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Critical review of uranium resources and production capability to 2020

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FOREWORD

At the beginning of 1997 there were 442 nuclear power plants in operation with a combined electricity generating capacity of 353 GW(e) (net gigawatts of electricity). Annual uranium requirements to fuel these reactors in 1997 was about 63 800 t U. While there is uncertainty about the long term utilization of nuclear power it is expected that its use may continue for many years given its environmental advantages and ability to contribute to the reduction of greenhouse and other gases and substances. It is therefore anticipated that the uranium requirements to fuel reactors will continue and also probably increase in coming years.

Since the first investigations of the availability of uranium resources to fuel civilian nuclear power programmes began in the mid-1960s an important role of the IAEA has been to make projections of uranium supply and demand. This report was prepared to address the uranium supply and demand situation through 2020.

Uranium production has been meeting only 50 to 60 percent of world requirements with the balance met from sale of excess inventory offered on the market at low prices. As a result, the world uranium inventory has been drawn down by over 160 000 t U since 1990, when world production fell below world demand. It is generally agreed by most specialists that the end of the excess inventory is approaching. With inventory no longer able to meet the production shortfall it is necessary to significantly expand uranium production to fill an increasing share of demand. Non-production supplies of uranium, such as the blending of highly enriched uranium (HEU) warheads to produce low enriched reactor fuel and reprocessing of spent fuel, are also expected to grow in importance as a fuel source.

This report was prepared to assess the changing uranium supply and demand situation as well as the adequacy of uranium resources and the production capability to supply uranium concentrate to meet reactor demand through 2020. It also addresses the issue of what contribution is to be expected from non-production supplies such as conversion of stockpiles of nuclear weapons to reactor grade fuel and through reprocessing of spent fuel. It provides analysis of how these alternative supplies may influence the level of required production.

This is the first analysis of the world uranium supply and demand prepared for the IAEA since 1990. At that time details on world uranium production was incomplete and no information was available regarding the conversion of HEU weapon material to reactor grade uranium. There have also been fundamental changes in the world uranium production industry during the last decade. While there are still uncertainties regarding the details of the future uranium supply, this report makes use of the more complete information that has become available since the last report was prepared.

The last analysis of this topic, together with other related work, appeared in IAEA-TECDOC-650, New Developments in Uranium Exploration, Resources, Production and Demand (1992).

The IAEA wishes to thank the consultants who took part in the preparation of this report for their valuable contribution. The IAEA is also grateful to the Member States and individual organizations for their generous support in providing experts to assist in this work. The IAEA officer responsible for this publication is D.H. Underhill of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. SUMMARY

Analysis of uranium supply and demand indicates that the relationship will undergo a major change over the next few years. The transition, including a substantial change in uranium supply sources, is already under way. The changes are projected to last up to 5 years or more, and could result in market instability if new supply sources do not meet expected delivery schedules. This report provides an analysis of the critical near term transition period, together with an analysis of the longer term uranium supply through 2020.

Based on a projected, modest one percent/annum growth, world uranium requirements are expected to increase from 61 500 t U in 1997, to 75 000 t U in 2020. Cumulative demand over the period is 1.634 million t U.

Production of 36 195 t U in 1996 met about 60% of world requirements, with the balance coming primarily from inventory. The inventory draw down, which has been averaging about 22 000 t U/annum since 1992, is coming to an end. The remaining excess inventory is estimated to be 80 000 t U; comprised of 50 000 t U held by utilities, and 30 000 t U from the Russian Federation. The level of uncertainty in the utility inventory is concluded to be low. Uncertainty regarding the Russian inventory is greater, as very little is known about this supply source. There have however, been several indications supporting the conclusion that the Russian inventory available for sale is limited to about 30 000 t U.

With the end of excess inventory in sight, other uranium supplies will have to increase to meet requirements. What supply sources are available to meet requirements through 2020?

This analysis indicates uranium mine production will continue to be the primary supply providing about 76 to 78% of cumulative needs through 2020. Alternative sources supplying the balance, in order of relative importance are: (1) low enriched uranium (LEU) blended from 500 tonnes of highly enriched uranium (HEU) Russian weapons, plus initial US Department of Energy (USDOE) stockpile sales (11 to 13%); (2) reprocessing of spent nuclear fuel (6%) and; (3) utility and Russian stockpiles (5%).

Uranium production is expected to increase from 36 195 t U in 1996 to between 37 400 and 43 000 t U in 2000, meeting between 59 and 68% of annual requirements. The variation primarily depends upon the rate at which LEU blended from HEU is sold over the next few years. Annual production will further increase to about 52 500 t U in 2005, equivalent to about 80% of annual demand. Thereafter production contributes about 80% of annual requirements, increasing to about 65 000 t U by 2020. Production will contribute about 76 to 78% of cumulative requirements (or about 1.25 million t U) through 2020.

Decommissioning of nuclear weapons by the Russian Federation and the USA is expected to increase as a supply source. Low enriched uranium (LEU) for reactor fuel from blending of 500 t Russian highly enriched uranium (HEU) (equivalent to 153 000 t natural uranium equivalent) is already being delivered to the United States of America under a sales agreement with the Russian Federation. The amounts are scheduled to increase from 5 733 t U (natural uranium equivalent) in 1997 (9% of demand), to 9 555 t U in 1999 (15% of demand). The annual deliveries remain at about this level through 2012. In addition US law authorizes transfer of 20 000 t U natural equivalent of HEU, LEU and natural U from USDOE stockpile material for sale by United States Enrichment Corporation (USEC). The potential for additional contributions from US and Russian government weapons stockpiles is not known at this time. In this analysis, it is projected that additional LEU from HEU will be available over the period through 2020 equivalent to up to 3% of total requirements.

Adequacy of known uranium resources

There are adequate known reasonably assured resources (RAR) and estimated additional resources (EAR-1), producible in the low (≤\$33.80/kg U or ≤\$13.00/lb U_3O_8) and medium (\$33.80

to \$52/kg U (\$13 to \$20/lb U_3O_8) cost categories, to meet requirements through about 2010. After 2010 it will become necessary to also produce from the high cost (≥\$52.00/kg U or ≥\$20.00/lb U_3O_8) category. The market price is therefore expected to range from the current levels up to \$52.00/kg U by 2010, and then rise above that level in following years. It will also be necessary to continue exploration (i.e. delineation and evaluation) of the EAR-1 resources to transfer them into the RAR class.

Adequacy of production capability; recommended required actions

As of 1 January 1997 annual world uranium production capacity was 43 000 t U. The Russian capability for blending HEU to LEU, either installed, or being installed, was 18 t HEU/annum (or 5733 t U natural equivalent). The capacity of facilities for fabricating mixed oxide (MOX) and reprocessed uranium (REPU) fuel was about 1500 t U (natural equivalent).

To meet the increased amounts of supply projected for each of these sources it will be necessary to increase the respective capabilities. Increasing the uranium production capability in the high HEU case is not necessary until after 2000. In the low HEU case, uranium production will increase to 43 000 t U in 2000, which could, in principal be achieved with existing installed capacity assuming 100% capacity utilization.

Under the same assumption, it will be necessary to increase production capacity in both the high and low HEU cases by about 9300, 11 700 and 18 500 t U/annum, respectively in 2005, 2010 and 2020. If however, a more reasonable 85% capacity utilization is achieved, the production capability will have to increase by 10 900, 13 400, and 21 800 t U/annum, respectively in 2005, 2010 and 2020. This is equivalent to an increase of 25, 31 and 50%, respectively over 1997 capability.

For the Russian Federation to meet the planned delivery of LEU blended from 500 t HEU warhead material, Russia will have to increase its HEU blending capability. The required increase is from 18 t HEU/annum in 1997, to 24 t HEU before 1998 and 30 t HEU before 1999.

It may be concluded that it is necessary to expand production capacity of all of the contributing supply sources (mine production, LEU blended from HEU, as well as MOX and REPU fuel) to meet the expected supply shortfall resulting from the complete drawdown of excess inventory. The most critical period is the next five years during which significant production increases are needed from all sources. There may be significant market instability unless all of these supply sources are developed according to the projected schedules. Delay in the development of any of the sources would result in a market shortfall leading to additional price increases. The greatest impact would result from delays in putting new uranium production centres into operation. Shortfalls in the delivery of LEU blended from HEU would have less, but still significant impacts. Delays in delivery of MOX or REPU fuel would be small because of the minor importance of this supply source.

Factors which could reduce the urgency of increasing the availability of supply from the sources described above are sales of additional large amounts of US government stockpile material and/or the availability of a significantly larger excess inventory from the Russian Federation than is estimated in this report. However, the probability of either of these events occurring is believed to be low.

2. INTRODUCTION

Following a period in which world uranium production fell to only about half of annual reactor requirements, world output increased in both 1995 and 1996. Excess inventories held by western utilities, which built up in the period to 1985, have been gradually liquidated (See Fig. 1). Although inventories remain substantial, the increase in spot uranium prices during 1995–1996 was a sign that inventories are much closer to desired levels.

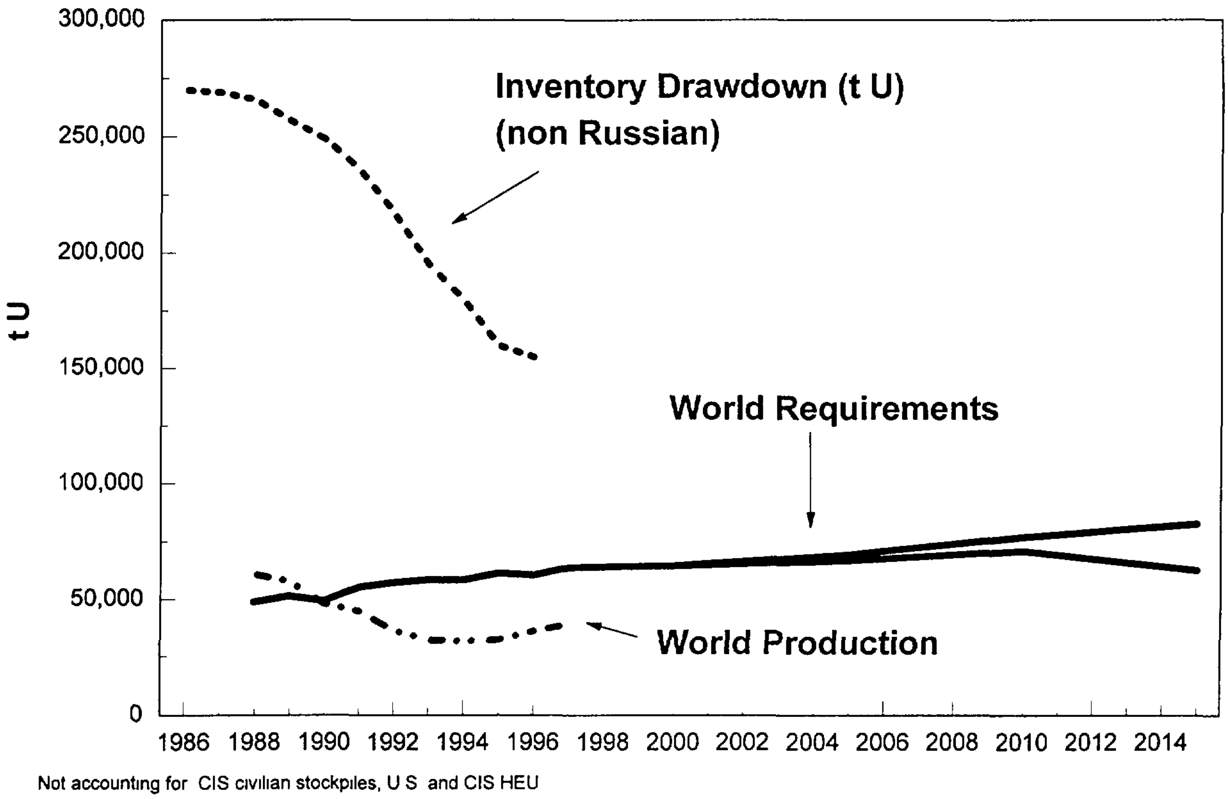

FIG. 1. Production, requirements and the inventory in the world uranium market.

