Economic
- Physical
- Environmental

The Task Force considers that there are, however, other classes of threats to be considered, namely overregulation and political overburdening and interference.

From an operational/practical point of view another classification is adopted in this report to classify the risks threatening the fuel cycle supply chain at various time frames, under various types of situations.

This report is focusing at fuel cycle chain disruption risks that can force a reactor to cease power production.

The two following tables include the definitions contemplated in the analysis for the categories of consequences and the categories of probability of occurrence.

Table 1: Consequences Scale

Category	Impact on Supply	Impact on NPPs
1	**Temporary impact (one year or less)** 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	**Multi-year impact (one to five years)** 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 shut downs within the most affected geographic areas.**
3	**Durable impact (over five years)** Generalised supply chain disruption. Requires a massive industry adaptation.	**Many temporary NPP shut downs, potentially 100% in the most severely impacted areas.** Permanent local shut downs possible due to induced replacement of nuclear power by other forms of power generation.

Table 2: Probability Scale

Category	Probability of Occurrence
1	**Very unlikely** Has never happened or is very unusual.
2	**Likely to happen** Seen several times in the industry history, or seen as likely for documented reasons.
3	**Rather frequent** Seen several times during the past ten years, or made almost inevitable for documented reasons.

3.2. Listing and Classifying the Risks

In addition to the categories previously explained a distinction was made between delivery disturbances occurring in the short term and long term.

The root causes leading to short term delivery disturbances – that leave no time to act on these root causes - are likely to represent the most troublesome risks, in particular because they are more difficult to mitigate.

Long term refers to disturbances that could occur in the future if no action is taken beforehand.

On the other hand, supply shortages foreseen for now that could develop only on a horizon of 15-20 years do not pose great threats because it is believed that the market and the industry will have time to adjust.

A special mention should be devoted to market distortions which are mainly commercial risks, and not direct S.o.S. risks, even if they ultimately can induce S.o.S. risks through their impact on the industry structure.

LIST OF IDENTIFIED ROOT CAUSES:

After a careful examination of all the risks mentioned by the Task Force members, the following list was retained for further evaluation. The risks are gathered under three categories, and each of them applies to one or more segments of the front-end supply chain.

Delivery Disturbances

1. Temporary suspension of production, or shortages, in uranium mines, conversion, enrichment, fabrication facilities

2. Financial/legal difficulty for producers

3. Interruption of the US-Russia HEU Agreement

4. Lack of sea ports open to nuclear transports – concentration of nuclear transport companies

5. Withdrawal from uranium mining towards more profitable activities Uncertainty on long term prices and costs in mines – currency inflation, regulatory interference.

6. Uncertainty in relation to secondary supplies: lack or postponement of investment in new mines, conversion and enrichment facilities.

Commercial and Technical Causes

7. Overdependence on a single source of supply

8. Excess restrictions to Russian enrichment services, decrease of competition

9. Common centrifuge technology for Urenco & Areva, and its effect on competition

10. Uncertainty of US enrichment capacity in future

11. Vertical business integration vs. competition and technological development.

12. Loss of EU know-how in uranium exploration and mining

Political / Regulatory Causes

13. Overregulation, frequent changes and lack of harmonization in transport approvals/authorization

14. Reduction in number of fuel fabrication plants and increase in related logistics

15. Delays and increased uncertainty of new projects due to licensing/ environmental regulations

16. Supply disruption from politically unstable regions

3.3. Risk Evaluation

3.3.1. Methodology for evaluating the listed causes and their potential impacts

All the above listed selected causes were evaluated independently by the Task Force members. Each individual cause received a quotation according to the "Consequences Scale" (see Table 1) and to the "Probability Scale" (see Table 2). An average score, being the product of the two average quotations, was computed for each, as well as a range of the scores. All the significant discrepancies were discussed and then generally reduced through a harmonization of the appraisal of the meaning of the listed risks, according to recorded experiences.

Detailed results of the evaluation are provided in Annex 2. The findings are provided in section 3.3.2.

3.3.2. Major risks classified by their potential impacts

Table 3: Categorisation of the Top 10 Risks
according to the importance of their consequences and impact,
their probability of occurrence, and short or long term horizon

Identified Root Cause		Consequences/Impacts	Occurrence Probability	Score	ST/LT
1.	Uncertainty in relation to secondary supplies: Lack of investment in conversion	2.17	2.58	5.6	LT
2.	Uncertainty in relation to secondary supplies: Lack of investment in new mines	2	2.58	5.16	LT
3.	Financial/legal difficulties for producers	2.17	2.3	4.99	ST+LT
4.	Overregulation, frequent changes and lack of harmonisation in transport approvals/authorisations	1.92	2.58	4.95	ST
5.	Permanent closure of a uranium mine	2	2.4	4.8	ST+LT
6.	Lack of ports open to nuclear transport - concentration of nuclear transport companies	1.92	2.42	4.65	ST

7.	Permanent closure of a conversion facility	2.8	1.6	4.48	LT
8.	Interruption of the US-Russia HEU Agreement	2.17	1.92	4.17	LT
9.	Uncertainty of US enrichment capacity in future	1.67	2.5	4.17	LT
10.	Delays of new projects due to licensing/ environmental regulations	1.58	2.58	4.08	LT

Scale: 1-3 for impact and probability; 1-9 for score

LT = Long term

ST = Short term

For definitions of ST/LT, please see section 3.2.

Note: This score ranking is indicative of the perception among the members of the Task Force.

Figure 1: Detailed Risk Assessment for the Uranium Segment[6]

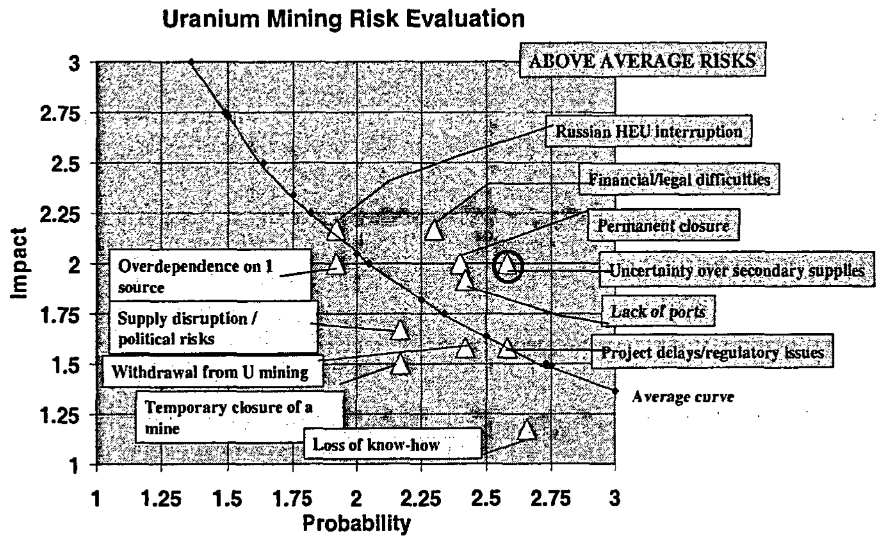
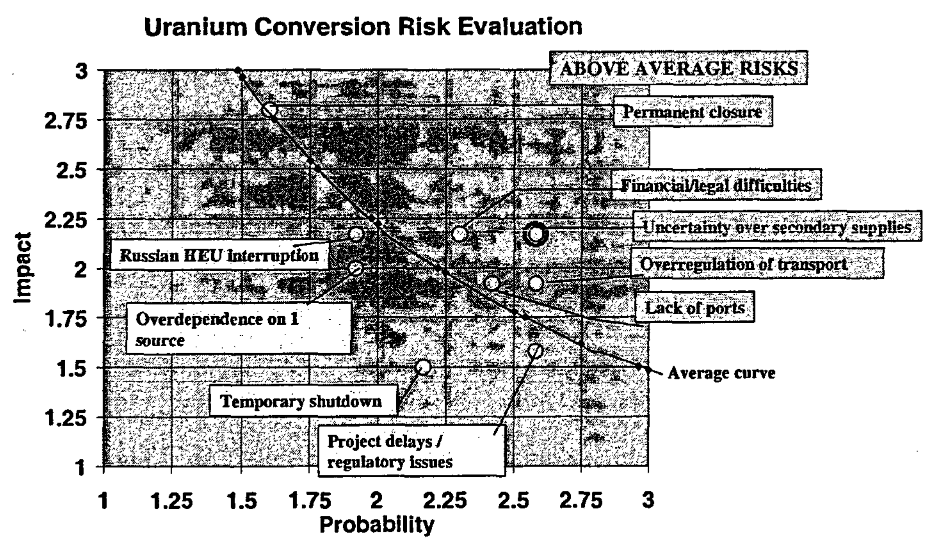


Figure 2: Detailed Risk Assessment for the Conversion Segment



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[6] **Notes:** The curve shows the average risk by fuel cycle segment

For a given probability value:

Impact = calculated average risk / probability

For a given impact value:

Probability = calculated average risk /impact

Figure 3: Detailed Risk Assessment for the Enrichment Segment

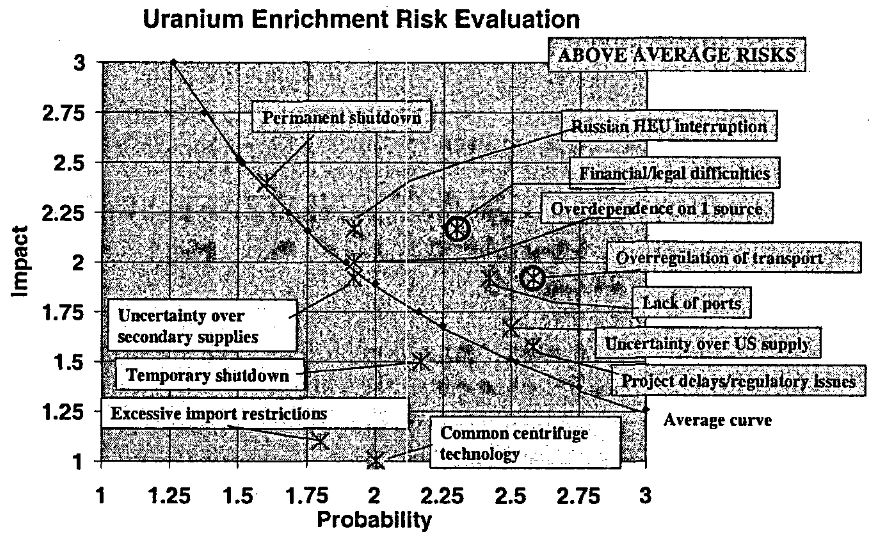
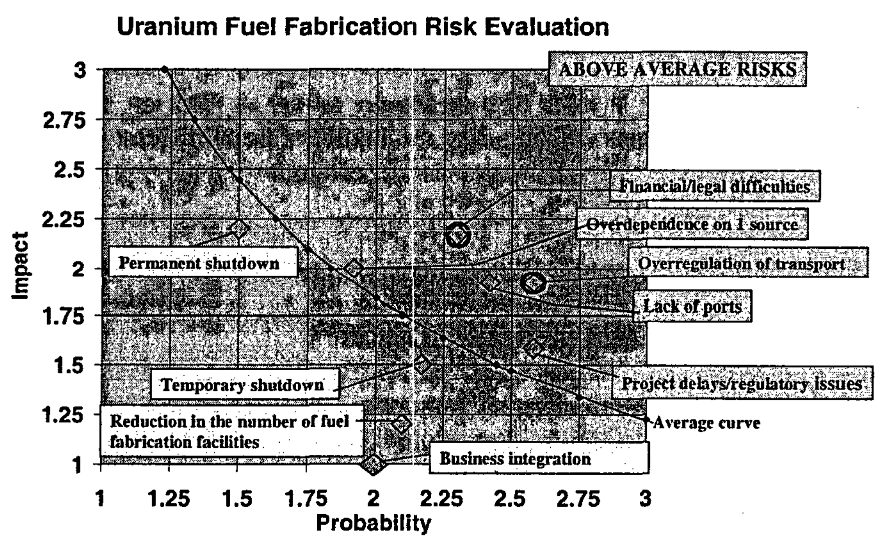


Figure 4: Detailed Risk Assessment for the Fuel Fabrication Segment



3.4. Summary of the Main Risks

There are four major risk clusters that can be sorted by their importance and root cause:

 # 1: Uncertainties on secondary supplies (top 1, 2, 8), with a special emphasis on **Russian HEU** are predominantly on top of the list due to their consequences on required investments. The importance given to secondary supplies reflects the share of this supply source especially in the US, which in turn affects all regional markets.

 # 2: Transportation problems of various origins (regulatory, lack of ports, **top 4 & 6**) are listed as very serious, essentially because of their potential very short-term potential of occurrence and consequences.

 # 3: Permanent closure of a mine or a conversion facility (top 3, 5 and 7). Currently, conversion is generally considered the weakest link of the fuel cycle, and for the EU the situation is especially acute, since about 60% of the Western world conversion capacity is in North America. Therefore, the problems of conversion and transport are closely linked together.

 # 4: Uncertainties on US enrichment capacity (top 9 & 10). This is not totally disconnected from the item #1. Currently, 35-50% of annual US enrichment requirements are fulfilled by down-blended Russian HEU material.

4. MEASURES TO MITIGATE THE RISKS

The risks may also be classified according to their short term or long term potential of occurrence. Indeed, against short term risks (one or two years) the preferred mitigation measure remains inventories of one sort or another. Such inventories should be available at the different stages of the process according to the perception of the risks, which may vary in time.

Against long term risks (not susceptible to happen in less than a year or two) remedies are more mixed, e.g. exploration and investments in new production facilities, diversification, long term contracting, and partnerships.

In any case, an effective monitoring of the supply and demand situation at EU and world levels and its likely evolution would be a very important tool for the Commission's analysis in view of the Euratom Community's responsibilities in the EU energy security of supply, as well as for the nuclear industry. The ESA which already has a unique insight into the market through its concurrence privilege, could be this monitoring tool, but would benefit from accurate information from all nuclear industries operating in the EU, on their sources and commitments as well as their stocks of nuclear material (including their quantity, form and location).

5. RECOMMENDATIONS

5.1. Risks and Proposals

To prevent risks of shortages or interruptions of production at any step of the nuclear fuel supply cycle, investments are needed in plants and in exploration. Such decisions need long term visibility on profitability, that is to say on market equilibriums, on price levels in the long term, on risks and on regulations.

To give this visibility, the Task Force recommends to the ESA, in addition to the Annual Report, to provide the European nuclear industry with periodical market surveys on

- EU stockpiles (both from utilities and producers),
- EU utilities' long term contract coverage, and
- risk analysis and general recommendations.

Additionally, specific reports could be provided on particular issues like investment finance, financial analysis, transports, insurance, regional studies, competition, etc. These documents should build a coherent corpus of high standard references accepted world wide.

On the basis of these studies, ESA should provide recommendations which could be summarised in a code of good practices, like balanced mixed, geographically diversified portfolios of contracts, solutions of partnerships between producers and utilities, adequate levels of inventories owned by producers and utilities, adequate extra capacities of enrichment allowing fair competition, and tails or REPU re-enrichment within EU territory, etc.

To improve smooth and fair operations on the market, proposals of operational measures could be elaborated and discussed with involved professional associations (ports, transporters, insurance companies, rating agencies, finance companies, etc.). Proposals on regulations could be explained and promoted before international organisations like IAEA or discussed in bilateral meetings with officials of countries involved in nuclear affairs.

Because of the importance of secondary supplies in the overall supply, the Task Force recommends that the EC should strive to be properly informed about future plans for HEU use.

Issues to be addressed include how to avoid incoherent, differing and too restrictive regulations, how to preserve a high level of safety through appropriate, efficient, objectively based and non-discriminating measures, and how to preserve fair competition on the market.

Elaboration of proposals, recommendations and codes, actions of information could be achieved through programmes conducted by specific task forces under the coordination of the Agency.

In case of any supply problem in the EU, it would be necessary to use an existing forum like the ESA Advisory Committee where actors involved in the nuclear industry (representatives of Euratom, of governments, utilities and producers) are used to meet

and work. It would provide a formal arena where discussions and decisions in the appropriate framework could take place.

The ESA could also be the appropriate place where the issue of building strategic inventories could be addressed under the aegis of the Commission and within the control of involved governments, utilities and producers.

5.2. ESA Objectives and Resources

The issue to be addressed at the time the Euratom Supply Agency had been created (1960), was to ensure a regular and equitable supply of nuclear fuels for all EU users in a context of (1) US government fissile material ownership and monopoly on the offer of nuclear materials and services, (2) strict governmental control of the nuclear industry with few references to commercial applications, (3) close administrative survey of the industrial and commercial operations, (4) perceived scarcity of source material. The ESA was to be the European "owner" and supplier of EU users, counterweight to this dominance. Times have changed: The European nuclear industry (producers and utilities) is now operating in a relatively open commercial market with the support and monitoring of the ESA, which remains however in a unique position to analyze the contractual coverage structure of the European fuel cycle operations for the users,. The more insight the ESA will add to secure a smooth and fair running of the market, the more legitimate the ESA will be for playing its part with the support of the European nuclear industry.

The following recommendations are done from this viewpoint:

To achieve the above recommended actions ESA should secure a higher level of competences in order to perform its missions in monitoring, evaluation, recommendation or normalisation. This would be conducted in balanced cooperation with institutions like the IAEA or organisations like the WNA, WNFM, NEI, WNTI etc.

ESA should have at its disposal a staff of high level experts in charge of operating and maintaining a system for collecting and analysing data provided by European nuclear industry operators. These experts would be expected to have a large experience of the market and would be subject to a status guaranteeing absolute confidentiality and that they would not join firms operating on the market before an appropriate delay, should they leave the ESA.

Operating rules of the ESA data system (obligations of data providers, obligations of ESA) would be established in consultation with providers of data, that is to say with the accordance of European nuclear companies and of qualified governmental representatives. With the support of experts from the industry, ESA should define the list of required data, calculation methods for indicators and publication procedures.

ESA should annually propose a program of recurrent and specific studies, i.e. market surveys, risk analysis, studies on technical issues, and regional surveys. These studies and actions could be performed with task forces staffed with experts from the industry and governments. The Advisory Committee would be in charge of advising on the programme and its achievement.

6. CONCLUSIONS

Although the security of nuclear fuel supply is an order of magnitude better than for coal, oil or gas, it has become weaker than in the recent past, for several reasons:

- The large and durable inflow of secondary supplies (up to 50% of demand and mainly from weapons dismantlement) has created a market environment that is prone to volatility and has induced a reduction of primary supplies below reactor needs, and an adjustment of investment in exploration and production facilities.
- Reactor performance has improved and needs have increased while new reactors appear likely.
- Inventories have been reduced, under competitive pressures.
- During 2003-04, a series of supply shocks occurred which increased reliance on non-US mined production at a time of significant US dollar weakness.

