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The Global Nuclear Fuel Market to 2020

Gerard Pauluis

This paper summarises the findings and main conclusions of the 1998 supply and demand report of the Uranium Institute.[1] The report is the ninth in the series since the Institute's foundation in 1975. Its objective is to present an updated, objective view of the status of the fuel cycle markets as of mid 1998. It intends to highlight important developments which have occurred since the previous report was published in September 1996 and to address future trends in the market, in order to provide the readers with the elements to build their own better understanding.

The report follows previous practice by making use of the information and experience of the Institute's member companies. A working group comprising a well balanced group of representatives from member companies was formed to oversee the drafting process, of which the present author was chairman. Questionnaires to both member and non-member organisations active in the fuel cycle were used to update the information base and to help produce the forecasts included in the report. Confidentiality of the answers was secured by having a firm of chartered accountants aggregate the data on a regional basis before making them available to the Institute. This procedure allowed access to information which otherwise would not have been made available, and resulted in a high response rate.

An important contribution was also made formally by another UI working group, theReserves and Production Capacity Working Group. UI members have offered useful additional advice and suggestions. These sources were supplemented, where necessary, by judgements applied by the Institute, based on published material and other reliable sources of information.

The forecast period has been extended from 2015 in the 1996 report to 2020. The additional five years are important for nuclear fuel demand, as increasing numbers of nuclear reactors may be retired from service, either because they will reach the end of their current operating licence, or for financial reasons or under political pressure. On the other hand, these five years may also witness a revival of nuclear power led by an eventual realisation by the public of its long term environmental and economic benefits.

Trends in Energy and Nuclear Power

Nuclear power must be regarded within the wider framework of trends in energy and electricity supply. Electricity demand has consistently risen faster than energy demand. This is true even in the OECD countries, where the strong growth of light industry and services still requires a significant electricity input, while demand from heavy industry may fall. The World Energy Congress, in its reference case, predicts that world demand for electricity will double between 1990 and 2020, from 11 490 TWh to 22 700 TWh.

Nuclear power has increased its share in worldwide electricity production from a meagre 2% in 1971 to roughly 17% in 1990, before plateauing until today (Figure 1). During that expansion phase, nuclear has been the only form of electricity generation to increase its share of the total. In the three leading industrialised areas, the European

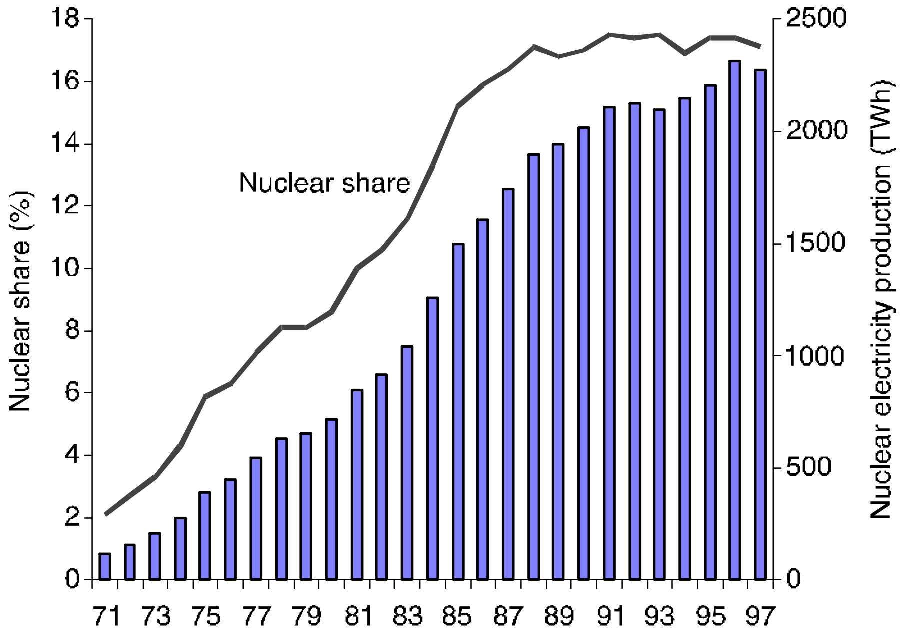

Figure 1. World nuclear electricity production, and nuclear share of total generation, 1971–97.

Union, Japan and the United States, nuclear energy provides between roughly one-third and one-fifth of total electricity.

Since the last market report in 1996, important developments have occurred which have had or may have an impact on energy demand growth, and therefore have repercussions for the demand for electricity and nuclear energy.

The most important of these in the short term directly concerns electricity generation. It is the accelerated restructuring of electricity markets in many countries around the world. There may remain large uncertainties as to how fast and how far this restructuring will go in the countries concerned. The general tendency, however, will be to place more emphasis on the short term economics. This will lead to substantial improvements in the efficiency of nuclear generation, to make existing reactors among the cheapest sources of power on a forward cost basis. It may also result in premature closures of reactors where the standard cannot be met, and will make the construction of new nuclear plants more problematic, because of their high capital cost.