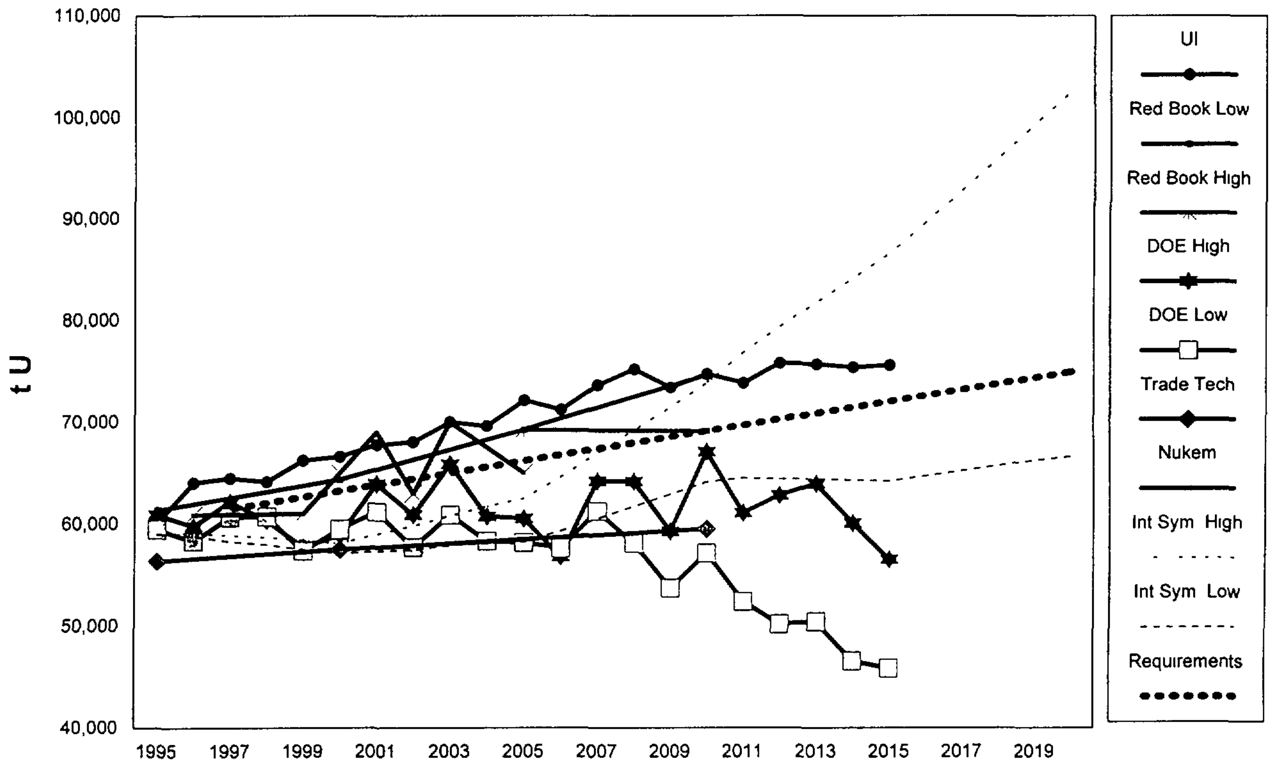

FIG. 2. Projections of world uranium requirements.

While expectations of nuclear power growth during the next 25 years are modest, most forecasters expect some further increase in world uranium requirements. Since utility inventories are nearing desired levels, inventory draw down will diminish as a significant supply source. Uranium from the conversion of military weapons and stockpiles is expected to increase in importance as a supply source. It is anticipated, however, that uranium production will continue as the predominant fuel source. Therefore, the question arises as to the adequacy of both uranium reserves and production capacity to match demand on a timely basis.

3. SCOPE OF STUDY

The objective of this study is to evaluate uranium supply and demand relationships on an annual basis through the year 2020. The following steps were taken in completing the study:

- Establish annual worldwide reactor demand expressed in metric tonnes of uranium metal (t U).
- Identify all sources of uranium potentially available to fill reactor demand.
- Determine the most likely contribution that each potential source will make toward satisfying demand.
- Assess the adequacy of projected supply and broadly define market prices required to ensure supply availability.
- Define what actions must be taken to meet uranium requirements:

  - new mine-mill development }
    } (to a schedule)
  - additional blending capacity for HEU }

4. METHODOLOGY AND ASSUMPTIONS

To focus attention on primary uranium production, the largest contributor to supply, relatively simple assumptions are made for other potential supply sources. There are ranges of possibilities for future reactor requirements on the demand side of the equation and for further inventory draw down and the entry of ex-military high enriched uranium (HEU) on the supply side. However, a single case of uranium requirements is adopted, together with 2 levels of market entry of ex-military HEU. The 2 levels are believed to bound the likely range of supply from the 500 t of Russian HEU plus sales from the US Department of Energy (USDOE) stockpile. The high HEU case is equivalent to the schedule for delivery of low enriched uranium (LEU) from 500 t HEU purchased by the USA from Russia; and a low HEU case, equivalent to the rate at which, under US law, the Russian origin LEU may be sold in the US market, together with 20 000 t natural uranium equivalent from the USDOE stockpile.

4.1. DEMAND

Worldwide reactor uranium requirements (demand) have been the subject of several recent studies. To establish the requirements projection for this study, forecasts of annual reactor requirements from 9 projections shown in Fig. 2 were reviewed. They include: the high and low cases from the 1995 Red Book [1], the reference (i.e. mid-range) scenario from the Uranium Institute (UI) report "Global Nuclear Fuel Market Report - Supply and Demand" [2], the US Department of Energy's reference (i.e. low) and high cases from the "Nuclear Power Generation and Fuel Cycle Report 1996" [3]. NUKEM's uranium requirements projection through 2005 [4] and TradeTech's projection through 2010 [5] are also included. The projections through 2020 identified as "Int. Sym. High and Low", are Shani and Deroubaix's [6] high and low cases from a study of long term nuclear fuel cycle requirements.

There is a reasonable consensus in the trend of the projections of reactor requirements through about 2003. The projections then diverge to 2010. After 2010 the high level of uncertainty regarding the continuing utilization of nuclear energy is reflected by the wide range of projected uranium requirements. The low trend is clearly shown by the decreasing requirements in the USDOE reference case. In this projection requirements decrease by 30 per cent from a high of 64 800 t U in 2003, to a low of 45 600 t U in 2015. This contrasts with the UI's reference projection indicating 76 300 t U will be required in 2015. In Shani and Deroubaix's longer term study, uranium requirements in 2020 range from a low of approximately 67 000 t U, to a high of 103 000 t U.

Several recent forecasts of reactor demand consider more than one scenario. For this report a single case has been adopted for uranium requirements. An estimated best-fit straight line was drawn through the projections defining the approximate middle of the demand range. The straight-line, identified as "Requirements" in Fig. 2, is the demand projection used in this study. Reactor demand is projected to increase steadily by nearly 600 tonnes per year from 61 500 t U in 1997 to 75 000 tonnes in 2020. This represents a rate of growth of close to one per cent per annum, unremarkable by any standards, and reflecting the strong likelihood that new reactor startups will be few in number. The cumulative requirements over this period are about 1 638 000 t U. This is a substantial amount of uranium, equivalent to about 85 per cent of total world production through 1996 [7].

4.2. SUPPLY

Supply sources expected to be available to satisfy reactor requirements include:

- utility and producer inventory (western and Russian Federation);
- 500 t HEU from Russian nuclear weapons, plus 20 000 t U natural equivalent from the USDOE stockpile;
- mixed oxide fuel (MOX) and reprocessed uranium (REPU); and
- newly mined and processed natural uranium.

Estimates were made of the availability of inventory, HEU, MOX and REPU on an annual basis. The sum of these estimates was subtracted from annual reactor demand to determine the amounts of newly produced natural uranium necessary to meet the remaining unfilled requirements. Following is a brief description of assumptions used to establish the annual availability of each component of total supply.

4.2.1. Inventory

Two types of inventory are addressed in this analysis: excess western inventory and estimated inventory held by the Russian Federation. The majority of non-Russian inventories are held by utilities for security of supply reasons. There are also smaller amounts owned by producers, uranium traders and the US Department of Energy. Discretionary utility inventory at the beginning of 1997 (inventory held by utilities in excess of preferred or mandated levels) is estimated to total about 50 000 t U. In this study the last discretionary inventory (designated "Invent. W" on figures) is projected to be sold in the year 2000.

Inventory of natural and/or low enriched uranium held by the Russian Federation at the beginning of 1997 is estimated to total about 30 000 t U. This inventory (identified as "Invent. CIS" in this report) is projected to be gradually drawn down through 2004.

The projected schedules for draw down of the utility and Russian (CIS) inventory, in t U, are as follows:

Year	Invent. W	Invent. CIS
1997	17 000	4 000
1998	14 000	6 000
1999	11 000	5 000
2000	8 000	5 000
2001	0	4 000
2002	0	3 000
2003	0	2 000
2004	0	1 000

No reliable estimate of inventory held by producers/suppliers is available; and therefore no provision was made for this potential source of supply.

4.2.2. Russian HEU plus USDOE stockpile material transferred to USEC

This supply source consists of HEU from the Russian Federation, together with US Department of Energy (USDOE) stockpile material transferred to the United States Enrichment Corporation (USEC). The Russian HEU consists of 500 t warhead material under sales agreement with the US government. The quota for US sales of the LEU blended from the 500 t HEU ranges: from 769 t U (2 million pounds U_3O_8) in 1998, to 5000 t U (13 million pounds U_3O_8) in 2004, reaching 7692 t U (20 million pounds U_3O_8) in 2009. An additional amount equivalent to 5384 t U may be sold from 2001 to 2005 at the rate of 1154 t U/annum.

Sale of the USDOE stockpile material (including up to 20 000 t U natural equivalent of HEU, LEU and natural uranium) for use in the USA, following transfer to USEC, is provided for in the law authorizing privatization of USEC [8]. Following transfer to USEC, the USDOE stockpile material is to be sold at the rate not exceeding 1538 t U/annum from 1998 to 2010.