Subsequently, the risk of a delivery disturbance has increased. Over the short-term this can be mitigated by an adequate inventory of nuclear material adjusted to each utility's special needs and situations. In the long-term new facilities are needed.

The industry is aware that this necessary supply infrastructure is capital intensive and requires stable and predictable markets to guarantee the required return on an investment.

It is recommended that:

- the industry look at their supply chain including the inventory and adjust their policies (purchasing, logistics, inventory etc.) accordingly;
- utilities enter into diversified long-term business relationships at reasonable price levels with suppliers in order to secure the visibility and resilience of their own supplies and make it easier for their suppliers to decide on new investments;
- co-operation between the users of the nuclear fuel (utilities) and the producers is improved;
- a stable regulatory context is promoted to facilitate new investments for the new builds or extensions;
- ESA conducts a close monitoring and analysis of price-insensitive secondary supply.

The issues identified in this report will require a more proactive approach from the ESA to heighten its awareness of the European supply and demand situation and enable it to highlight actions that would limit the risk of a significant supply disruption within the Community.

This will demand resources, financial, but mostly human, and it is our primary recommendation that these are made available.

ANNEX I

Report on

Western Reactors Uranium, Conversion, and Enrichment Demand and Supply

prepared for

the EURATOM Supply Agency (ESA)

by

Task Force "Security of Supply"

(March 2004)

Table of Contents

Figures

Western Reactors Uranium, Conversion, and Enrichment Demand and Supply

- Executive Summary -

1. General

The EURATOM Supply Agency's Task Force "Security of Supply" analysed Western reactors uranium, conversion, and enrichment demand and supply, thereby taking into account – to the extent possible – the findings of the London-based World Nuclear Association's (WNA) new Market Report published in September 2003.

Within the Task Force's analysis, the term "Western reactors" is referring to all Western-design reactors, including those in the new European Union (EU) Member State Slovenia and in the future EU Member State Romania, plus all Russian-design reactors in the new EU Member States Czech Republic, Hungary, Lithuania, and Slovakia, and in the future EU Member State Bulgaria.

2. Fundamentals of the Front End of the Nuclear Fuel Cycle

The previous robustness and diversity of the front end of the nuclear fuel cycle is eroding gradually. Given the reduced number of players on the sellers' side, the utilities' diversification of nuclear fuel supplies is endangered, mainly in conversion services and fuel fabrication, but to a lesser extent also in enrichment services. Furthermore, it will become increasingly difficult to develop new options for any part of the nuclear fuel cycle on a short notice.

Transport of nuclear fuel is a particularly weak link, to which all players in the nuclear fuel cycle should give particular attention.

3. Western Reactors Uranium, Conversion, and Enrichment Demand and Supply

3.1 Uranium

The rising primary uranium production profile, as assumed in the WNA's "Upper Supply Scenario", combined with the contribution from inventory drawdown, allows uranium supply to stay almost in line with the WNA's Reference Case Demand to fuel Western reactors until about 2010. But in the years thereafter, a large gap between uranium supply and demand will emerge. The gap will still be large if taking into account that by experience uranium demand forecasts tend to be up to 5% too high.

Should such large gap between supply and demand tend to develop in the West, it would readily translate into a significant natural uranium price increase ahead of the effective gap appearance, because of industry time lags in fuel contracting. Higher uranium prices at stable SWU prices, or - more generally speaking - higher ratios of the UF6 price versus the SWU price, will in turn reduce the optimum tails assay, thus lowering both natural uranium and conversion demand, but also increasing enrichment needs. In case the UF6/SWU price ratio would double, the gap between uranium supply and demand in 2020 would decrease from possibly more than 20,000 tonnes U to less than 10,000 tonnes U.

To prevent such gap, huge endeavours and investments will be necessary in exploration, but also to bring new uranium projects into operation in time, in addition to the operating, planned and prospective mines which were already taken into account in the Task Force's analysis. Importantly, taking into account that new uranium projects need lead times (for licensing, development, and start-up) in the range of 7-10 years, decisions to open new mines and milles are overdue.

3.2 Conversion

If potential future Russian exports of conversion services to the West are disregarded, a gap between conversion supply and demand of the Western reactors will emerge after 2008, widening gradually. The gap would remain huge even if taking account of the fact that by experience uranium demand forecasts and, accordingly, also conversion demand forecasts tend to be up to 5% too high.

Proceeding on the assumption that the Western nuclear fuel market - after a transitional period - could take benefit of several thousand tonnes per year of Russian conversion services, such input would fill most of the gap between Western World conversion demand and supply until about 2013, the year when the current US-Russia HEU Agreement will expire. Nevertheless, after 2013 even more conversion services would be needed to bring Western reactors' aggregate conversion demand and supply into balance. The European utilities would appreciate if these additional conversion services would contribute to level out the current regional imbalances in conversion demand and supply.

But a doubling of the UF6/SWU price ratio (as stipulated above) would reduce the gap between conversion supply (including potential Russian exports) and demand for conversion services in 2020 to just a few thousand tonnes U.

3.3 Enrichment

The Task Force's analysis suggests that there is no urgent need for Russian SWU deliveries to the West, in addition to those under the current US-Russia HEU Agreement, until about 2013.

But after the expiration of the US-Russia HEU Agreement, Russian SWU deliveries would fit well into the SWU supply and demand picture of the Western reactors. Assuming that after 2013 Russia would supply toll enrichment services to the West of about the same SWU quantity as they currently deliver under the US-Russia HEU Agreement, then Western World SWU demand and supply would be pretty much in balance after 2013.

However, much higher UF6/SWU price ratios (as discussed above) will reduce the current optimum tails assay of Western reactors. As a direct consequence, the enrichment demand will increase. In this particular case additional enrichment capacities will have to be brought on line or - alternatively - new secondary SWU sources will be needed, in order to prevent SWU supply shortages.

4. Summary

Should shortages of uranium develop, the UF6 vs. SWU price ratio would likely rise. As a consequence, the optimum tails assay would drop, thereby reducing Western reactors' uranium and conversion needs substantially. However, enrichment needs would go up, transferring on the enrichment industry part of the demand.

Western Reactors Uranium, Conversion, and Enrichment Demand and Supply

- Complete Report -

1. Uranium

1.1 Fundamentals of the Uranium Industry

The uranium market is currently characterised by the following features:

- **Natural uranium production** worldwide is about 34,300 tonnes U per year (preliminary figure for 2003), accounting for about 52% of worldwide uranium demand to fuel reactors. Thus, about 48% of the current worldwide annual uranium needs are covered by secondary sources, which comprise all nuclear material other than freshly mined and milled uranium that can be fabricated into reactor-grade fuel.

- There are **only few big uranium producers**. In 2003, the five leading producers accounted for 69% of worldwide natural uranium production, and the ten leading companies provided even 89% of worldwide uranium production.

- There is a **regional concentration of natural uranium production**. Canada's Province of Saskatchewan alone accounted for about 31% of worldwide natural uranium production in 2003. The five leading uranium producing countries supplied about 77% of total production, and the ten leading countries' uranium production represented even 95% of worldwide production.

- About **10% of today's uranium supply is inelastic** with respect to price, meaning that material produced as a by-product of copper and gold will depend more on price movements of the primary commodity.

- There is a **regional imbalance between uranium production and demand**. Among the five leading uranium producing countries (77% of worldwide uranium production) there is just one (Canada) with moderate uranium needs to fuel reactors. The others have currently no operating NPPs.

The massive influx of uranium inventories experienced in recent years depressed uranium prices to extremely low levels, causing a cut-back not only in uranium production, but also in exploration efforts. Inventory holders selling uranium at low prices drove higher-cost uranium mines out of the business, thus

preventing investments in existing and new uranium production centres. And the **prospects for future uranium production** are still far from being good:

- There are just a **few new uranium production projects in the pipeline.**

- There is only limited ability to squeeze additional uranium out of existing projects.

- **Constraints to starting up a new mine**, such as lengthy Environmental Impact Assessments (EIA) uncertainties with regard to future decommissioning costs of mines and mills, play negatively on the time needed to bring a uranium production project into commercial operation.

- Uranium producers have had such hard times lately that they are not about to invest in new uranium mines and mills on the mere promise of an improving uranium market. Furthermore, **currency evolutions** make the planning of new mining and milling projects difficult.

- Uncertainties into investments due to **governments potentially selling additional nuclear fuel** (such as military uranium and plutonium) are influencing the ability of uranium producers to plan for the future and maintain expert know-how.

- Many **fuel buyers** delayed new long-term uranium contracting, **failing to send the needed signals to** existing and potential new **uranium producers** encouraging them to provide for more and/or additional uranium production.

- For uranium producers which are not so large sourcing capital for new uranium projects on the financial markets can be difficult these days. Banks are increasingly shying away from <u>long-term</u> capital projects, even when secured by so-called bankable uranium supply contracts. The economics of a new uranium project have to be extremely attractive to allow a relatively <u>short</u> payback of funds.

Secondary uranium sources have **started to evaporate** slowly, but surely:

- Utilities' excess inventories resulting from the "mismatch" between procurement and actual reactor requirements have become much smaller over the recent years.

- Russia has obviously sold most of its previous natural uranium inventories, and its nuclear fuel needs are expanding, both internally and for its captive fuel export markets.

- Russia and the USA are currently not (yet) expected to decide to mobilize more weapons-grade material just because of uranium price increases (see above).