Electricity markets are thus quickly becoming increasingly competitive and nuclear has to prove that it can measure up to other fuels. This can best be achieved when operating nuclear power plants are kept running as many years as possible, to the full extent of their technical lifetimes. Since the vast majority of reactors likely to be operating in the world by 2020 are already in use today, it is therefore important to look at their age structure (Figure 2) in assessing the future capacity.

Two other factors affect energy growth and the structure of energy supply in general. The first is the recent turbulence in East Asian financial markets which has cast doubt on some of these countries' electricity generating capacity plans. In most countries, it is believed that the disturbance will be only temporary, and will cause a few years delay rather than outright cancellation of existing plans.

The climate change debate is the second factor, and it may prove the most important in the long term. The Kyoto climate conference resulted in an agreement in principle on tough emissions targets for the developed countries. We know they will be extremely difficult to achieve without the help of the nuclear industry. Yet, considerable effort will be required in order to achieve full recognition of nuclear power's potential by the general public.

These elements have been taken into consideration in revising the forecasts of nuclear generating capacity in individual countries, but account was also taken of a variety of other technical or local factors, such as likelihood or not of plant licence extensions, cost competitiveness, reactor technology developments, as well as public policy and acceptance matters. Particular attention has been paid to those countries which are expected to see the largest variations in installed nuclear generating capacity, namely China, Japan, Korea, Russia and the United States.

To reflect the range of the uncertainties which surround any such forecast, three scenarios have

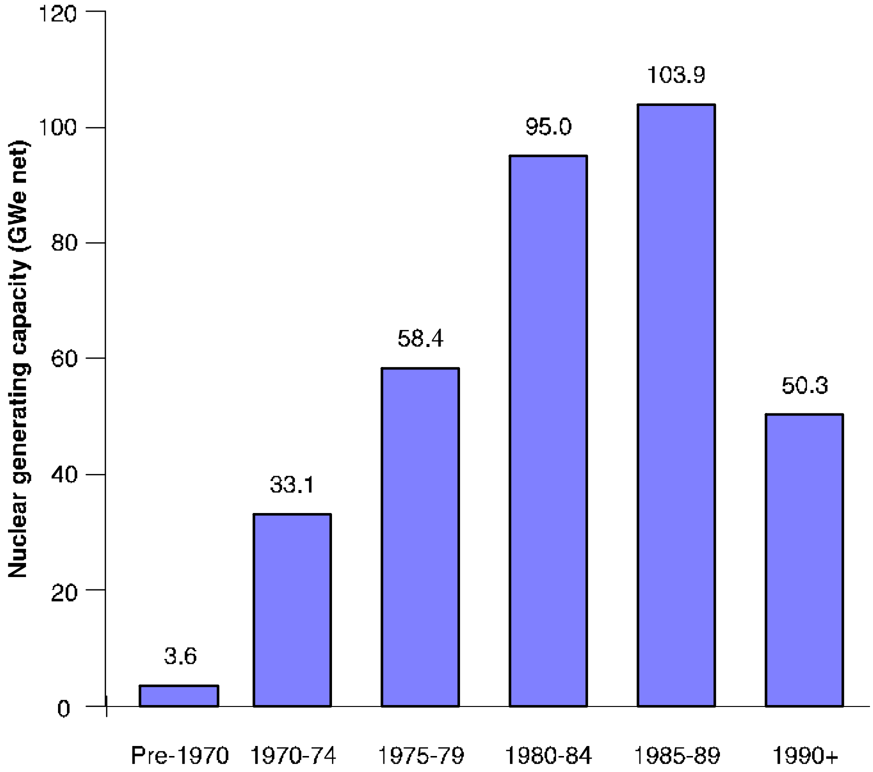

Figure 2. Age structure of nuclear generating capacity, by year of start-up.

been prepared. The reference scenario assumes that, broadly speaking, nuclear power development continues on a path similar to recent years. That is, for countries and areas with existing nuclear power programmes, and expansion plans backed by a long term national vision, these will be continued. But for countries and areas without nuclear units, no such development is generally considered. The scenario assumes that almost all existing units will remain in operation for their full nominal lifetime (40 years in most cases), and that in several countries operating lifetimes will be extended beyond this period. For many reactor types, an operating lifetime of 50 to 60 years is considered feasible from a technical and safety point of view.

In the upper scenario it is assumed that over the next five to ten years the economics of nuclear plants improve relative to alternative electricity generation options, that progress on the public acceptance of waste management and decommissioning eventually reduces opposition to nuclear power, and that concern about the environmental impact of fossil fuels continues to increase. The upper scenario thus foresees a modest revival in nuclear power.

In the lower scenario it is assumed that investment in nuclear power will be curtailed in favour of other electricity generation options, and that political opposition to nuclear power remains strong in many countries and areas. As a consequence, some existing plants might close before their nominal lifetimes, and reactor lifetimes are not extended, leading to a slow, long term decline in nuclear capacity and perhaps an eventual phase-out.