Probably no other supply source is surrounded by more uncertainty than HEU held by the Russian Federation. Politics, economics and technology will all play a role in determining the availability of uranium from Russian HEU. A total of 500 tonnes HEU, equivalent to 153 000 t U natural, is scheduled for delivery. The high HEU case for this report assumes that the HEU delivery schedule agreed upon in 1996 will be adhered to over the period. A total of 18 tonnes was delivered prior to 1997, the initial year of this report. The annual delivery schedule for the remaining 482 tonnes is as follows:

Year	t HEU	t U equivalent*
1997	18	5 733
1998	24	7 644
1999 to 2012	30/year	9 555/year

*The HEU is to be blended with 1.5wt% LEU in Russia to produce 4.4wt% LEU for use in commercial reactors. The blending of 1.5% LEU with 94% HEU to obtain 4.4% product (the assay of the material to be imported into the USA) requires 30.85 kg U of LEU for each kilogram of HEU. To process 10 tonnes of HEU requires 308.5 tonnes U of 1.5% LEU and produces 318.5 tonnes U of 4.4% product.

In the high HEU case of this report, it has been assumed that all of the uranium derived from the 500 tonnes of Russian HEU will be available on the world market in the year it is delivered to the USA. There are, however, political and technical uncertainties as to whether the proposed delivery schedule can be maintained. In the low HEU case, it has been assumed that the uranium derived from the Russian HEU will be available on the world market at the rate mandated for sale in the USA, according to US law [8]. It is also assumed that the USDOE stockpile transferred to USEC will also be available for sale at the maximum rate mandated by the same US law. The delivery of HEU under the high and low cases is shown in Fig. 3. The potential for additional sales of uranium derived from US weapons HEU or stockpiles is not directly addressed in this study. However, this potential mitigates the uncertainty surrounding the Russian HEU delivery schedule.

It should be noted that both the low and high HEU cases provide for market entry by 2020 of amounts of uranium in excess of the 173 000 t U derived from both the 500 t of Russian weapons HEU under purchase agreement with the USA, and the 20 000 t U from the USDOE stockpile. In the low and high HEU cases respectively, the total amount of natural U equivalent projected to enter the market by 2020 is 181 000 and 219 150 t. The low and high cases exceed the 173 000 t U of Russian plus US HEU equivalent by 8 000 and 48 150 t U, respectively. In the low HEU case market entry of the Russian and USDOE equivalent will end in 2019, while in the high HEU case it would end in 2015. The excess amounts provide for market entry of either Russian or US weapons and/or military stockpile material not otherwise provided for in this analysis. The possibility that additional amounts of such material may be made available to the market is believed to be a realistic possibility over the more than 20 year term of this analysis.

4.2.3. Mixed oxide utilization and reprocessed uranium

Assuming that countries maintain existing policies regarding the reprocessing of spent nuclear fuel versus opting for direct disposal, the future market for these options will be limited. Reprocessed uranium and plutonium for MOX fuel is an important component of the supply in only a limited number of countries. The contribution of MOX and REPU is not expected to exceed about 6 per cent of annual requirements through 2020. The rate of utilization of MOX and REPU is shown in Fig. 4.

In summary, the total non-production supplies (inventory, LEU from HEU, MOX and REPU) for the high and low HEU cases are shown in Figs 5 and 6. The requirements not filled by these non-production sources will have to be met from production of natural uranium.

4.2.4. Natural uranium

Potential sources of natural uranium were subdivided into three categories:

1. Supply from the Commonwealth of Independent States (CIS);
2. National programmes in which production is dedicated to domestic nuclear power programmes ("captive production");
3. All "Other" uranium production centres not included in the first two categories.

Following are assumptions made as to the availability of supply from each of these sources.

4.2.4.1. CIS supply

The projected production schedule for the CIS producers (t U) is as follows:

	1997	1998	1999	2000	2001
Kazakhstan	1 700	2 485	3 525	3525	3 525
Russian Federation	2 500	2 500	2 500	2500	2 500
Ukraine	385	385	385	385	770
Uzbekistan	1 700	2 130	2 560	2560	3 000
TOTAL	6 285	7 500	8 970	8970	9 795

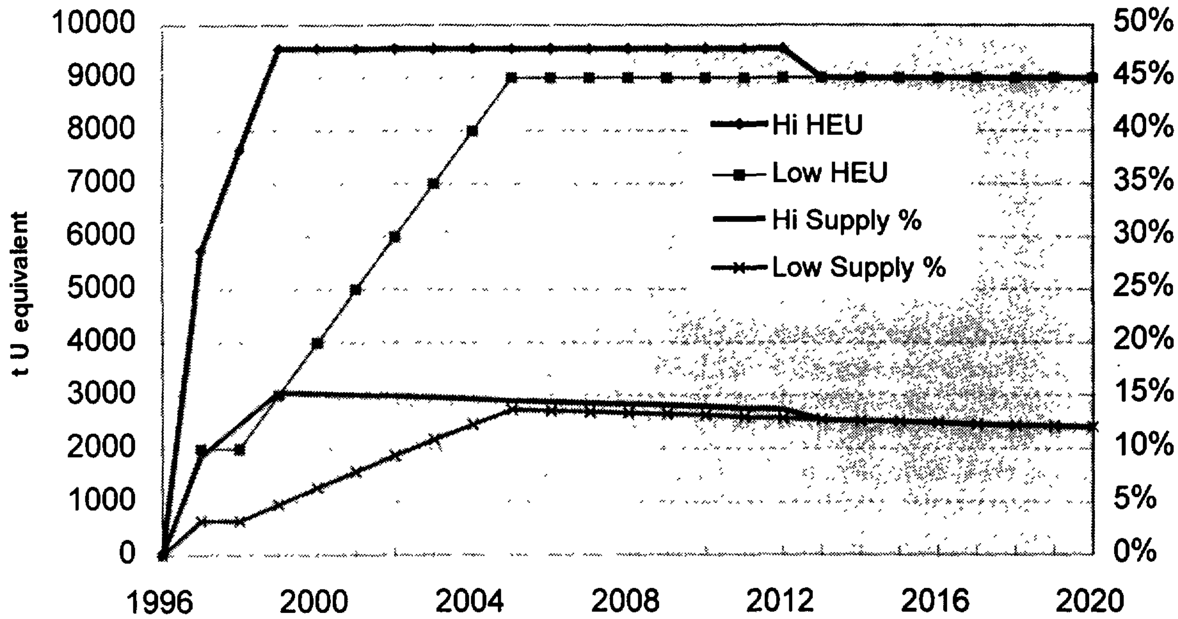

FIG. 3. Delivery of uranium (Nat. Equiv.) in high and low HEU cases.

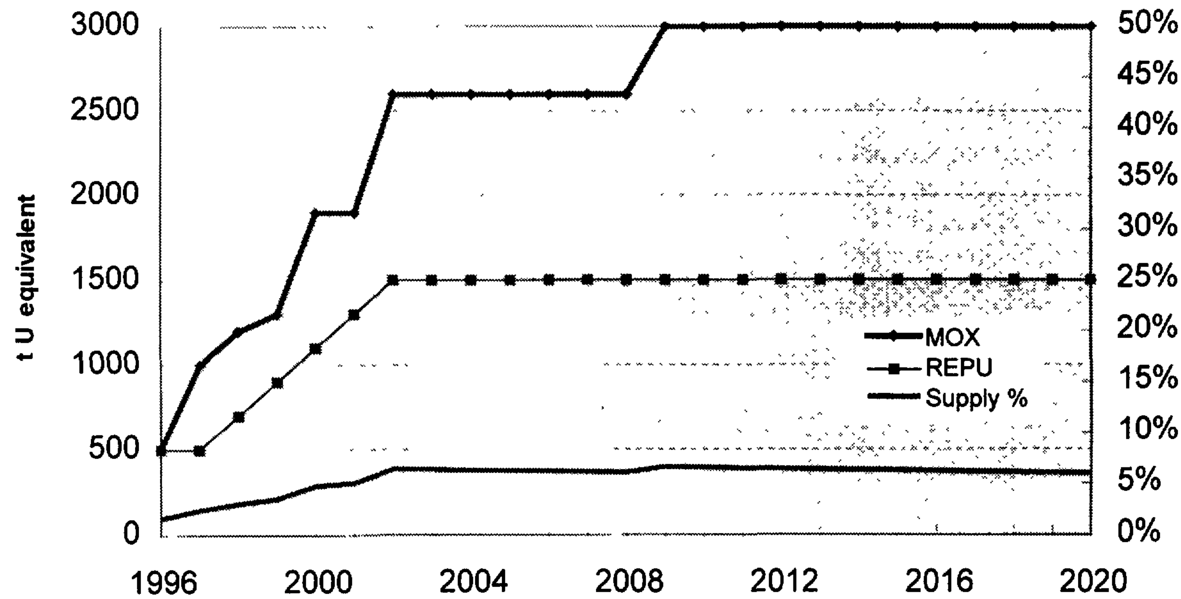

FIG. 4. MOX and REPU use by year.

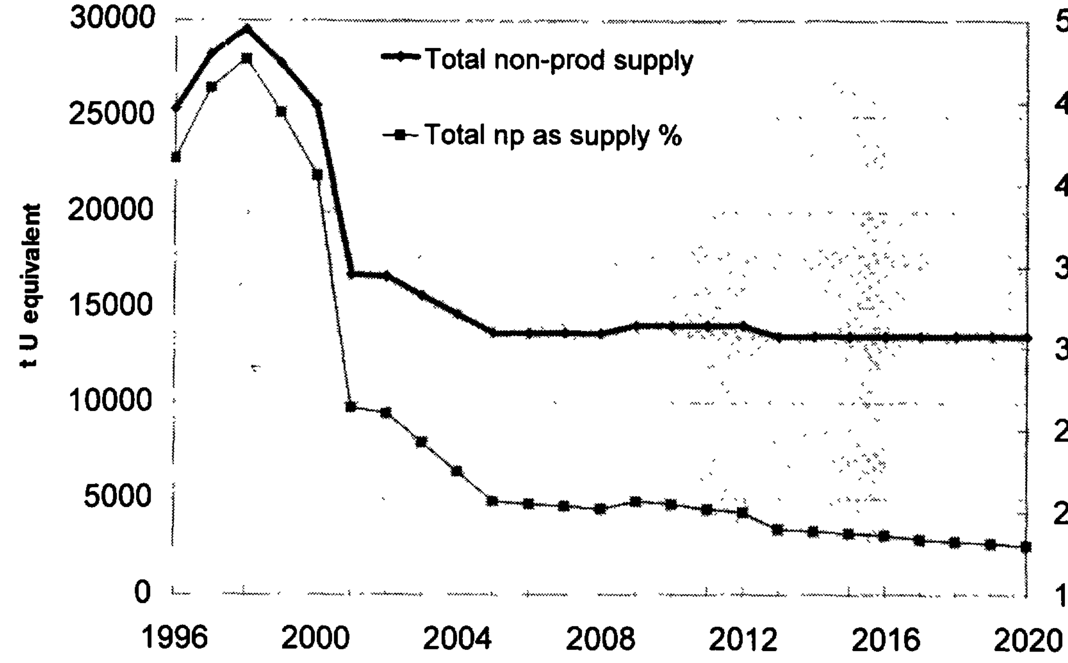

FIG. 5. Non-production uranium supply and share (high HEU case).