Utilities' security of nuclear fuel supply is the result of meshing and dynamic interaction between the control of primary supply sources, long-term contracting with reliable suppliers, diversification of supply sources, and carrying stocks of appropriate quantities, forms and assays at logistically optimized places. Given these requirements, and in view of uranium producers' financial constraints, utilities may feel forced to re-evaluate their procurement strategies and take a more active role in stimulating new production.

1.2 Western Reactors Uranium Demand and Supply

1.2.1 Uranium Demand Based on World Nuclear Association (WNA) Data

In September 2003, the London-based World Nuclear Association (WNA) published its new Market Report entitled "The Global Nuclear Fuel Market, Supply and Demand 2003-2025".

Figure 1a compares the uranium **demand** to fuel "Western Reactors", i.e. requirements according to the WNA's Reference Case (see Figure 5.3 and Table II.1 of the Report), with uranium **supply** according to the WNA's Upper Supply Scenario. Hereinafter the term "Western Reactors" is referring to

- all Western-design reactors, including those in the new European Union (EU) Member State Slovenia and in the future EU Member State Romania; plus
- all Russian-design reactors in the new EU Member States Czech Republic, Hungary, Lithuania, and Slovakia, and in the future EU Member State Bulgaria.

WNA's Upper Supply Scenario is based on the following assumptions:

- Uranium production includes present and planned production operating at 80% of capacities, plus prospective production (for further details, see WNA Report, Tables 4.9, 4.10, and 4.11).
- The US-Russia HEU Agreement will run smoothly until 2013. However, beyond that date there will be no further HEU Agreement (HEU II Agreement) between the USA and Russia. Furthermore, Figure 1a proceeds on the assumption that no substantial US HEU quantities will reach the uranium market.
- The tails re-enrichment deal between Russia and the European enrichers will be extended throughout the period considered at about constant levels.
- The recycling of reprocessed uranium (RepU) and plutonium (in form of mixed oxide (MOX)) will increase over time slightly and almost steadily, to reach a natural uranium equivalent of about 4,500 tonnes U by 2012.
- All Russian uranium exports to the Western-design reactors are low enriched uranium (LEU), apart from the material coming from Russian

HEU and from tails re-enrichment deals. These LEU exports are expected to decrease gradually, and to reach about zero by 2015 at the latest.

- Russia is expected to maintain the fuel supply to all the VVER-440, VVER-1,000, and RBMK reactors it has installed in the new and the potential future EU Member States. All Russian uranium exports to the Russian-design reactors in these states are low enriched uranium (LEU). This LEU is assumed to be produced at a constant tails assay of 0.1% U-235, which is representative for the Russian enrichment facilities' current operation mode.

- The reduction of Western inventories (meaning stocks of all fuel cycle participants, including the US Department of Energy (DOE)) is substantial, amounting to 66,000 tonnes U on a cumulative basis over the period 2003-2013.

- Fabrication of ex-military plutonium into power reactor fuel will start in 2010, contributing just 400 tonnes Unat equivalent per year.

The rising primary uranium production profile, combined with the contribution from inventory drawdown, allows uranium supply to stay almost in line with the Reference Case demand (calculated for an average tails assay of Western-design pressurised water reactor (PWR) and boiling water reactor (BWR) fuel of 0.31% U-235) until 2010 (see red graph: WNA Ref. Case). But after 2010, a large gap between uranium supply and demand will emerge, amounting to almost 18,000 tonnes U by 2020.

But should part of the WNA's assumptions underlying their Upper Supply Scenario not apply, the gap between uranium supply and demand would be much higher than 18,000 t U. Particularly, individual mines assumed by the WNA to operate at constant production levels over longer periods might be forced to shut down, due to economic and/or currency evolution reasons. Furthermore, individual planned and prospective mines might not be realised, for different reasons.

However, several factors are susceptible to affect above conclusions:

- By experience, uranium demand forecasts tend to be up to 5% too high. Thus, real uranium demand may be almost 3,800 tonnes U/year smaller in 2020, reducing the gap between uranium supply and demand in that year to about 14,100 tonnes U (see blue graph: WNA Reference Case (adjusted=95%)).

- Mainland China's and India's requirements are considered to be fulfilled from Western supplies, essentially foreign to these countries. This assumption deviates from past practice and is to be monitored closely. According to the WNA, its impact is about 3,200 tonnes U/year at the end of the period under consideration.
- The non-existence of an HEU II Agreement does not signify that this material will not be made available for CIS reactors, thus freeing an equivalent quantity for exports to the West.

- The Russian nuclear front-end industry is highly integrated and self-sufficient today. It is also under pressure to remain a net contributor to the balance of payments of Russia, and can be anticipated to remain a net exporter either of LEU or SWUs, or both.
- No inventory release of US HEU is considered beyond the quantities already declared excess.

Should such a gap between supply and demand tend to develop in the West, it would readily translate into a significant natural uranium price increase ahead of the effective gap appearance, because of industry time lags in contracting.

To prevent such a gap

- huge endeavours and investments will be necessary in exploration, but also to bring new uranium projects into operation in time, in addition to the operating, planned and prospective mines which were already taken into account under "Primary Uranium Upper"; and

- substantial uranium price increases are needed to keep currently operating mines in production, to realize all planned and prospective projects, and to trigger the launching of a number of additional ones.

Higher uranium prices at stable SWU prices, or - more generally speaking - higher ratios of the UF6 price versus the SWU price, will in turn reduce the optimum tails assay, thus lowering both natural uranium and conversion demand, but also increasing enrichment needs.

1.2.2 Uranium Demand Based on Optimum Tails Assay

Figure 1b shows the impact of an increasing UF6 vs. SWU price ratio on uranium needs:

- The red graph represents the uranium demand based on the following tails assays: For the Western-design reactors on the optimum tails assay of 0.329% U-235 which applies for the currently prevailing natural uranium, conversion, and enrichment prices of US$ 12.50/lb U3O8, US$ 5.50/kg U, and US$ 95/SWU, respectively; and for the Russian-design reactors on the constant tails assay of 0.1% U-235. At these tails assays, Western reactor uranium demand would increase to about 79,800 tonnes U by 2020.

- However, it is assumed that - triggered by the increasing awareness of an approaching potential uranium supply shortage - during the period 2008-2010 the UF6/SWU price ratio applicable to the fuel for the Western-design reactors will double.

- The new UF6/SWU price ratio will reduce the current optimum tails assay of Western-design reactor fuel from 0.329% U-235 to then 0.25% U-235. As a direct consequence, the uranium demand will decrease by about 11,200 tonnes U/year (or 14%) to 68,600 tonnes U in 2020 (see black graph: Opt. TA; Doubled UF6/SWU Price Ratio).

As stated in Chapter 1.2.1, by experience uranium demand forecasts tend to be up to 5% too high. Thus, real uranium demand may be about 3,400 tonnes U/year smaller, leading to a uranium demand of just 65,200 tonnes U in that year (see blue graph: Doubled UF6/SWU Price Ratio (adjusted=95%)).

Thus, while this is in no way a forecast on the price evolution, Figure 1b shows that the doubled UF6/SWU price ratio applicable to Western-design reactor fuel, together with the slight downward adjustment of the demand, will reduce the gap between uranium supply and demand in 2020 from 22,100 tonnes U to just 7,550 tonnes U (or 12% of the demand of 65,200 tonnes U).

2. Conversion of U3O8 into UF6

2.1 Fundamentals of the Conversion Industry

The conversion industry is characterised by the following features:

- This industry is no longer very robust: Western conversion plants are getting on in years. In the medium- and longer-term, the operators may face increasing financial challenges in maintaining high technical and safety standards as well as in meeting almost steadily increasing environmental requirements.

- In the conversion industry the degree of concentration is even more distinct than in the uranium production business. After British Nuclear Fuel plc. will have ceased conversion of U3O8 to UF6 (Hex Line 4) in March 2006, only three main Western competitors (Comurhex in France, ConverDyn in the USA, and Cameco in Canada) as well as Techsnabexport (TENEX) in Russia will be left to compete for customers.

- The purchase of uranium conversion services tends to follow the enrichment services commitments of nuclear utilities. That means, due to the transportation logistics and costs involved, nuclear utilities have generally found the most economic source of conversion services to be those suppliers which are located in the same geographic region as the enrichment suppliers.

- There is a growing imbalance of UF6 supply and demand between North America and Europe. The combination of primary conversion services from ConverDyn and Cameco, plus the volume of HEU feed returned to the HEU sales agents in North America, exceeds substantially the volume of UF6 feed needed in North America. Conversely in Europe, the demand for UF6 feed represented by primary low-enriched uranium (LEU) production at Eurodif and Urenco exceeds the volume of UF6 that will be produced by Comurhex in France once BNFL's Hex Line 4 is shut down. However, logistic problems are arising from the transporting companies' decreasing interest in transoceanic UF6 transports.

- From the current point of view, the construction of a new large-sized conversion facility seems to be unlikely, given the difficulties to receive authorization for the construction and operation of such facility and the uncertainties concerning the utilization of such new facility's capacity at high load factors over the entire depreciation period.

2.2 Western World Conversion Demand and Supply

2.2.1 Conversion Demand Based on WNA Data

Figure 2a compares the **demand** for the conversion of U3O8 into UF6, i.e. requirements according to the WNA's Reference Case (see Figure 5.3 and Table II.1 of the Report), with conversion **supply**. This Upper Supply Scenario is based on the following assumptions:

- While BNFL will shut down for good its Springfields Hex Line 4 in 2006, both Cameco and Comurhex will increase the capacities of their facilities, but only slightly.[7]

- The output of the remaining three Western converters will increase according to demand, so that from about 2007 onwards all facilities will operate at maximum capacities (on average about 90% of the nameplate capacity).