The results of the Institute's nuclear generating capacity forecast for each scenario are shown in Figure 3, together with the forecasts of the previous report. At the end of 1997, world nuclear capacity was 343 GWe (11 GWe below the 1996 forecast). In the reference scenario, this capacity is expected to be 348 GWe by 2000 and then grow to 376 GWe and 405 GWe by 2010 and 2020 respectively. The annual average rate of growth 1997–2020 is 0.7%. Given expected world electricity demand growth substantially in excess of this, the share in electricity generation is thus forecast to decrease. In the upper scenario, the equivalent figures are 355 GWe in 2000, 422 GWe in 2010 and 483 GWe in 2020. In the lower case they are 346 GWe, 345 GWe and 293 GWe respectively.

Reactor Requirements

The Institute continues to consider reactor requirements as its key demand indicator for nuclear fuel. The demand forecasts were derived from the answers to the questionnaires and were assisted by a model developed at the Institute over several

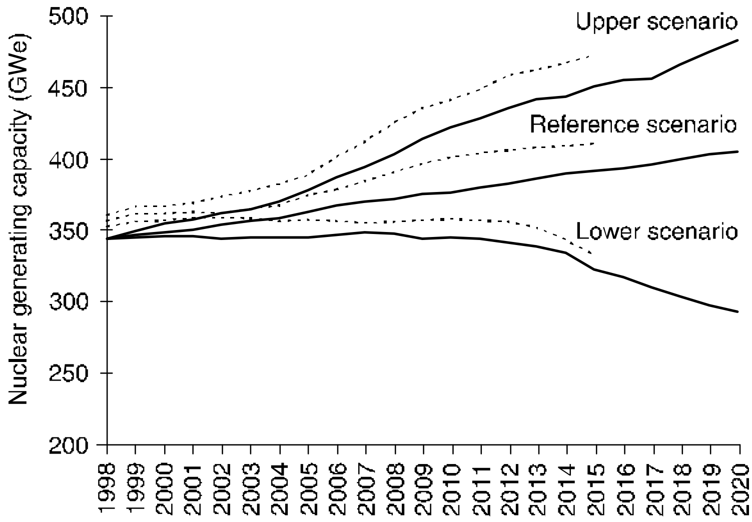

Figure 3. Comparison of 1998 nuclear generating capacity forecast (solid lines) with 1996 forecast (dashed lines, to 2015 only).

years, which incorporates the key operating characteristics, such as enrichment levels and fuel burn-up, on a reactor by reactor basis. Figure 4 gives the results of this exercise and compares them with the 1996 demand forecasts.

It is also worth mentioning that a comparison has been made for the first time between the specific requirements (in tU / TWh) calculated from historical fuel loadings and those predicted by the model, using data provided by utilities and other sources. This exercise, besides showing interesting regional variations, has enabled an estimation of the accuracy of the model to be made. The forecast specific requirements appear overestimated by some 5%, when compared with those calculated from historical reactor fuel loadings. This question will deserve further analysis in following reports.

Uranium Supply

The demand for nuclear fuel is satisfied either via primary uranium production or via secondary sources, such as inventory reductions, recycling of fissile materials from spent fuel reprocessing or from military stockpiles or tails re-enrichment.

Uranium Reserves and Primary Production

World reserves of uranium are more than adequate to satisfy reactor requirements to well beyond 2020. The Reserves and Production Capacity WG (mentioned above) carried out a survey of uranium

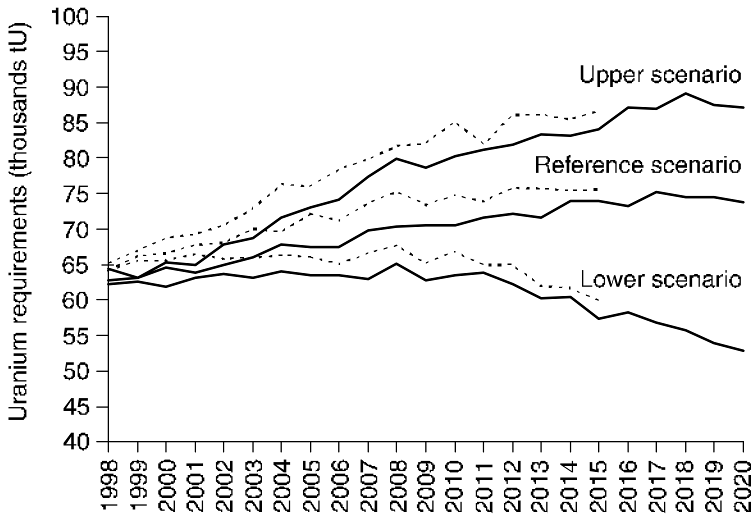

Figure 4. Comparison of 1998 uranium requirements forecast (solid lines) with 1996 forecast (dashed lines, to 2015 only).