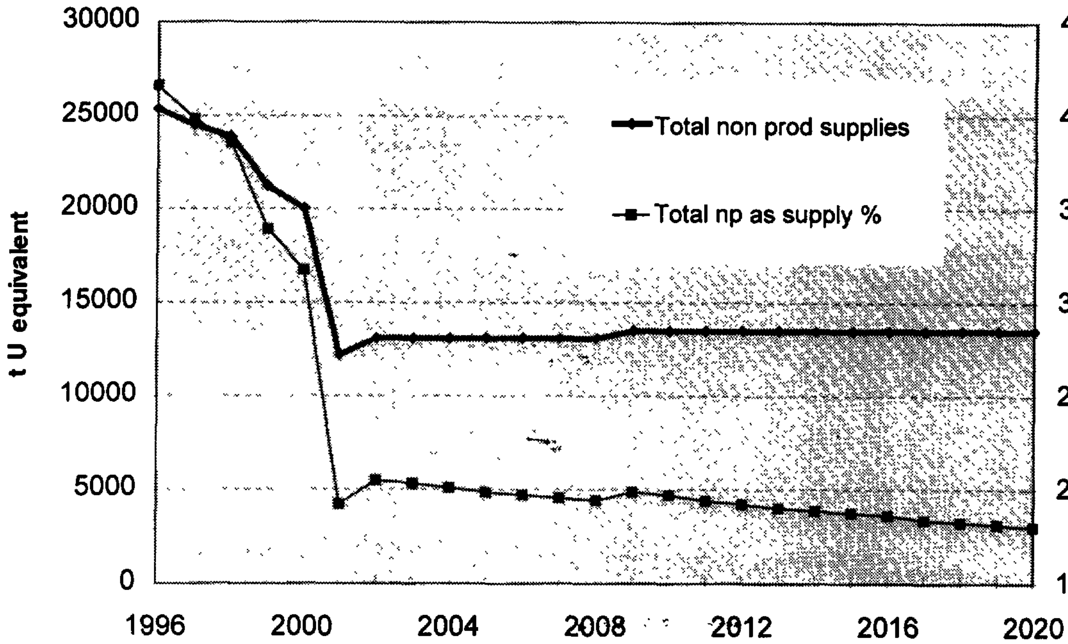

FIG. 6. Non-production uranium supply and share (low HEU case).

This schedule projects a 55 per cent increase in CIS uranium production between 1997 and 2001. Projected capacity levels for the year 2001 are used throughout the remainder of the study (i.e. through 2020). In 2001 the CIS production equals about 15.5 per cent of requirements. It then decreases gradually to about 13 per cent of requirements in 2020. Over the period 1997 to 2020 CIS production meets 14 per cent of requirements.

4.2.4.2. Captive (national) programmes

Several countries have small uranium production programmes dedicated to meeting domestic nuclear power programme requirements. While several of these programmes have high production costs, they are maintained either because of their importance to local economies or for reasons of national security. For this study, the production schedule for the captive programmes is balanced with reactor demand in the following countries:

Argentina	Pakistan
Brazil	Romania
India	Spain

Also included in the captive programmes category are the production industries of:

France (projected to produce through 1999)
The Czech Republic (projected to produce through 2003)
Hungary (production scheduled to terminate in 1997)
Portugal (projected to continue production through 2020)

Over the period of this study captive production equals about 5 per cent of requirements.

4.2.4.3. "Other" natural uranium production

Total projected annual availability of CIS and captive programme material was subtracted from total natural uranium requirements to determine uranium demand supplied from "Other" sources (i.e., non-CIS and non-captive sources).

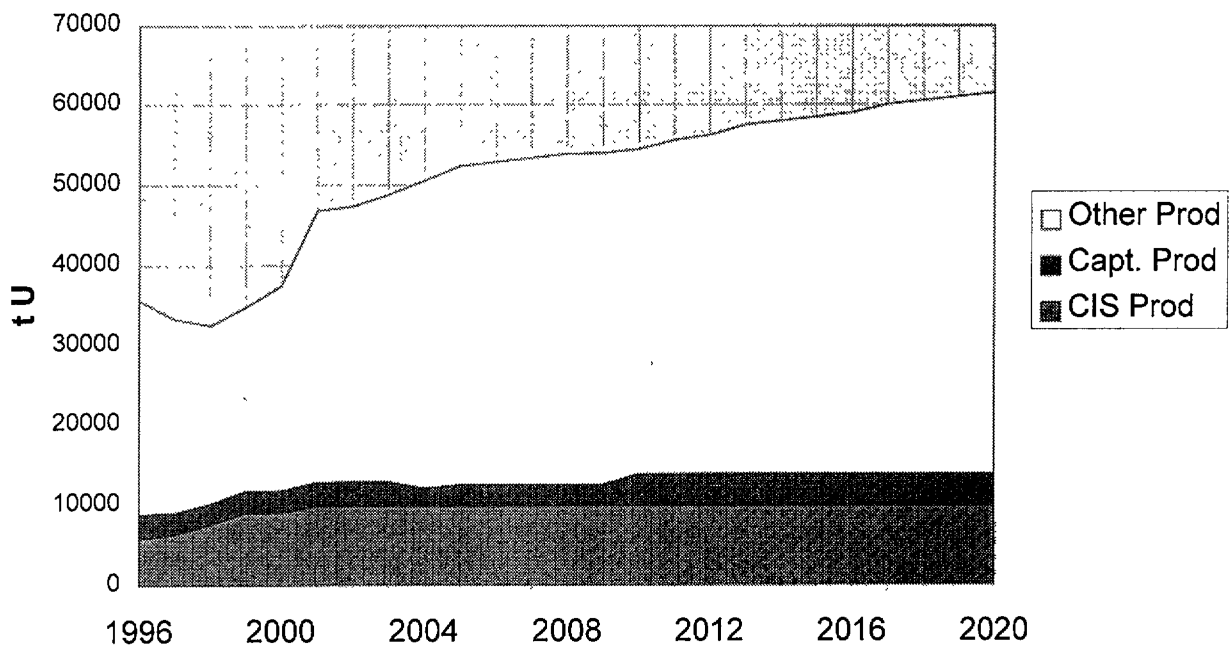

FIG. 7. Uranium production forecast (high HEU case).

Figure 7 shows the distribution of production between CIS, captive and "Other" producers. ***Projections of annual production were then made for each "Other" project, based on announced plans of these existing or potential producers.*** Using NAC International's *Uranium Supply Analysis (USA) System* (Appendix), an initial analysis was completed based on the assumption that the lowest cost producers will fill uranium requirements for the "Other" category. Higher cost capacity not required to meet a given year's production is assumed to be deferred to subsequent years when, and if, it becomes cost competitive.

For this study the forward production cost is used. The production cost of all production centres are classified in three categories:

Low cost	<$33.80/kg U ($13/lb U_3O_8)
Medium cost	$33.80 to $52.00/kg U ($13 to $20/lb U_3O_8)
High cost	>$52.00/kg U ($20/lb U_3O_8)

The market balancing routine of the *USA System* provides a rigorous evaluation based on competitive market theory in which demand is filled by the lowest cost producers. In reality, however, there are exceptions to this theory in which higher cost operations continue production for contractual, political or social reasons. In the real world, therefore, these higher cost producers displace lower cost projects, which are then forced to delay startup to later years. Modifications were made to results from the *USA System* market balancing routine to accommodate these special situations. In addition to project deferrals, adjustments were also made in output from lower cost production centres already in operation to accommodate output from the higher cost producers.

Results of the analysis indicate production from current operations and proposed projects with well established reserves is adequate to supply demand for "Other" natural uranium through the year 2012. Table I lists current and proposed production centres expected to contribute to the supply of "Other" natural uranium.

In addition to the projects with well established reserves (reasonably assured resources, RAR) listed in Table I, exploration programmes in Australia, Canada and the United States have identified resources in the estimated additional resources-Category 1 (EAR-1) that are expected to be developed in the future. Contributions from these less well known resources are expected to be needed to fill demand from some projects beginning in the year 2013. Exploration programmes are ongoing in these three countries, the results of which are expected to increase confidence in these less well known resources. These delineation and evaluation programmes will have to continue for the EAR-1 to become available to meet future requirements.

In this analysis "Other" production meets 57 and 59 per cent respectively, of requirements in the low and high HEU cases. The main differences between these 2 cases occurs over the period through 2004. In the low case, "Other" production increases from 28 000 t U in 1997 to 38 500 t U by 2001. It then gradually increases to 47 700 t U in 2020. For comparison, in the high HEU case "Other" production increases from 24 000 t U in 1997, to 34 000 t U in 2001. It then increases to 39 900 t U by 2005, and then gradually expands to 47 700 t U in 2020.

5. ANALYSIS

Three major concerns were addressed in this study:

- adequacy of resources to meet projected demand;
- adequacy of production capability to produce the uranium; and
- market prices needed to sustain production to fill demand.

Analysis of these issues are discussed in this section.

TABLE I. CAPACITY AND STATUS OF CURRENT AND PROPOSED PRODUCTION CENTRES

	1 Jan. 1997 [9] capacity	Maximum capacity (tonnes U)*	Status (if known)
Australia	5000		
Ranger/Jabiluka		6000	Operating
Olympic Dam		4100	Operating
Kintyre		1500	Permitting
Koongarra		1000	
Beverley		600	Preliminary
Yeelirrie		2120	Feasibility study
Canada	12950		
Key Lake/McArthur River		6920	Operating
Rabbit Lake		4620	Operating
Cluff Lake		1200	Operating
McClean Lake/Cigar Lake		9230	Under construction
Dawn Lake		770	Exploration
Kiggavik		1400	Exploration
China & Mongolia	890	1730	
Gabon	587		
Okelobondo/Mounana		630	Operating
Namibia	3000		
Rössing		3850	Operating
Niger	3800		
Akouta		1970	Operating
Arlit		1000	Operating
South Africa Gold & Copper	1900		Operating
By-product		1320	
United States of America	4230		
Highland		580	Operating
Crow Butte		380	Operating
Kingsville Dome/Rosita		770	Operating
Christensen Ranch		770	Operating
Smith Ranch		1150	Operating (1997)
Gas Hills		960	Permitting
Church Rock/Crownpoint		770	Permitting
Uncle Sam & New Wales		960	Operating (Uncle Sam)
Reno Creek/Dewey Burdock		380	Permitting
Alta Mesa		380	Permitting
Jackpot/Sweetwater		1540	Stand-by
Ticaboo		380	Permitting
TOTAL	**32357**	**58980**	

* Maximum capacity expected to be achieved during study period.

5.1. ADEQUACY OF URANIUM RESOURCES

As previously noted, production from projects with well-defined reserves is adequate to fulfill requirements through the year 2012. Beyond that time, lower confidence resources will be required to fill demand. The main question to be answered is the source of the lowest cost resources most likely to be produced for the market.