- The US-Russia HEU Agreement will run smoothly until 2013 (see above). However, beyond that date there will be no further HEU agreement between the USA and Russia. Furthermore, the Figure proceeds on the assumption that no substantial US LEU quantities derived from US HEU will reach the conversion market.

If potential future Russian exports of conversion services to the West are disregarded, a gap between conversion supply and demand will emerge after 2008, widening gradually up to about 22,700 tonnes U (or 32% of demand) by 2020 (see red graph: WNA Ref. Case). The gap would remain huge even if taking account of the fact that by experience uranium demand forecasts tend to be up to 5% too high. In that particular case, the gap would still measure about 19,200 tonnes U (or 29% of demand) in 2020.

The Ministry of Atomic Energy of the Russian Federation (MINATOM) (the non-military part of which will soon be transferred into the Federal Nuclear Energy Agency within the Russian Federal Industry and Energy Ministry) controls substantial uranium conversion capacity, which was historically sufficient for the past needs of the military-industrial Soviet complex. It is located at two of the four operating enrichment facilities: The Angarsk Electrolyzing Chemical Combine (AEKhK) and the Urals Electrochemical Integrated Plant (UEKhK). The total nameplate capacity of both facilities is believed to be as high as 24,000 tonnes U/year. It is unknown whether the two facilities could still operate at such high throughput levels.

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7 The toll-conversion agreement concluded for 10 years between BNFL and Cameco in March 2005 changes this assumption, as the Springfields facility will now remain in operation.

MINATOM's conversion facilities support the indigenous commercial nuclear power program as well as MINATOM's other nuclear fuel commitments, including fuel exports to countries with Russian-design reactors. Moreover, Russia's conversion facilities may provide services for TVEL-supplied nuclear fuel to utilities in Western Europe and the Asian/Pacific region.

The Russian Federation's uranium conversion facilities are an integral part of the Russian nuclear fuel cycle, but as yet they do not provide toll conversion services to Western utility customers. Thus far, impediments to marketing strictly conversion services include the remote location of the facilities and resultant transportation costs, the absence of necessary governmental agreements (e.g. an US-Russian nuclear bilateral agreement), and the lack of requisite cylinder filling and handling facilities.

Currently, just 2,200 tonnes, but almost certainly not more than 4,400 tonnes of natural uranium are converted in Russia into UF6, leaving the two Russian conversion facilities largely under-utilized. Thus, it is reasonable to assume that the aggregate load factor of Russia's conversion facilities is less than 30%, and possibly even less than 20%.

Detailed analyses show that after the expiration of the US-Russia HEU Agreement in 2013, about 6,400-7,400 tonnes U per year will be converted in Russia to UF6, which still only represents a moderate utilisation of the two Russian conversion facilities. Thus, it is perfectly feasible that – from a mere capacity availability point of view - remaining Russian conversion capacity could be offered to Western utilities.

However, MINATOM/TENEX indicated that this would be done mainly in combination with Russian enrichment services. There are both technical and commercial reasons for this particular marketing approach:

- Firstly, yellow cake entering the Russian conversion facilities has to fulfill special purity criteria. Thus, most of the uranium mined and milled in Western facilities (ASTM grade material) may require prior purification before entering the Russian conversion facilities. (While Russian purification capacities are believed to be limited, exact figures are not available.)

- At current conversion price levels, U3O8 and UF6 (nat) transport costs plus U3O8 purification costs would make Russian conversion services unattractive for Western utility customers.

Given the fact that Russia can offer enrichment services at attractive prices, U3O8 purification and transport costs are carrying less particular weight in case conversion and enrichment services are offered together, as packages.

Proceeding on the assumption that the Western nuclear fuel market - after a transitional period - could take benefit of about 8,000 tonnes of Russian conversion services, such input would fill most of the gap between Western World conversion demand and supply until about 2013, the year when the current US-Russia HEU Agreement will expire. However, after 2013 and depending on much the same constraints as the U3O8 developments, more conversion services could be needed to bring demand and supply into balance.

2.2.2 Conversion Demand Based on Optimum Tails Assay

Figure 2b shows the impact of an increasing UF6 vs. SWU price ratio on conversion needs:

- The red line represents the conversion demand based on the following tails assays: For the Western-design reactors on the optimum tails assay of 0.329% U-235 which applies for the currently prevailing natural uranium, conversion, and enrichment prices of US$ 12.50/lb U3O8, US$ 5.50/kg U, and US$ 95/SWU, respectively; and for the Russian-design reactors on a constant tails assay of 0.1% U-235. At these tails assays, Western reactor conversion demand would increase to about 75,300 tonnes U by 2020.

- The black line gives the conversion demand if it is assumed that during the period 2008-2010 the UF6/SWU price ratio applicable to Western-design reactor fuel will double. The new UF6/SWU price ratio will reduce the current optimum tails assay of Western-design reactor fuel from 0.329% U-235 to then 0.25% U-235. As a direct consequence, the conversion demand will decrease by about 11,100 tonnes U/year (or 15%) to 64,200 tonnes U in 2020 (see black graph: Opt. TA; Doubled UF6/SWU Price Ratio).

As stated in Chapter 1.1, by experience uranium demand forecasts and, accordingly, also conversion demand forecasts, tend to be up to 5% too high. Thus, real conversion demand may be about 3,200 tonnes U/year smaller, leading to a conversion demand of just 61,000 tonnes U in 2020 (see blue graph: Opt. TA; Doubled UF6/SWU Price Ratio (adjusted=95%)).

Thus, a doubling of the UF6/SWU price ratio, together with the slight downward adjustment of the conversion demand, will reduce the gap between conversion supply (including potential Russian exports) and demand in 2020 from 18,900 tonnes U (or 25% of demand) to just 4,600 tonnes U (or 7.5% of demand).

3. Enrichment

3.1 Fundamentals of the Enrichment Industry

The uranium enrichment industry is characterized by the following features:

- As in the conversion industry, also in the uranium enrichment industry the degree of concentration is even more distinct than in the uranium production business. There are only three bulk producers in the West (US Enrichment Corporation (USEC) in the USA, Eurodif (with Cogema as major shareholder and sales agent) in France, and the tripartite Urenco Group, with facilities in Germany, the Netherlands, and the United Kingdom), plus TENEX in Russia.

- There has been a marked reduction in the industry's and the governments' funding of research and development in all parts of the nuclear front end. Furthermore, funding of individual advanced enrichment technologies did

not result in the desired progress. Direct effects of this are reduced infrastructures (particularly in the USA) and aging plants (particularly in the US an France).

- In 2005, some 70% of the enrichment equipment will be more than 25 years old. Given the fact that the US Department of Energy's (USDOE) Paducah plant is much older than Eurodif's George Besse enrichment facility, USEC is under much stronger pressure than Eurodif to replace its enrichment capacities by modern ones.

- Today, advanced centrifuge technology is seen as the future. But concerning centrifuges fulfilling all requirements for commercial operation, the Western market has just two "haves", namely Urenco and Minatom/TENEX, and two "have-nots", namely USEC and Eurodif/Cogema. The "have-nots" currently have not demonstrated any credible alternative to centrifuge enrichment. The "chase" after Urenco's enrichment technology is expected to provide a driving force for the prospect of further consolidation in the enrichment segment.

- Currently, USEC's SWU deliveries to its clients are more than 50% based on the enrichment component of the LEU provided under the US-Russian HEU Agreement. But this Agreement is about to expire early next century (around 2013). Thus, in order to stay in the enrichment business even beyond that date, USEC has to hurry to provide a replacement enrichment technology, to demonstrate this technology's reliability and economic competitiveness, and to establish industrial-sized plants in time. Alternatively, USEC had to become sole executive agent also under a follow-on US-Russian HEU Agreement. However, such agreement will unlikely assume a definite form anytime soon. Thus, USEC's long-term competitiveness may give the enrichment market some reasons for concern.

3.2 Western Reactors SWU Demand and Supply

3.2.1 SWU Demand Based on World Nuclear Association (WNA) Data

Figure 3a compares the enrichment **demand** according to the WNA's Reference Case (see Table III.1 of the Report), with enrichment **supply**. This Upper Supply Scenario is based on the following assumptions:

- USEC is expected to have available throughout the period considered a constant enrichment capacity of about 5.5 million SWU/year. This capacity could be based solely on the diffusion technology if the American Centrifuge program would fail or turn out to be not economical. Alternatively, it could be based in the later part of the term under consideration on a combination of both diffusion and centrifuge enrichment technology, if the American Centrifuge project would materialize only gradually, or it could be based on the centrifuge technology alone, if the American Centrifuge project would turn into a success story.

- In case of Eurodif about the same applies as for USEC: The capacity shown in Figure 3a could be either diffusion technology alone, a mix of both diffusion and enrichment technology, or centrifuge technology alone.

- Urenco is expected to increase its European enrichment capacities gradually, at a rate of almost 1.0 million SWU per year, until about 2010. At about the same time Louisiana Energy Service's (LES) planned enrichment capacity is expected to emerge. However, as centrifuge plants can – and most likely will - be built pretty much in accordance with enrichment needs, the Figure proceeds on the assumption that Urenco's /LES' capacity expansion plans will come to a halt at the beginning of the next decade.

- The three Western enrichers do not expand beyond their replacement programs and seek individual capacity expansion after 2011.