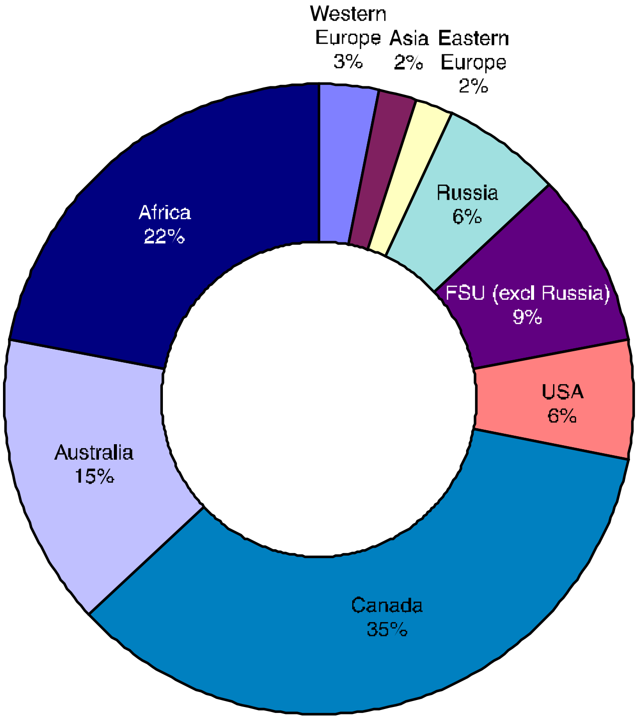

Figure 5. World uranium production by mining method, 1997.

reserves in 1997, which followed up on a previous UI survey in 1995. An important difference between the 1997 survey and the 1995 survey is that substantially more reserves are now categorised in the lowest cost category (1.885 million tU, below US$40 / kg U), even allowing for the inclusion of Russia, Kazakhstan and Uzbekistan (which did not respond in 1995). There are various possible explanations for this, such as the increased importance of the in-situ leach (ISL) mining technique, other cost-cutting measures, and the difficulties of allocating costs in operations where uranium is a by- or co-product. Currency exchange rate fluctuations may have also played a part.

Although outside the scope of the Institute survey, uranium reserves in cost categories above US$80 / kg U are extensive. Based on likely demand for the next 20 years in the 60–80 000 tonnes per annum range, the 3.4 million tU of reserves extractable at a cost below US$80 / kg U could cover over 40 years 'supply. Given the relatively low impact of the uranium cost on nuclear power economics, the ultimate potential supply base is comparable to those of other energy commodities, in excess of 100 years.

World uranium production rose slightly again in 1997 to 35 692 tU, continuing the trend established since 1995, which experienced the first rise after ten years of decline. Output in 1997, however, still filled only 58% of world reactor requirements. The balance was made up by secondary supplies. Output in the FSU countries stabilised after falling for several years, while Western production has become increasingly concentrated in a small number of major mines in the major Western producing nations, particularly Canada and Australia (Figure 5). The development of smaller in-situ leach (ISL) operations in a number of countries is the only source of diversification at present.

The corollary of this evolution is that as the major mines are owned by a small number of companies, the share of production attributable to these companies is also rising (Table 1).

By 2001, a 10 000 tU reduction in production from existing mines is anticipated, because of the phase out of two large mines in Canada (Key Lake and Rabbit Lake). However, this should be compensated by the start up of new capacity, mainly in Canada, but also, to a lesser degree, in Australia (Table 2).

Secondary Sources

An appreciation of the extent of uranium production and its utilisation dating from the beginning of the nuclear age is essential for understanding the volume of material available for potential recycling and from inventories. Cumulative world production

Table 1. Leading world uranium mining companies, 1997.

	Production (tU)	World share (%)
Cameco	7 407	21
COGEMA	4 943	14
ERA	4 095	11
Uranerz	3 532	10
Rio Tinto	2 019	6
Priagunsky	2 000	6
Navoi	1 764	5
WMC	1 425	4
KazAtomprom	1 000	3
Sub total	**28 185**	**80**
World total	**35 692**	**100**

Note: Figures reflect equity interest in production facilities.

Table 2. Timing of planned capacity increases (tonnes U).

	1999	2000	2001	Total
Australia	2 300	1 700	850	4 850
Canada	9 200	0	6 900	16 100
Mongolia	1 300	0	0	1 300
USA	1 000	0	0	1 000
Total	**13 800**	**1 700**	**7 750**	**23 250**

Table 3. Estimated uranium production and consumption, 1945–97 (tonnes U).

	West	East	World
Production	1 167 000	733 000	1 900 000
Reactor requirements	–850 000	–125 000	–975 000
Military use	–260 000	–450 000	–710 000
Net imports/exports	+100 000	–100 000	–
Remaining inventories	157 000	58 000	215 000

since 1945 is estimated at 1.9 million tU, and can be split into roughly 1.165 million tU from Western producers and 735 000 tU from the former USSR, Eastern Europe and China. However, these figures remain affected by the uncertainties about the amounts of uranium mined in the former Soviet Union and its satellite countries in the period between 1945 and 1990, with estimates ranging between about 650 000 and 750 000 tonnes.

Table 3 shows that, of estimated world uranium production of 1.9 million tU since 1945, just over half has been used in civil power reactors. However, the uranium used in reactors, usually in an enriched form, has given rise to spent fuel discharges, from which both uranium and plutonium may be extracted by reprocessing. These materials are being recycled as fresh fuel for reactors in several countries, although cumulative reprocessing of LWR fuel in Western countries amounts to only about 15 000 tU.