Based on extensive exploration programmes completed to date, Australia, Canada and the USA are considered the most likely sources of the lowest cost resources among those countries contributing to the "Other" natural uranium category. Accordingly it was assumed that new projects in these countries will be the source of additional production after 2010. The Athabasca Basin is considered the most likely source of additional low- to medium-cost resources in Canada. The Northern Territory, South Australia and Western Australia are all considered to have excellent potential to host low- to medium-cost resources. Sandstone deposits amenable to in situ leach extraction are considered to be the most likely source of additional low- to medium-cost resources in the United States of America.

Figures 8 and 9 show the projected distribution of production by country from 1997 through 2020 for the high and low cases. Canada is expected to be the dominant producer throughout the study period. Canada's production is expected to peak at 20 400 t U in the year 2002 (54% of requirements in the "Other" natural U category) of the low HEU case when McArthur River and Cigar Lake reach capacity. Canada's total production capacity is greater than that shown in the year 2000. It has, however, been adjusted downward along with other low-cost production to accommodate continued output of high-cost producers elsewhere in the world. Canada's share of the world market is expected to decline to about 38% of the "Other" natural uranium category in 2020 as reserves are depleted and as low-cost production capacity increases elsewhere in the world.

Production in Australia and the USA is expected to increase from about 21% and 10% of "Other" natural uranium in 1997 low HEU case, respectively, to about 29% and 16% in the latter part of the study period. Cumulative output from Niger and Namibia is expected to meet between 5 and 10% of demand through 2020. A summary of production from the major producing countries is given in Figure 10.

5.2. ADEQUACY OF SUPPLY CAPABILITY

Uranium: As reported in the Red Book, the world annual production capability on 1 January 1997 was 43 000 t U [9]. This is comprised of 8050, 2600 and 32 350 t U/annum, respectively of CIS, captive and "Other" production capability.

Uranium production in 1996 was 36 195 t U. This represents a world production capability utilization of 84%. Production capability utilization is defined as: production divided by available production capacity. Production was distributed: 6275, 2440, and 27 450 t U, respectively in the CIS, captive and "other" groups. In 1996 capability utilization was: 78, 93 and 85 per cent, respectively for the CIS, captive and "Other" production groups.

Based on historical performance, 85 per cent is about the maximum sustainable utilization level achieved by the uranium industry.

In the high HEU case total uranium production will change little through 2000. If, as planned, CIS production expands by 42 per cent, "other" production could decrease by nearly 2000 t U, or a temporary production surplus could develop. In contrast, in the low HEU case world production will increase to 43 000 t U by 2000, or by 19 per cent. In principal this requires no production capability increase over the capability reported in the 1997 Red Book. It should be noted that CIS production is projected to increase 55 per cent by 2001. However, achieving this increase will require substantial growth from an industry segment where production has fallen in every year since information on production first became available in 1992 [9].

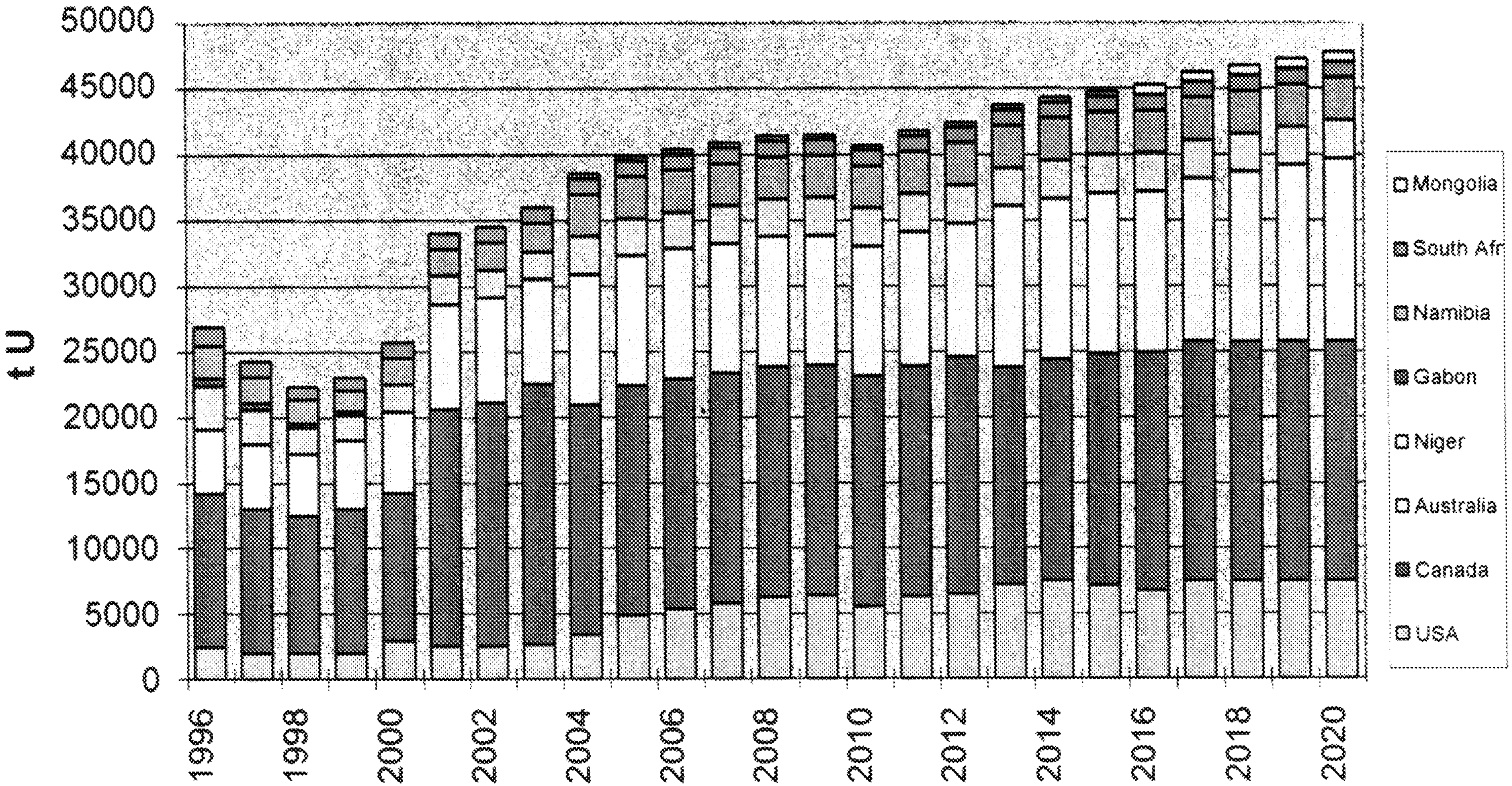

FIG. 8. Detailed production forecast (high HEU case).

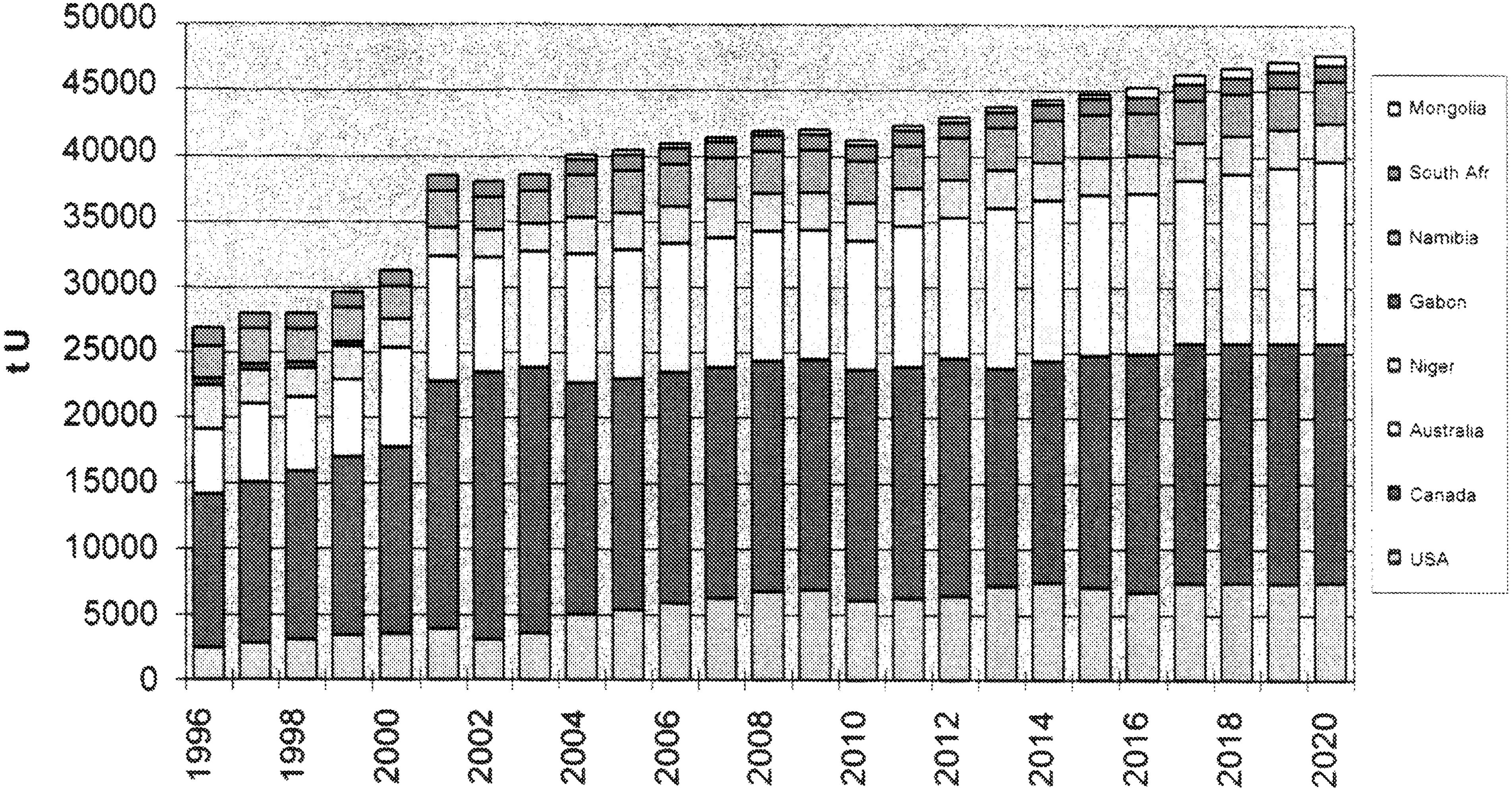

FIG. 9. Detailed production forecast (low HEU case).