MINATOM appears to have a capacity to replace obsolete centrifuges, and to expand production at roughly 1 million SWU per year. MINATOM also is strongly interested in selling to Western customers a substantial portion of those domestic enrichment capacities which are not needed for the supply of Soviet-design reactors in Russia and abroad under toll enrichment services, rather than under economically less attractive tails re-enrichment deals, as currently being performed. However, Figure 3a suggests that according to above assumptions there would be no urgent need for Russian SWU deliveries to the West, in addition to those under the US-Russia HEU Agreement, until about 2013.

But after the expiration of the US-Russia HEU Agreement, Russian SWUs would fit well into the picture. Assuming that after 2013 Russia would supply toll enrichment services to the West of about the same SWU quantity as they currently deliver under the US-Russia HEU Agreement, than Western World SWU demand and supply would be pretty much in balance after 2013.

3.2.2 SWU Demand Based on Optimum Tails Assay

Figure 3b shows the impact of an increasing UF6 vs. SWU price ratio applicable to Western-design reactor fuel on enrichment needs:

- The red line represents the SWU demand based on the following tails assays: For Western-design reactor fuel, on the optimum tails assay of 0.329% U-235 which applies for the currently prevailing natural uranium, conversion, and enrichment prices of US$ 12.50/lb U3O8, US$ 5.50/kg U, and US$ 95/SWU, respectively; and for Russian-design reactors on a constant tails assay of 0.1% U-235. At these tails assays, Western reactor enrichment demand would increase to about 39.7 million SWU by 2020.

- The black line represents the SWU demand if it is assumed that during the period 2008-2010 the UF6/SWU price ratio applicable to Western-design reactor fuel will double. The new UF6/SWU price ratio will reduce the current optimum tails assay of Western-design reactors from 0.329% U-235 to then 0.25% U-235. As a direct consequence, the enrichment demand will increase by about 6.4 million SWU/year to 46.1 million SWU in 2020 (see black graph: Opt. TA; Doubled UF6/SWU Price Ratio).

Figure 3b suggests that in this particular case additional enrichment capacities will have to be brought on line or - alternatively - new secondary SWU sources will be needed, in order to prevent SWU supply shortages.

4. Fuel Fabrication

4.1 Fundamentals of the Fuel Fabrication Industry

Prior to 1999, there were many players operating in a fragmented mature buyer's nuclear fuel market on a constrained profitability. However, recent major consolidation in the nuclear fuel industries led to a reduction of both the number of independently operating fuel vendors and the fuel fabrication capacities. Thus, the diversification of the fuel supplies of many utilities which had carefully constructed elaborate fuel fabrication competition policies suddenly collapsed.

There are currently three major LWR fuel supplier groups in the Western world:

- The **BNFL Group** for the fabrication of PWR and BWR fuel, accounting for an overall LWR fuel market share of roughly 25-30%.

- The **Framatome ANP Group** for the fabrication of PWR and BWR fuel, accounting for an overall LWR fuel market share of roughly 40%.

- The **GE Group** for the fabrication of BWR fuel, accounting for an overall LWR fuel market share of roughly 20%.

Other fuel fabricators are currently accounting for just about 10% of the market volume.

The **PWR fuel market** is dominated by the Framatome ANP Group (about 50-55%) and the BNFL Group (about 35%). The GE Group as a sole BWR fuel vendor is not represented in this market segment. The **BWR fuel market** is clearly dominated by the GE Group (about 70%), with minor shares held by the Framatome Group (15-20%) and the BNFL Group (10-15%).

4.2 Western Reactors Fuel Fabrication Demand and Supply

Today, the fuel fabrication market is characterised by the following features:

- **Fuel fabrication capacity** for all types of fuel in the Western world (all countries excluding the CIS, Eastern Europe and China) exceeds 15,000 tonnes heavy metal (HM), with Russia accounting for over 3,000 t HM in addition.

- In the Western world, **light water reactor (LWR) fuel fabrication capacities** are totalling about 9,570 t HM, according to the WNA's new Market Report (see Chapter 1.2.1). These capacities compares to current annual LWR reload needs of about 7,120 t HM (calculated on average annual reloads of pressurized (PWR) and boiling water reactors (BWR) of

3.4 t HM per TWh of produced electricity). Thus, Western world fuel fabrication facilities have currently average load factors of just about 75%.

5. Summary

The previous robustness and diversity of the front end of the nuclear fuel cycle is eroding gradually. Given the reduced number of players on the sellers' side, the utilities' diversification of nuclear fuel supplies is endangered, mainly in conversion services and fuel fabrication, but to a lesser extent also in enrichment services. Furthermore, it will become increasingly difficult to develop new options for any part of the nuclear fuel cycle on a short notice.

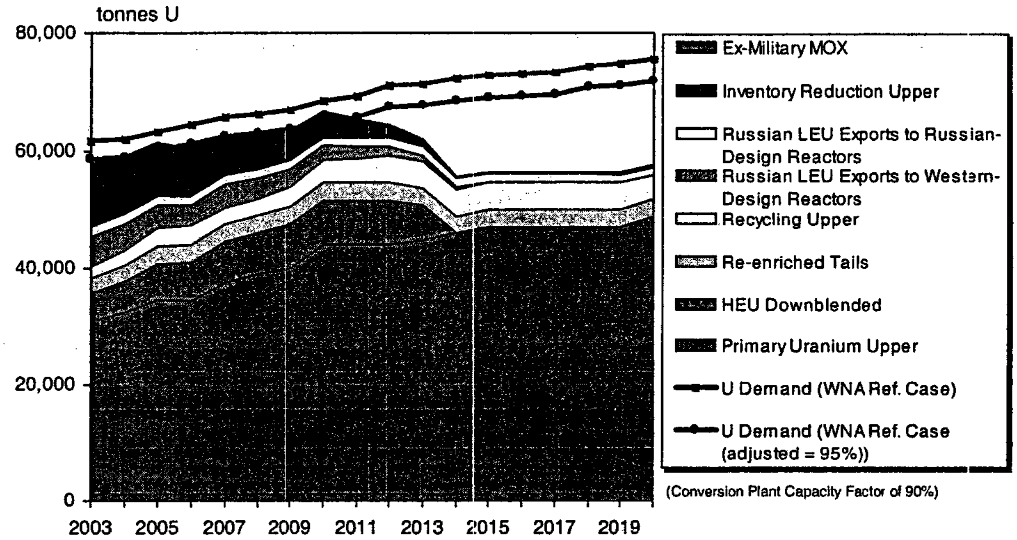
Transport of nuclear fuel is a particularly weak link, to which all players in the nuclear fuel cycle should give particular attention.

There is still no unfettered free trade in the individual sections of the front end of the nuclear fuel cycle, for the following reasons: Firstly, despite increasing nuclear trade between the Western countries on one side and the CIS and Eastern European countries on the other side, there remains a clear segmentation between the supply for Western-design reactors and Russian origin reactors. Secondly, the markets for nuclear fuel are still subject to a variety of political and administrative impacts (involvement of nationals and international political and regulatory bodies).

Based on current Western World prices for natural uranium (US$ 12.50/lb U3O8), conversion (US$ 5.50/kg U), and enrichment (US$ 95/SWU), the optimum tails assay of Western-design reactor fuel is about 0.329% U-235).

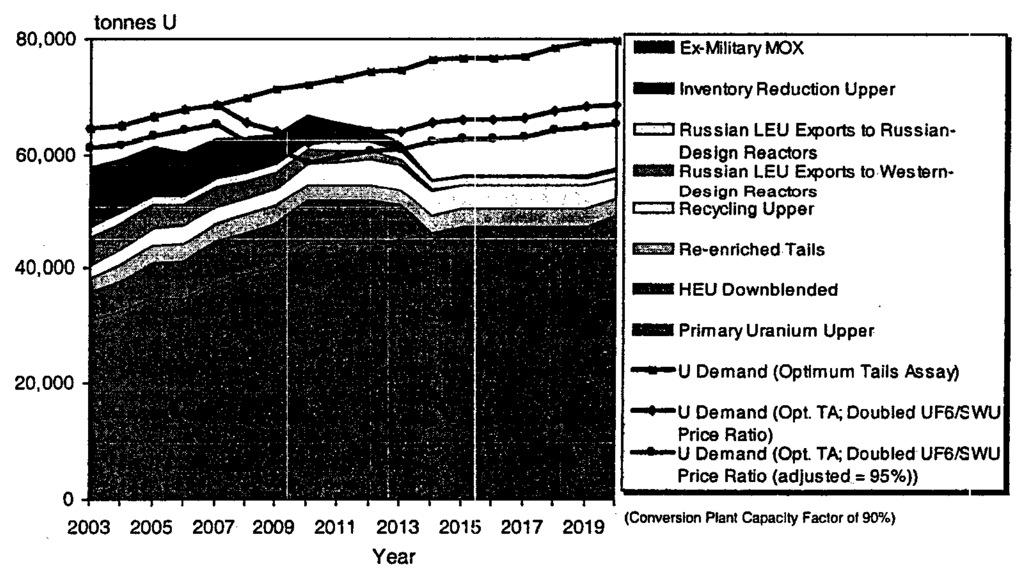
Should shortages of uranium develop, the UF6 vs. SWU price ratio would likely rise. E.g. for a doubling of the ratio, the optimum tails assay would drop to 0.25% U-235, reducing Western-design reactors' uranium and conversion needs substantially (see Figures 1b and 2b). However, enrichment needs would also go up (see Figure 3b), transferring on the enrichment industry part of the demand.