The 925 000 tU not used by civil reactors has either gone to military programmes or remains in inventory today. On the basis of an estimated military use of 710 000 tU, the level of world inventory of natural uranium may be approximately 215 000 tU.

The Institute questionnaires sought information on commercial inventories held by the industry by two means: firstly, by asking the participants for the amounts of material they owned; and secondly, by asking for the amounts of material they held on their premises, irrespective of ownership. This permitted some cross checking to test the accuracy of the results. The answers are summarised in Table 4. They indicate a only small decrease in the size of uranium inventories held by utilities, which still collectively hold two years of annual requirements. Inventories held by other fuel cycle companies appear to have grown. When compared to the questionnaire of eight years ago,

Table 4. Evolution of reported industry inventories (tonnes U).

	End 1990 total	End 1995 total	End 1997 total
Material owned:			
Utilities			
Europe	71 200*	62 000**	62 000**
North America	41 700*	15 000**	12 000**
East Asia	48 400*	54 000**	39 000**
Total utilities	161 300*	131 000**	113 000**
Producers	21 800*	10 000**	20 000**
Other industry	N.A.	10 000**	10 000**
Total	N.A.	151 000**	143 000**
Total material on industrial premises:*	N.A	N.A.	153 000 *

* includes pipeline material.
** excludes pipeline material.
N.A. information not available.
Note: Data exclude government inventories and USEC inventory.

Table 5. Impact of HEU on the uranium market (thousand tonnes U).

	1998	1999	2000	2005	2010	2015	2020
Upper case	8.2	10.1	10.1	10.1	10.1	10.1	10.1
Lower case	5.6	6.7	6.7	6.7	6.7	6.7	6.7

it becomes even clearer that Western industry inventories have not been used to make up the bulk of the shortfall between reactor requirements and primary production over this period.

Another secondary supply source is the recycling of reprocessed fissile materials. Their historic impact is, however, limited to the order of one to two thousand tonnes of uranium equivalent per year.

Former military material, in the form of low enriched uranium derived from ex-weapons high enriched uranium (HEU), is becoming available under the disarmament treaties entered into by the USA and Russia. The equivalent of 10 800 tU of natural uranium has been exported from Russia by this route between 1995 and the end of 1997. Up to 9000 tU / year could be delivered in the period until 2012, but it is still uncertain how much (if any) of the uranium component of the material will definitely return to Russia. By comparison, the military material declared excess by the US government is more limited, and it can be estimated that the equivalent natural uranium displaced by US HEU will be roughly 1000 tU per annum over the forecast period.

Given the uncertainties and the potential impact of the quantities of former military HEU, both from Russia and the USA, the Institute has developed two scenarios covering the expected range of possibilities (Table 5).

While ex-military HEU from both Russia and, to a lesser degree, the United States will be an critical element in the market in the period to 2020, ex-military plutonium will have only a limited impact.

A last source of material is depleted uranium. This can displace natural uranium in the market when it is re-enriched to form “reconstituted” natural uranium, i.e. it is enriched so that it has the same U-235 content as natural uranium. An inventory of about 1.35 million tonnes of depleted uranium has accumulated worldwide over the past 50 years. The economics of such re-enrichment depend on the U-235 content of the depleted uranium in stockpiles (the tails assay), and the cost relationship between natural uranium and enrichment services.

Russia has a considerable enrichment capacity, a large part of which is surplus, and has been re-enriching its depleted uranium for some years. Depleted uranium from other countries has now begun to enter Russia to take advantage of the surplus enrichment capacity there. The uncertainties about available enrichment capacity and the tails assays involved make it hard to assess the true current Russian capacity to supply export markets from re-enriched depleted uranium, but it is certainly considerable. Taking into account likely tails assays, 7000 tU per annum is a rough estimate, but the potential margin of error is large.

However, the Russian capacity to reconstitute uranium would be useless if there were not means to export this material to the West. At present, fissile material is physically exported from Russia to the West in essentially two forms: natural uranium concentrates (U_3O_8) and low enriched uranium (LEU). The latter comprises both the LEU from ex-military HEU (supplied in accordance with an intergovernmental agreement between the USA and Russia), and also the LEU supplied in accordance with long term enrichment contracts with Western utilities and intermediaries. For many years, no significant amount of natural uranium (as U_3O_8 or UF_6) has been physically shipped from the Western world to Russia. Therefore, Russia must also export all the uranium feed content of the LEU it supplies. The feed in the LEU under enrichment contracts with Western utilities and intermediaries (excluding the US-Russia HEU agreement) is estimated around 8000 tU / year.

The uranium component of the HEU delivered from Russia to the USA was 5600 tU in 1997 and will rise to 9000 tU / year from 1999. Even disregarding exports of any remaining natural U_3O_8 inventory, the full export supply potential of secondary material from Russia can therefore be estimated in the range of 13 600–17 000 tU per annum in the near future. Russian primary uranium production is today about 2000 tU per annum (at 80% capacity utilisation) and likely production from Kazakhstan, Uzbekistan and Ukraine collectively is around 3500 tU per annum.