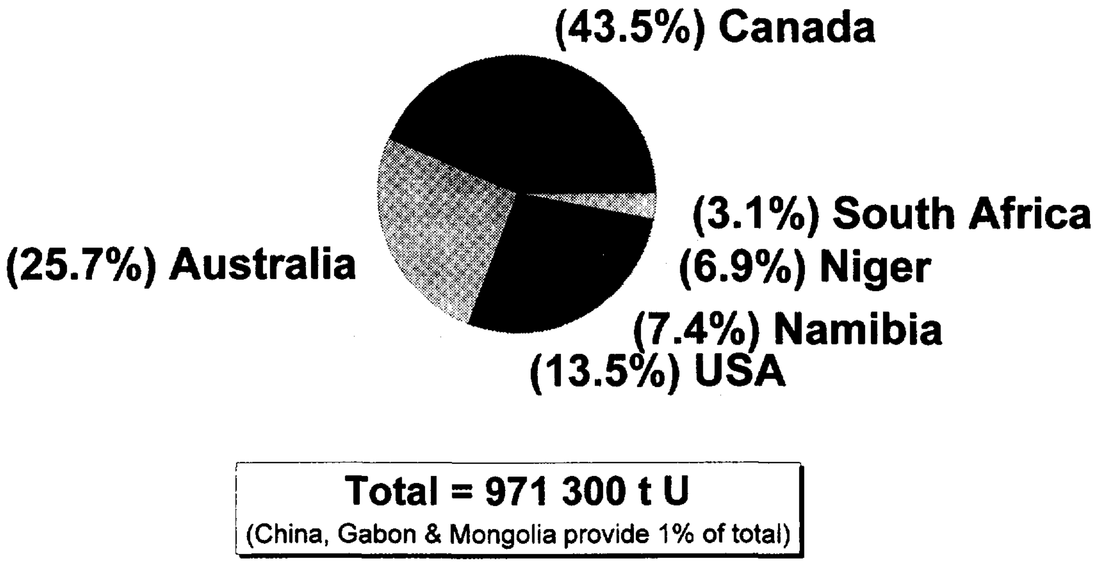

FIG. 10. "Other" production: 1997–2020.

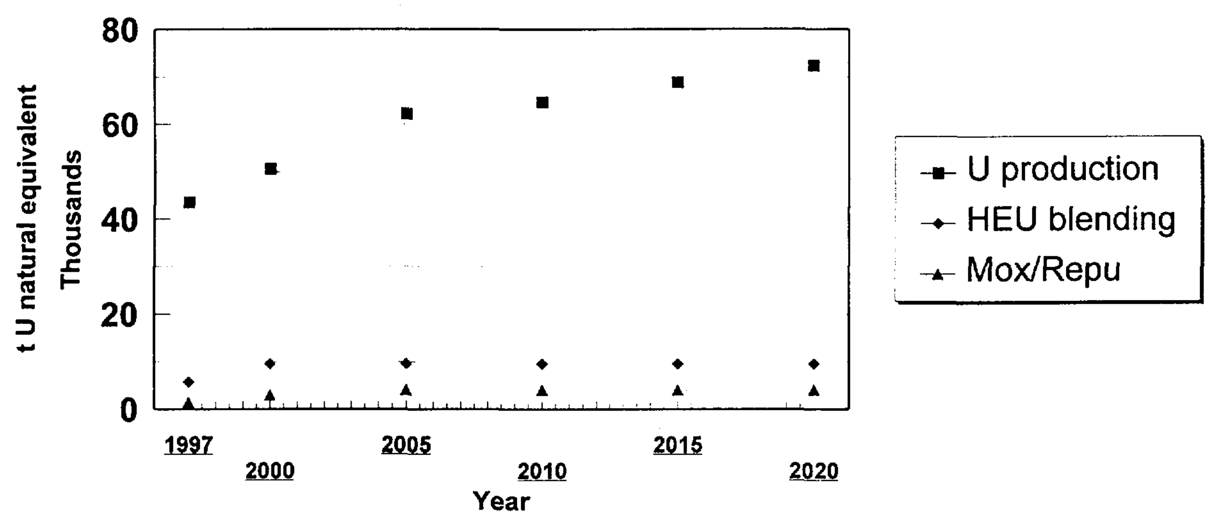

FIG. 11. Required capacity for uranium production, HEU blending and MOX/REPU fabrication (low HEU case).

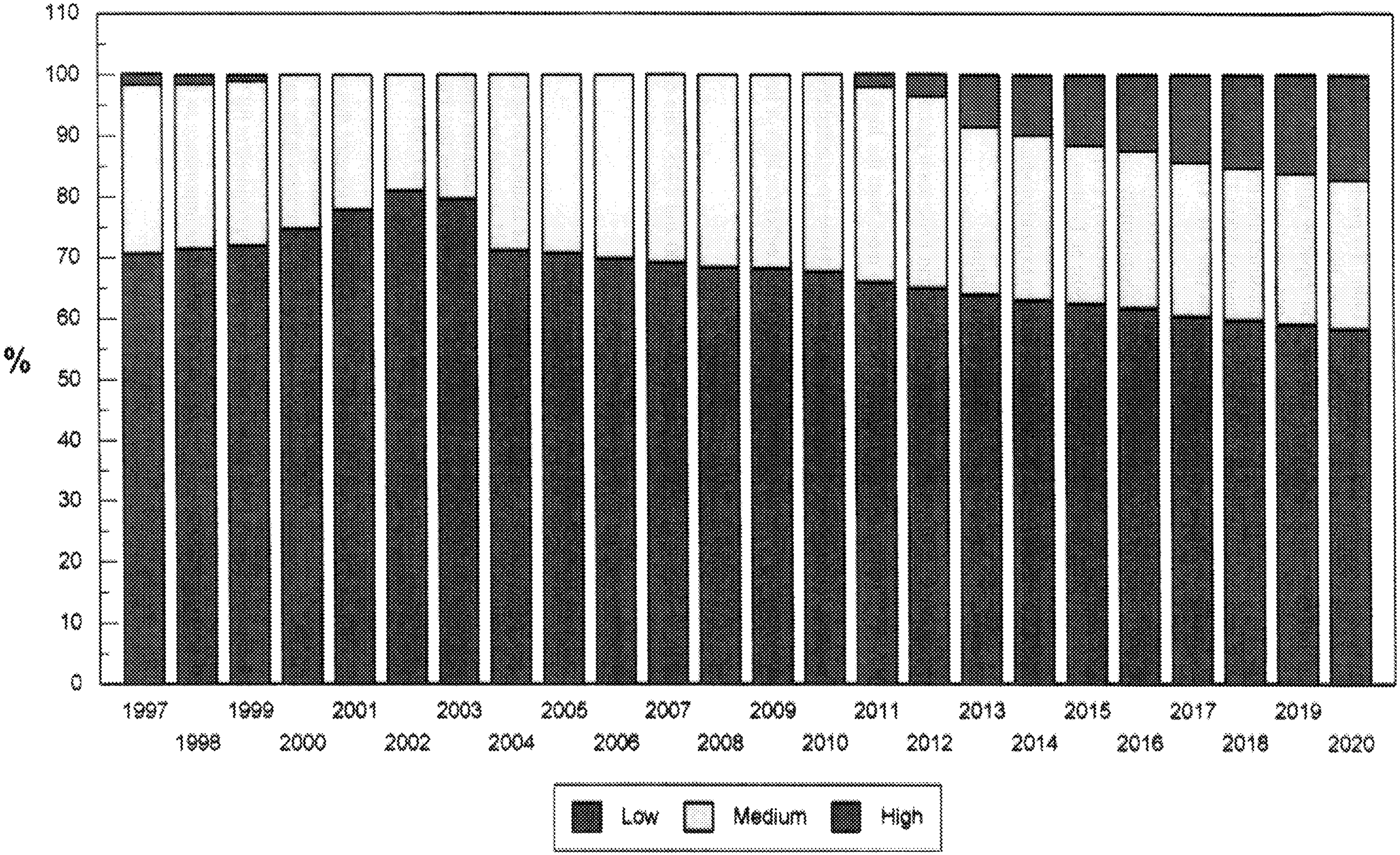

FIG. 12. Distribution of production by cost category (low HEU case).

Estimated production for both the high and low HEU cases is about 52 500 t U in 2005. This is an increase of over 16 000 t U, or about 44 per cent, from 1996. To produce this amount, a capability increase of between 22 and 26 per cent is required from the 1 January 1997 existing capability of 43 000 t U. The lower value is valid if 100 per cent capacity utilization level were achieved. However, a 26 per cent increase will be required if 85 per cent capacity utilization level is met. Under this schedule only 7 years remain to plan, license, construct and bring these projects into production. Additional capacity will be required to produce about 61 500 t U/year by 2020, as well as to replace capacity that closes because of resource depletion (see Fig. 11).

Installing new capacity requires substantial capital investment. It was recently reported the initial capital investment, in US $/t U annual capacity for high grade unconformity and in situ leach projects, ranges from $44 000 to $66 000 and $30 000 to $44 000, respectively [10]. In comparison the last conventional uranium mill built in the USA (in the early 1980s) at Ticaboo, Utah, required a capital investment of about $100 000/t U annual. Mine development costs added substantially to the capital cost of the project. Based on these estimates the capital costs to expand production capability by 1000 t U/year could range from $30 million to over $100 million. An expansion of 16 000 t U/year would cost between $480 million and over $1600 million.

HEU blending: It was reported in November 1996 that the Russian Federation planned to add a new facility at Tomsk-7 to increase its capability for blending HEU to LEU from 12 t/year to 18 t/year [11]. Russia will have to implement this capacity increase to meet both the high and low HEU cases of this report. Assuming this is the total blending capacity of the Russia Federation, it is apparent additional blending capacity will have to be put into service to achieve the planned deliveries from 24 t HEU in 1998 and 30 t HEU in 2000 and subsequent years. It therefore appears that substantial additional blending capacity must be added if Russia is to meet either the high or low HEU cases of this study. The cost of these facilities is not known.

MOX and REPU: The contribution for MOX and REPU is modest, increasing from about 1500 t U (equivalent) in 1996, to 3000 and 4100 t U, respectively in 2000 and 2005. This can only be achieved if planned expansion of facilities for recovering and fabricating these materials are developed and put into production.

5.3. URANIUM PRODUCTION COSTS AND MARKET PRICES

In this analysis the spot market price for uranium in any given year is assumed to be equal to the highest cost production required to fill that year's demand for "other" natural uranium. The forward production cost (exclusive of sunk costs) was used in this study. Production costs from NAC's *USA System* were used as the basis to group worldwide production centers into three cost categories: low, from < $33.80/kg U ($13/lb U_3O_8); medium, $33.80 to $52.00/kg U ($13 to $20/lb U_3O_8); and high, > $52.00/kg U ($20/lb U_3O_8).

Figure 12 shows the estimated percentage of production in each cost category that will be required throughout the study period in the low HEU case. In the high HEU case the need for high cost production will be deferred a few years. Low-cost production clearly dominates in the early part of the report, accounting for 80% of "Other" natural uranium in 2001 to 2003, when McArthur River and Cigar Lake are scheduled to begin operations. High-cost production is not required to fill "Other" natural U requirements until 2011. The small amount of high-cost production prior to 2011 is attributable to one production centre that continues to operate because of its importance to the local economy.

6. CONCLUSIONS

Based on a projected, modest one per cent/annum growth, world uranium requirements would increase from 61 500 t U in 1997, to 75 000 t U in 2020. Cumulative demand over the period is 1.638 million t U.