Figure 1a: Western Reactors Uranium Demand and Supply[1)] (Upper Supply Scenario; WNA Demand Scenario)



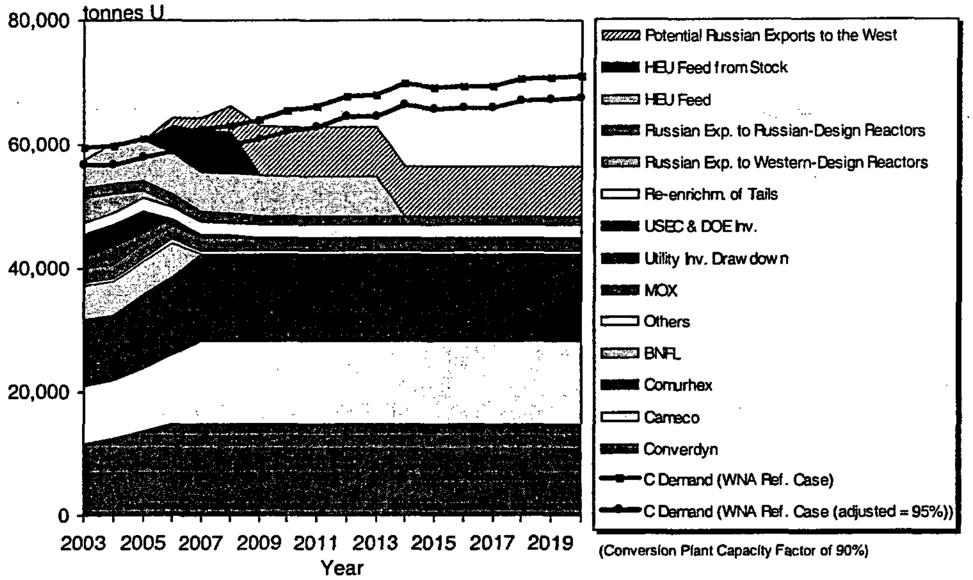
1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

Figure 1b: Western Reactors Uranium Demand and Supply[1)] (Upper Supply Scenario; Demand according to Optimum Tails Assay)



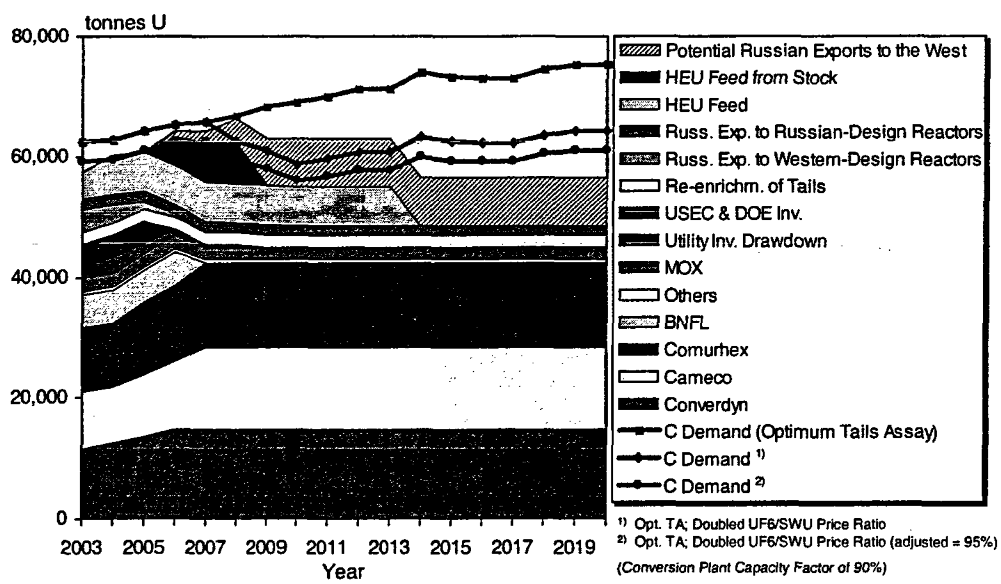
1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

Figure 2a: Western Reactors Conversion Demand and Supply[1] (Upper Supply Scenario; WNA Demand Scenario)



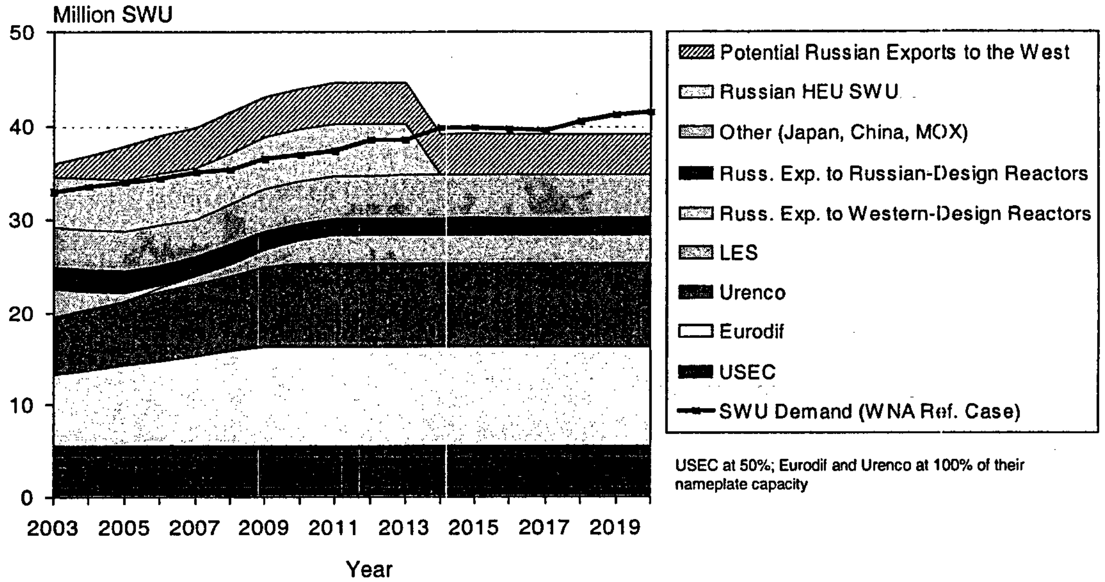
1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

Figure 2b: Western Reactors Conversion Demand and Supply[1] (Upper Supply Scenario; Demand according to Optimum Tails Assay)



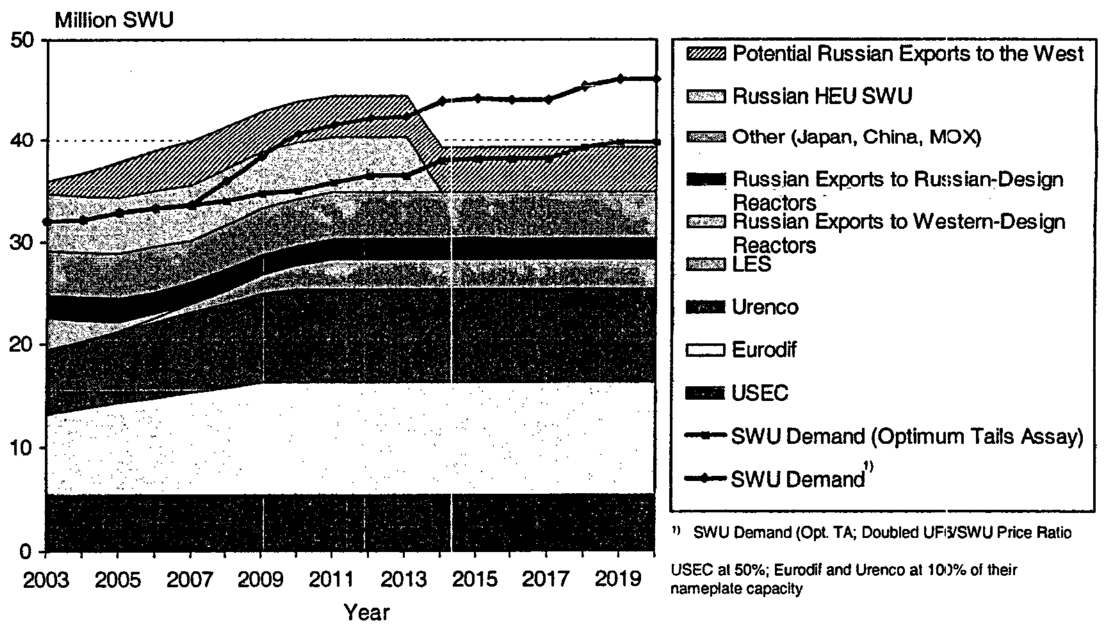
1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

Figure 3a: Western Reactors SWU Demand and Supply[1)] (Upper Supply Scenario; WNA Demand Scenario)



1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

Figure 3b: Western Reactors SWU Demand and Supply[1)] (Upper Supply Scenario; Demand according to Optimum Tails Assay)



1) "Western Reactors" = Western-Design Reactors plus Russian-Design Reactors in new European Union (EU) Member States (Czech Republic, Hungary, Lithuania, and Slovakia) and in future EU Member States (Bulgaria)

ANNEX II

TABLE ON RISK ANALYSIS FOR SECURITY OF SUPPLY IN THE NUCLEAR FUEL CYCLE

No.	*Identified Risks*[8]	*Root Causes of Risks*				*Probability*[9] *of Occurrence*	*Consequences Impact*[10]	*Mitigation Measures*
		Accident	*Regulations*	*Social/ Political*	*Market*	*(level 1,2 or 3)*	*(level 1,2 or 3)*	

[8] The list of risks is based on the document produced by the Task Force and endorsed at its meeting of 17 December 2003. This table is established in the same order as the reference document but in an abbreviated way.