If, in line with statements from the Russian

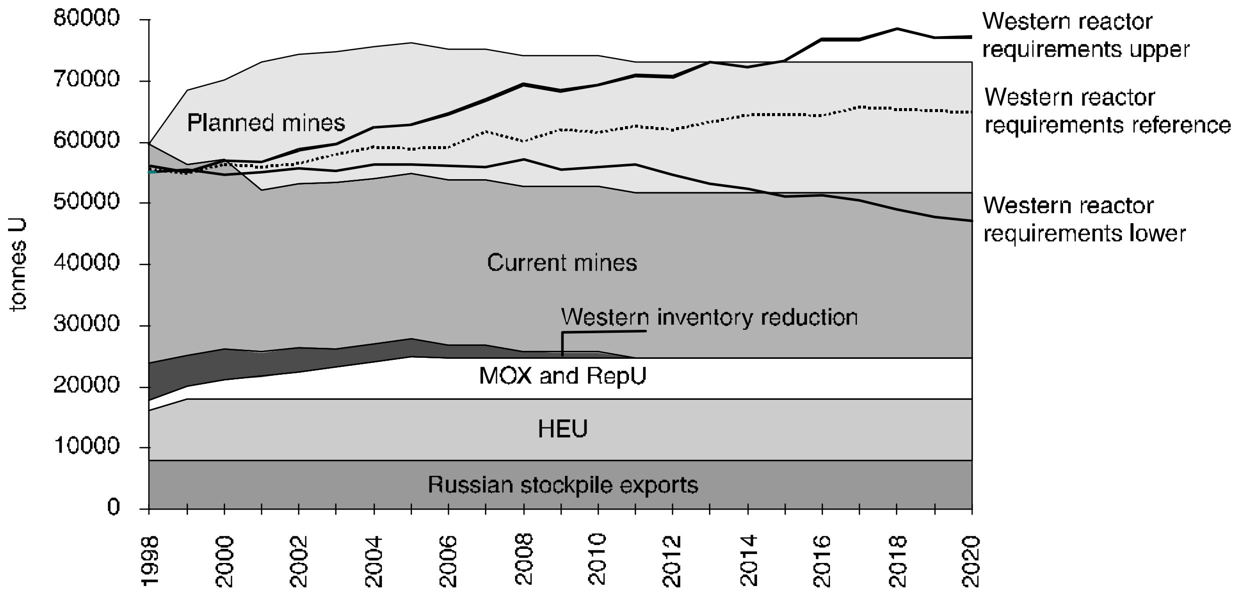

Figure 6. Supply/demand Case A

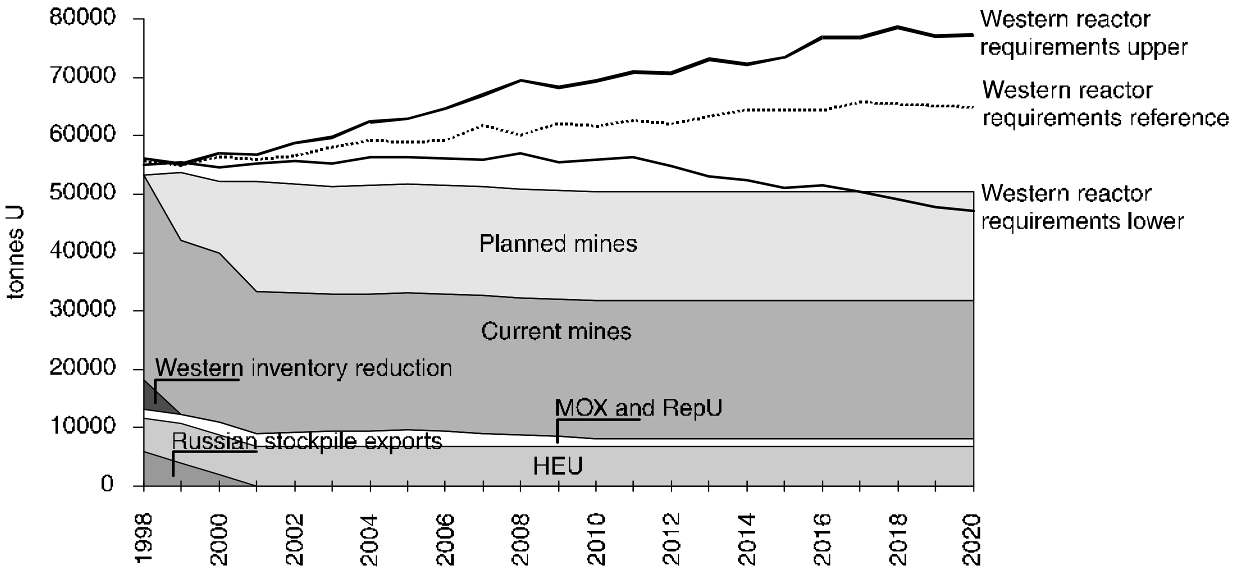

Figure 7. Supply/demand Case B

government, we assume that none of this primary production is required internally, the full export potential of the FSU may therefore be above 20 000 tU per annum in the future, once the full HEU shipments are being made (assuming that none of the feed component of the HEU is returned to Russia for internal use). As such, this would constitute 40% of world uranium demand outside the FSU.