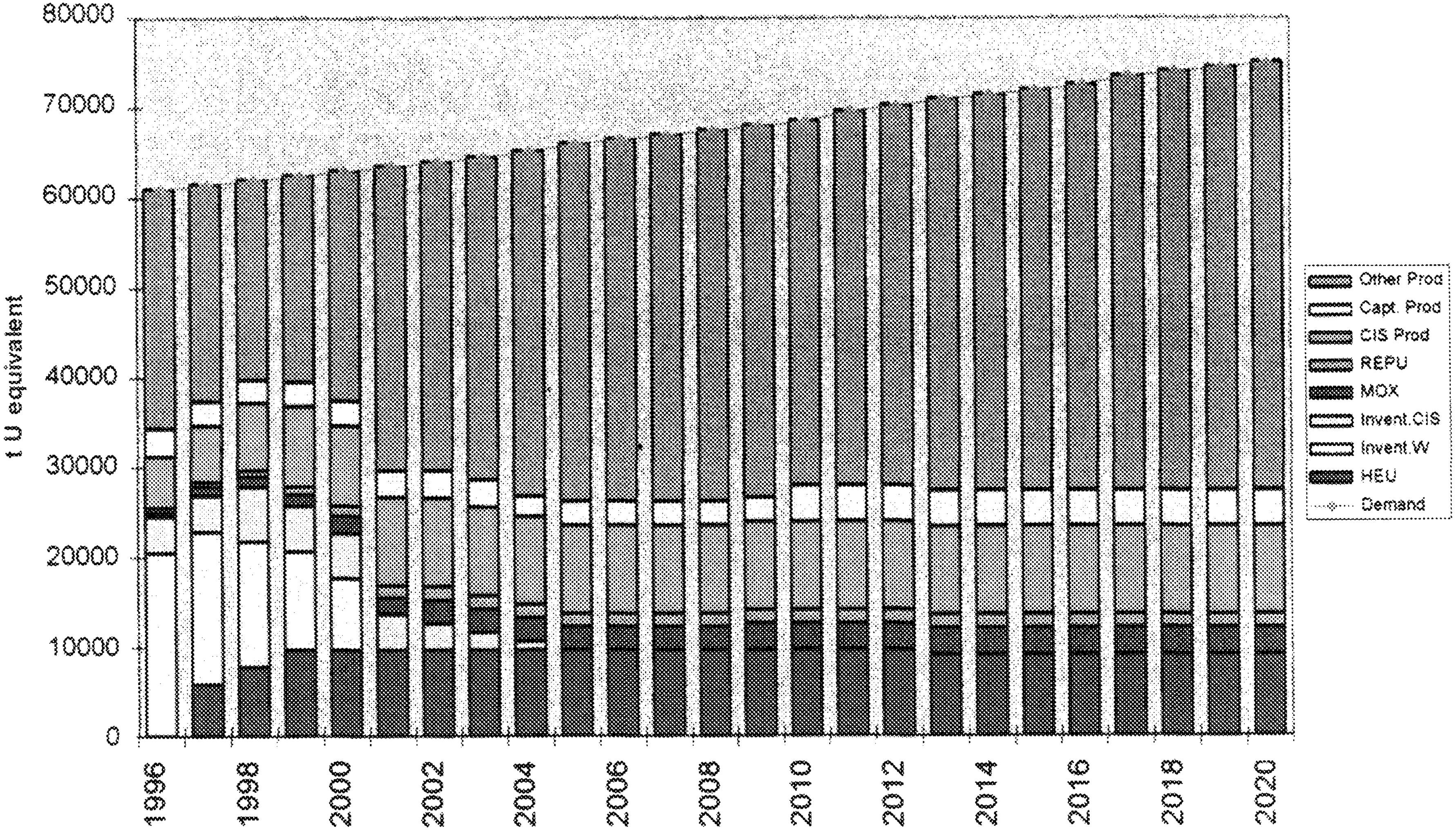

FIG. 13. World uranium supply and demand (high HEU case).

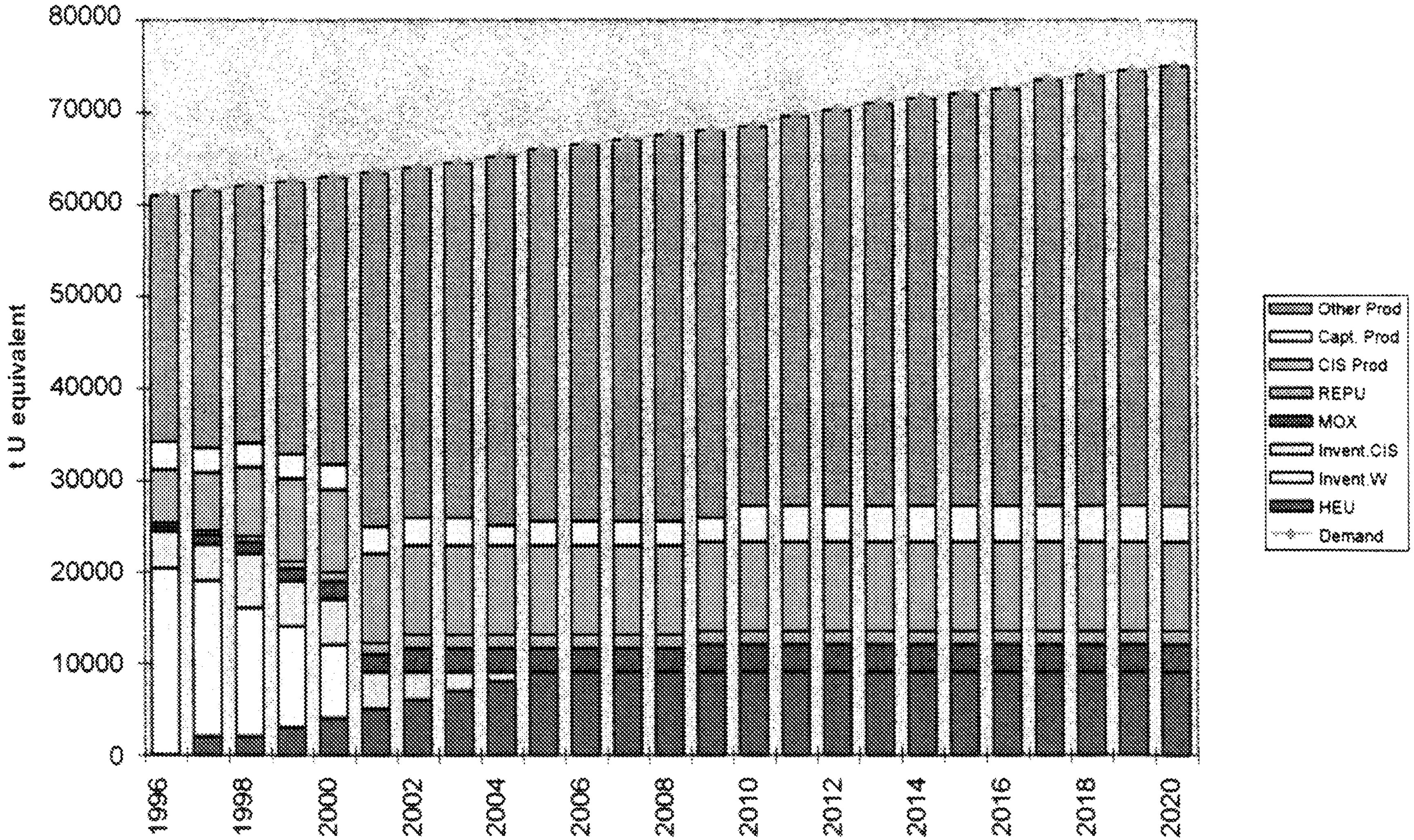

FIG. 14. World uranium supply and demand (low HEU case).

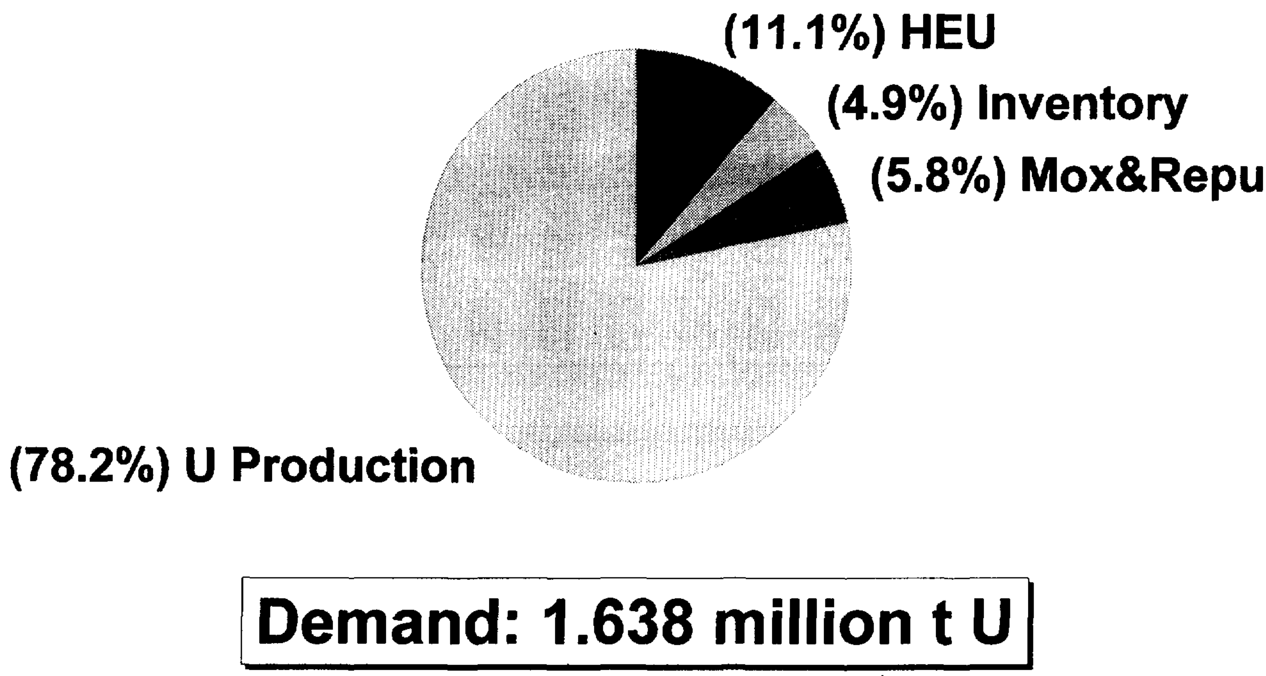

FIG. 15. Uranium supply to 2020 (low HEU case).

Production of 36 195 t U in 1996 met about 60 per cent of world requirements, with most of balance coming from inventory. This source, which has been supplying an average of about 22 000 t U/annum since 1992, is coming to an end. The remaining excess inventory is estimated to be 80 000 t U; comprised of 50 000 t U held by utilities, and 30 000 t U by the Russian Federation.

With the end of excess inventory in sight, uranium supplies from other sources will have to increase to meet requirements. What supply sources are available to meet requirements through 2020?