[9] **Probability Scale: 1= Very unlikely, has never happened or very unusual – 2 = Likely to happen, seen several time in the industry history, or seen as likely for documented reasons – 3 = Rather frequent; seen several times during the past ten years, or almost inevitable for documented reasons.**

The figures show the averages of the quotations given by the task force members.

[10] See Consequences Scale in Appendix.

Delivery Disturbances								
1	**Temporary suspension** of production in a uranium mine or in a conversion, enrichment, or fuel fabrication facility	X	X	X	-	2.17	1.5	**Utilities** can mitigate the risk inter alia by having inventory of fabricated fuel and/or components. The suspension could last maximum a year (then risk category should be 2) Other means of mitigation: Diversification of suppliers, reserve generating capacity. **Producers:** Diversification of production facilities (fabricators have several facilities each, see point 16). Importance of lead times for delivery. Short-term risk mitigation would come from physical inventory. In our consolidated industry more than 1 simultaneous event has a magnified affect (i.e. GNSS & Converdyn). The promotion of a diversified supply base is the long term solution.

2	**Permanent closure** of production in a uranium mine or in a conversion, enrichment or fabrication facility Mine Conversion Enrichment Fabrication					 **2.4** **1.6** **1.6** **1.5**	 **2** **2.8** **2.4** **2.2**	**Utilities**: *Long-term contracting, shareholding* in facilities. **Producers**: Long-term contracting. Two main risk areas are Commercial + political/technical. 1) Rio Algom (gone), Rössing (possible) 2) Converdyn (possible), ERA (possible).
3	Financial/legal difficulties for producers	-	X	-	X	**2.3**	**2.17**	Short-term problems (up to one year) can be *mitigated by utilities as explained above.* Longer term disturbances due to legal problems may cause more severe impacts. **Authorities** have to monitor the situation and act accordingly. The financial viability of the supply base could *be assured through a strategic procurement* policy that provides suppliers with sufficient income to survive. This policy needs to be dynamic so as to adapt to a changing economic environment. Aggressive competition from non-market based economies should be regulated.

4	Interruption of the US-Russia HEU Agreement	-	-	X	-	1.92	2.17	**Authorities** have to monitor the situation and act accordingly to secure the supply, including contacts with politicians. Disturbances could also be long-term. One source of supply to which the fuel cycle has significant exposure (uranium, conversion & enrichment). Mitigation strategy from 1& 2. Potential disruption after 2013 to be considered seriously.

5	Lack of ports open to nuclear transport - concentration of nuclear transport companies			X	X	**2.42**	**1.92**	Information to port authorities by Agencies like ESA. From the **utilities'** point of view: Regional diversification of supplies. Development of new logistics aimed at purpose-made joint/merged transports. Due to the long-term dimension of the problem, utilities' fuel stocks may be inappropriate to mitigate the problem. Short-term mitigation from inventory. Long-term mitigation would be a cost issue, and one that would need to be resolved by suppliers and consumers. If the supply chain is financially weak then the risk is greater. Strategy as for 1 & 2. Authorities have to monitor the situation and act accordingly to secure the supply, including contacts with politicians.

6	Withdrawal from uranium mining towards more prosperous activities - Prices lower than production costs in mines – currency inflation	-	-	-	X[11]	**2.42**	**1.58**	**Utilities:** Regional diversification of supplies, balanced mix of medium- and long-term contracts (with possibilities to extend), long-term contracting, shareholding in facilities. **Producers:** Long-term contracting, giving preference to base-escalated prices over market-related prices. A real risk that could be mitigated by 1 & 2. Investors require predictable returns over the long term. *Increase of inventories as in 1.*

[11] Including 'Currency/exchange rates' as a Root cause

7	Uncertainty in relation to secondary supplies -> Lack of investment in new mines	-	-	X	X	**2.58**	**2**	Watchful observation of supply & demand trends. **Producers** must be given more contractual and financial incentives, security and guarantees. **Producers and utilities** must be willing to accept longer lead times between the date of contract signature and the first delivery under that contract. Partnerships. Utilities should accept base-escalated prices. Utilities should accept limited upward and downward delivery flexibilities. Due to the long-term dimension of the problem, utilities' fuel stocks may be inappropriate to mitigate the problem. ESA monitoring of market and of future secondary supplies (HEU II Agreement?). Short-term mitigation: Inventory. Long-term: Strategic procurement policy as for 1 & 2. Clarify future HEU prospects (Euratom-Russia). Harmonisation of HEU policies in European countries.

8	Uncertainty in relation to secondary supplies: Lack of investment in conversion	-	-	X	X	2.58	2.17	**Authorities**: Watchful observation of supply & demand trends. Stimulate new investments. Same as with uranium: **Producers** must be given more contractual and financial incentives, security and guarantees. **Utilities** must be willing to enter into long-term contracts (see 7). Due to the long-term dimension of the problem, utilities' fuel stocks may be inappropriate to mitigate the problem. Same as for 1, 2 and 6. Utilities' purchase commitments with producers.
9	Uncertainty in relation to secondary supplies: Lack of investment in enrichment	-	-	X	X	1.92	1.92	**Authorities**: Watchful observation of supply & demand trends. Stimulate new investments. As for 1& 2. Life extension of gas diffusion technology.

Commercial and Technical Risks								
10	Overdependence on a single source of supply	-	-	X	X	**1.92**	**2**	**Authorities**: stimulation of competition. For **utilities**: Regional diversification of supplies (mining, conversion, enrichment, fabrication). Balanced mix of medium- and long-term contracts (with possibilities to extend) (U, C, E, Fab.). Up- and downwards delivery flexibilities (U, C, E). Small share of spot purchases (U, (C)). As for 1& 2 (significant dependence on Russia currently). Inventories and quotas. To be defined clearly. Potential role of a Clearinghouse.

11	Excess restrictions on Russian enrichment, decrease of competition (or insufficient restrictions on Russian enrichment, unfair competition, no long-term investment)	-	-	X	-	1.8	1.1	**Authorities:** Watchful observation of supply & demand, and of pricing trends in the market. For supply to compete fairly in a market economy, pricing must correspond to costs. Otherwise there is a risk that open market suppliers are pushed into bankruptcy or that no new investments are made. Flexibility in restrictions.
12	Common centrifuge technology for Areva & Urenco, absence of competition?	-	-	-	X	2	1	**Authorities:** Watchful observation of market pricing trends. EU competition policy. Flexibility on Russian imports to ensure competition.
13	Uncertainty over US enrichment capacity in future	-	-	X	X	2.5	1.67	**Authorities:** Watchful observation of supply & demand, and of pricing trends in the market. Currently heavy dependence on Russian enrichment. Limited diversity/competition. Mitigation as for 1 & 2.

14	Vertical business integration vs. competition and technological level.	-	-	-	X	**2.0**	**1.0**	**Authorities:** Watchful observation of supply & demand, and of pricing trends in the market. Control of competition by authorities.
15	Loss of EU know-how in uranium exploration and mining	-	-	-	X	**2.67**	**1.17**	No big problem, as U exploration and mining know-how available around the world. As long as a diversified supply base exists, then there should not be a major supply risk. As for 1 & 2. Institutional support for exploration.
	Political / Regulatory Risks							
16	Overregulation, frequent changes and lack of harmonisation in transport approvals/authorisations	-	X	X	-	**2.58**	**1.92**	**Authorities:** Stimulation of good sense! Mitigation – strong communication between industry bodies and regulators. Harmonisation of rules & regulations.

17	Reduction in fuel factories and related logistics	-	-	-	X	**2.1**	**1.2**	For **utilities:** Qualification of at least 2 suppliers. Due to the long-term dimension of the problem, utilities' fuel stocks may be inappropriate to mitigate the problem. Control of competition by authorities.
18	Delays of new projects due to licensing issues or environmental regulations	-	X	X	-	**2.58**	**1.58**	**Authorities**: Stimulation of good sense! Typically national problems with partly international dimensions (involvement of international anti-nuclear groups). Environmental standards will get tighter rather than weaker. Thus, it is difficult to help the applicant. Financial support from **utilities** (long lead times between contract signature and first delivery) as well as down-payments could help the producer to bridge temporary financial problems caused by exaggerated environmental requests. New projects are required but they cannot react quickly to market developments. Cigar Lake earliest in 2007. Jabiluka? Honeymoon? Long-term forward investments are required. Support of nuclear energy by the EU.

19	Supply disruption from politically unstable regions (Not just unstable, but also countries/regions opposed to uranium mining.)	-	-	X	-	**2.17**	**1.67**	For **utilities:** Regional diversification of supplies. Utilities' stocks can bridge supply gap only if disruption is just a glitch. Otherwise: Due to long-term dimension of the problem, utilities' fuel stocks may not be enough to mitigate the problem. *Euratom could qualify suppliers?*

Appendix to Annex II

Consequences Scale:

Category	Impact on Supply	Impact on NPPs
1	Temporary impact (less than 1 year) 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	Multi-year impact (1 to 5 years) exceeds 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 shut downs within the most affected geographic areas.
3	Durable impacts (over 5 y). Generalised supply chain disruption. Requires a massive industry adaptation.	Many temporary NPP shut downs, potentially 100% in the most severely impacted areas. Permanent local shut downs possible due to induced replacement of nuclear power by other forms of power generation.