Fuel Cycle Services

Conversion, enrichment and fuel fabrication services have discrete markets within their own area of the fuel cycle. Demand for each service is clearly linked to uranium and to the other services, but each market has to be considered individually.

It is worth mentioning that innovations in enrichment technologies may have a significant effect on conversion and uranium demand in the latter part of the period studied. If atomic vapour laser isotope separation (AVLIS) technology becomes available, as the US Enrichment Corporation has announced, this would entail a significant reduction of uranium demand as the technical characteristics of this process are such that tails assays of below 0.2% are to be expected.

The fuel fabrication market differs in that it supplies a highly differentiated product, rather

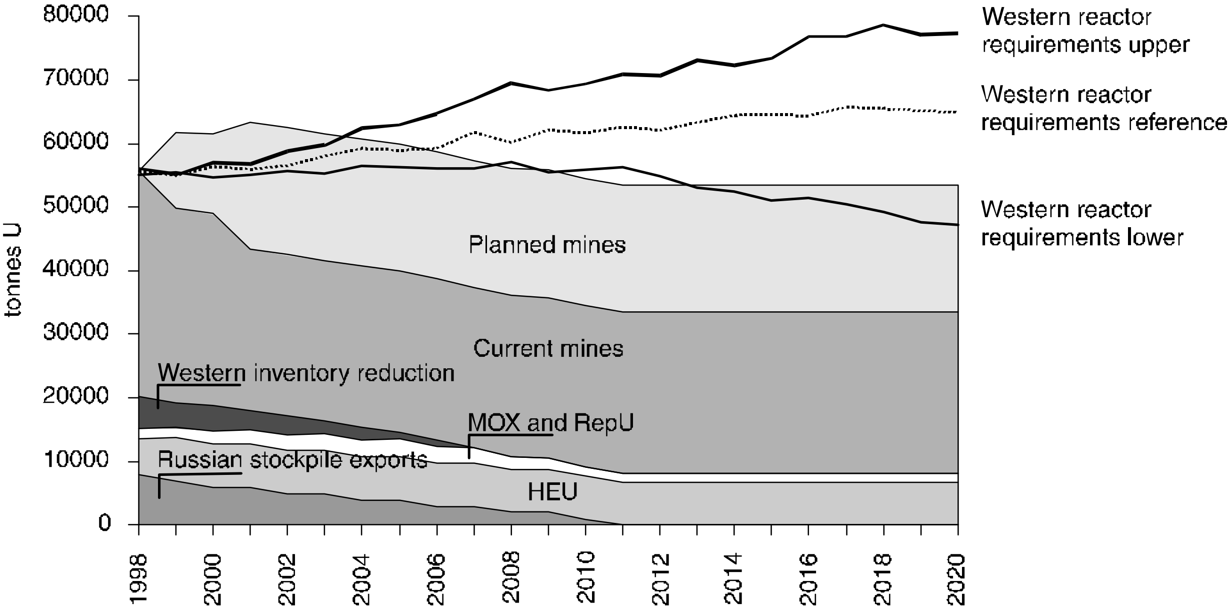

Figure 8. Supply/demand Case C.

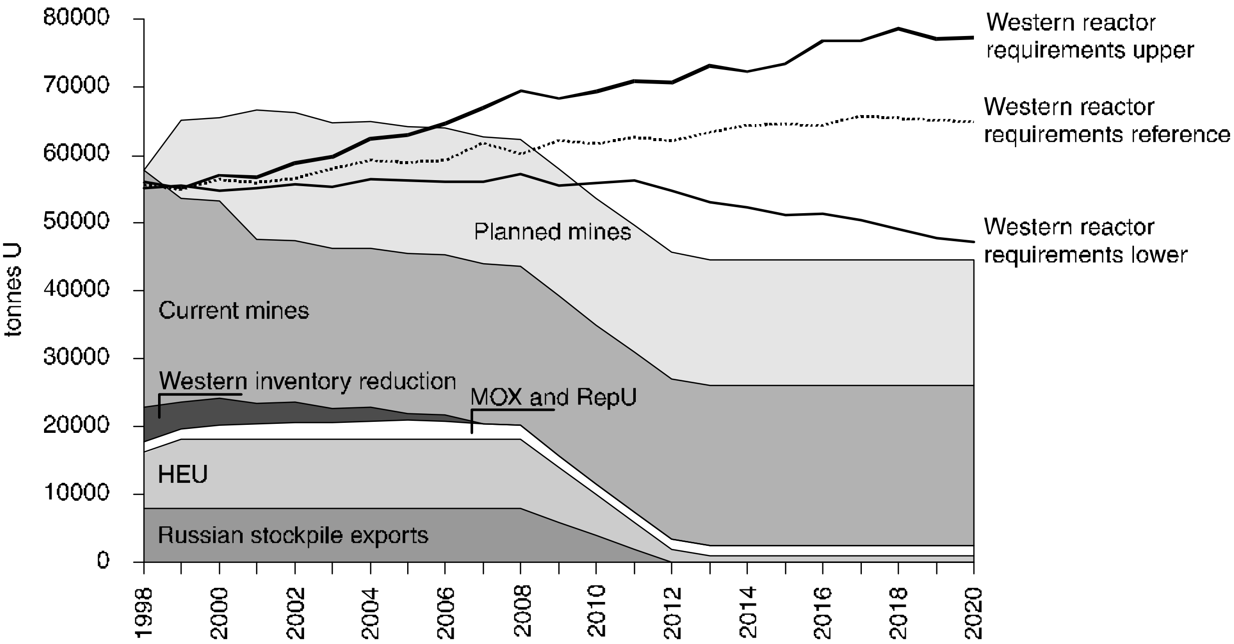

Figure 9. Supply/demand Case D.

than a bulk commodity-type service, but capacity is adequate to meet anticipated demand.

Conclusions on the Market

The Institute has brought together the three demand scenarios and compared them with the range of primary and secondary supply positions discussed above, to come to some conclusions on the likely development of the uranium market for the next 20 years.

It must be emphasised from the start that this mode of analysis has some limitations. The most obvious is that it is purely of a static nature. No account is taken of the way in which market participants will react to potential shortages or surpluses. In any one year, available supply and requirements balance through inventory movements, with companies reacting to market signals, of which price is the most obvious. Consideration of the likely price level is outside the scope of this report, but the scenarios presented could change substantially within a few years if perceived market conditions become very different from today.

Four cases are presented in the report. Figure 6 shows a maximum supply case, taking the highest primary and secondary supply scenarios, while Figure 7 is the opposite, taking low scenarios for each. Both of these extreme cases are clearly unrealistic and one or other element in the market would have to adjust to achieve market balance. In the first case, where there is oversupply, it may be costs of production which determine which supply element is curtailed. New mine development might be slowed, maybe even below that of the lower scenario, as inventory and stockpiled material (for which production costs may be regarded as sunk) enter the market.

With the second case, inventories in the West would likely be drawn down further until market balance came about through accelerated new mine development. This implies not only that planned mines would operate at a higher capacity utilisation rate, as in the upper scenario, but also that some prospective additional capacity would start up. Until increased production started to enter the market, localised disruptions could be anticipated, as inventories are not evenly distributed or available to all market participants.

It is clearly possible to contemplate many different scenarios based on various combinations of the key elements, and readers of the report are encouraged to do so, based on the analysis it presents. One possible variation is shown in Figure 8. This is, however, not to be taken as anything more than an illustration of one of many combinations. The supply conditions assumed for this case include the reference case for production from both existing and planned mines, no Western inventory reduction after 1998, the use of MOX and reprocessed uranium fuel are at their lower levels (30% of reprocessing capacity), and one third of the feed in the HEU is returned to Russia.

A new middle schedule for the Russian stockpile contribution is introduced, gradually running down exports on an annual basis from 8000 tU in 1997 to only 1000 tU in 2010. This case shows a much greater degree of market balance in the shorter term. Over the longer term, however, overall supply is only sufficient to satisfy the lower demand scenario, falling below the reference case from 2005 onwards.

As a final example, a more dramatic picture is shown in the Figure 9. It is based on a combination of high secondary supply from Russia, for both HEU and other exports to the West (8000 tU per annum). Western supply from current and planned mines, from MOX and reprocessed U fuel, and from inventory reduction, are at their lower cases until 2010. This shows the market as over-supplied in the shorter term, but moves towards balance on the reference demand case by 2010. The key feature, however, is a continued high level of dependence on secondary supplies from Russia. These are gradually cut off in the period 2008–12. This could occur for a variety of reasons (Russia's stated intention to push up domestic uranium production towards 10 000 tU per annum by 2010 may reflect this possibility). Such a situation would likely result in very severe disturbance, dramatically exemplifying the possible consequence of dependence on one source of supply for a large share of requirements. Such rapid supply changes have, however, been features of other commodity markets.

In conclusion, combining all primary and secondary supply sources suggests that the nuclear fuel market will be adequately supplied in the period to 2020. There is an obvious benefit for the world in reducing the size of military inventories of fissile material. For the nuclear industry there are, however, significant risks in relying to a great extent on secondary supplies from one source in meeting uranium demand, when it is not known how long such supplies might last. Secondary supplies are adding to competition in the market, and some consolidation of primary producers has already occurred. Should such secondary supplies be later curtailed, for whatever reason, severe disruptions could result. It takes years to bring new primary production facilities into operation, and inventories do not appear to be easily tradable in times of short supply.

Reference

1. *The Global Nuclear Fuel Market: Supply and Demand 1998–2020*. The Uranium Institute, London, September 1998.