This analysis indicates uranium mine production will continue to be the primary supply, meeting 76 to 78 per cent of cumulative requirements through 2020. Alternative sources supplying the balance, in order of relative importance, are: low enriched uranium (LEU) blended from highly enriched uranium (HEU) weapons (11 to 13%), reprocessing of spent nuclear fuel (6%), and excess inventory (5%). This information is summarized in Figures 13, 14 and 15. The contribution of US government and other Russian strategic stockpiles is not known at this time. However, the potential for supplying levels ranging from these sources (i.e. 28 000 (1.7%) and 68 150 (4% of requirements) are accommodated in this analysis.

6.1. ADEQUACY OF KNOWN URANIUM RESOURCES

There are adequate known reasonably assured resources (RAR) and estimated additional resources-Category 1 (EAR-1), producible in the low (≤\$33.80/kg U or ≤\$13.00/lb U_3O_8) and medium (≤\$52.00/kg U or ≤\$20.00/lb U_3O_8) cost categories, to meet requirements through about 2010. After 2010 it will become necessary to start producing from the high cost (≥\$52.00/kg U or ≥\$20.00/lb U_3O_8) category. It will also be necessary to continue exploration (i.e. delineation and evaluation) of the EAR-1 resources to move them into the RAR class. New discoveries elsewhere in the world could obviously change the production distribution shown in Figs 8 and 9. While the distribution may change, it is important to note that there are adequate known resources worldwide to satisfy demand through the year 2020.

Assuming equilibrium conditions between the supply sources and demand, the spot price would not be expected to exceed \$52/kg U (\$20/lb U_3O_8) until at least the year 2011. Of course this basic assumption may not hold during periods of market disequilibrium or disruption, which could result

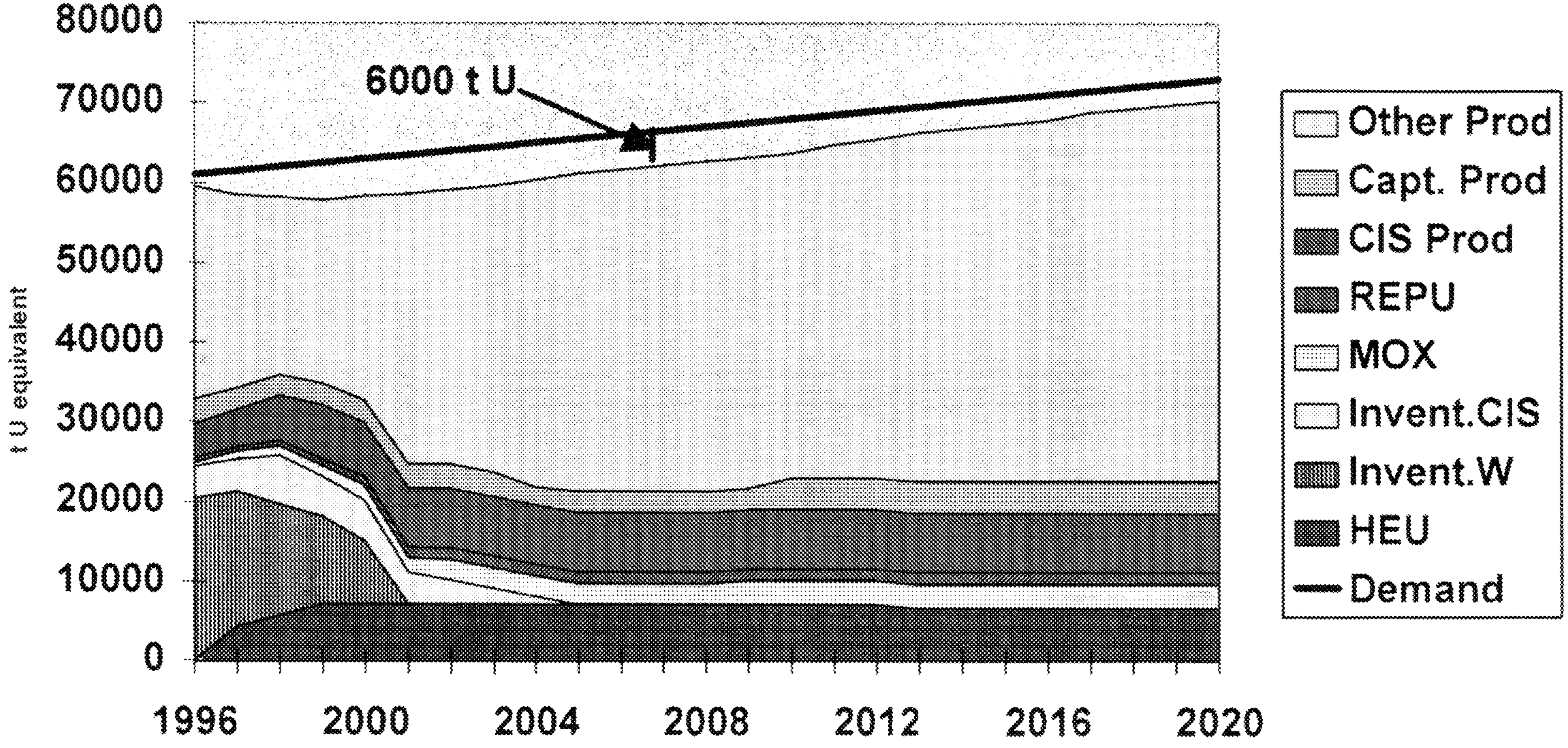

FIG. 16. Uranium supply shortfall scenario (high HEU case). (HEU: –25%; CIS production: –25%.)

in higher prices. As indicated in Fig. 11, high cost production is never expected to fill more than about 17% of the "other" natural uranium requirements through 2020. And, there is a very real likelihood that additional low- to medium-cost discoveries will be made that could displace some, if not most, of the high-cost production required in the middle to latter part of the study period. Introduction of additional low priced uranium to the market could also lower the price.

6.2. ADEQUACY OF PRODUCTION CAPABILITY

As of 1 January 1997 annual world uranium production capacity was 43 000 t U. The Russian capability for blending HEU to LEU, either installed, or being installed, was 18 t HEU/annum (or 5733 t U natural equivalent). The capacity of facilities for fabricating mixed oxide (MOX) and reprocessed uranium (REPU) fuel was about 1500 t U (natural equivalent). To meet the increasing amounts of supply projected for each of these sources it is necessary to increase their respective capabilities.

Assuming 100 per cent capacity utilization, it will be necessary to increase the uranium production capacity in both the high and low HEU cases by about 9300, 11 700 and 18 500 t U/annum, respectively in 2005, 2010 and 2020. The capability will have to be increased by 10 900, 13 400, and 21 800 t U/annum, respectively in 2005, 2010 and 2020, if an 85 per cent capacity utilization is achieved. This is equivalent to an increase of 25, 31 and 50 per cent, respectively.

For the Russian Federation to meet the planned delivery of LEU blended from 500 t HEU warhead material, the blending capability will have to be increased. The required increase is from 18 t HEU/annum in 1997, to 24 t HEU before 1998 and 30 t HEU before 1999.

6.3. RECOMMENDED REQUIRED ACTIONS

There may be significant market instability unless all of these supply sources are developed according to the projected schedules. Delay in the development of any of the sources would result in a market shortfall leading to price increases. The greatest impact would result from delays in expanding existing and putting new uranium production centres into operation. Shortfalls in the delivery of LEU blended from HEU could have smaller, but still significant impacts. Figure 16 shows an example of an hypothetical uranium supply shortfall where Russian HEU and CIS production both supply uranium at 25 per cent below planned levels. The failure of any supply component to operate at planned levels could result in a shortfall. It is expected that such a shortfall would not persist for an extended period. A shortfall would most probably lead to increased market prices which would be expected to stimulate additional production.

This is a period of major change and uncertainty for uranium supply and demand. In the short term there is a need for significant amounts of new production. In the longer term, particularly after 2010, the level of uncertainty surrounding uranium requirements is greater. Unforeseen events will likely impact the long term supply/demand balance. Under these conditions we must expect the unexpected.

Factors which could reduce the urgency of increasing the availability of supply from the sources described above are sales of additional large amounts of US government stockpile material and/or the availability of a significantly larger excess inventory from the Russian Federation than is estimated in this report. However, the probability of either of these events occurring is believed to be low.

7. URANIUM PRODUCTION INDUSTRY PROFILES[1] — CIS PRODUCERS

7.1. KAZAKHSTAN

7.1.1. Historical production

Pre-1993 production in Kazakhstan totaled about 74 800 t U. The following table summarizes Kazakhstan's production from 1993 through 1996 (t U):

1993	1994	1995	1996
2700	2240	1630	1210

7.1.2. Current operations

Kazakhstan currently has three active ISL production centers in the southern part of the country and had planned to resume production at the Stepnogorsk mine-mill complex in northern Kazakhstan by mid-1997. This activity was suspended when legal difficulties developed with a western joint venture partner. Recovery of uranium as a by-product of phosphate production in western Kazakhstan was terminated in 1994 because of high production costs.

All but about 100 t U of Kazakhstan's 1996 production came from ISL production. The remainder came from conventional milling operations at Stepnogorsk.

7.1.3. Future plans

Shortages of materials and supplies and a lack of investment capital have led to a 55% decline in production between 1993 and 1996. Further declines in production are expected until three joint ventures with western companies begin operations. Management of mining and milling operations at Stepnogorsk had been turned over to a western company which expected to resume production in mid-1997. Production was expected to total about 690 t U in 1997 and to increase to 885 t U by the year 2000. Achieving these production goals depends on the success of revised underground mine plans that will increase mill-head grades from an historical average of 0.1% U to 0.3% U.

Production from two western ISL joint ventures is expected to begin in 1999. The Inkai joint venture is scheduled begin production in 1999 at an initial annual rate of about 350 t U. Production capacity at Inkai be increased to 1000 t U as market conditions warrant. The Moynkum joint venture, which is projected to begin production in 1999-2000 at about 350 t U, will also have expansion potential.

7.1.4. Reserves

Kazakhstan's known resources (RAR + EAR I) total approximately 858 000 t U, of which more than 50% are projected to be recoverable at costs below $40/kg U. ISL-amenable resources, which account for about 57% of RAR, occur along oxidation-reduction roll fronts within sandstone units. The mines that supply ore to the conventional mill at Stepnogorsk are developed in fault controlled vein-stockwork deposits in complex igneous-metamorphic terrain.

[1]Annual and total production values are reported from "Uranium 1997 - Resources, Production and Demand", a report jointly prepared by the IAEA and the Nuclear Energy Agency of the OECD and published by the OECD, Paris (1998).

7.2. RUSSIAN FEDERATION

7.2.1. Historical production

Pre-1993 production in the Russian Federation was 93 980 t U. Following is a summary of Russia's reported annual production between 1993 and 1996 (t U) is:

1993	1994	1995	1996
2697	2541	2160	2605

7.2.2. Current operations

Russia's only operating uranium production center, Priargunsky, is located in the Streltsovsk geological province in southeastern Siberia. Priargunsky operations include three underground mines and a conventional mill, with an annual production capacity of 3500 t U. Surface heap leaching and underground block or stope leaching are being implemented to lower production costs. Open pit mining at Priargunsky nearly ended in 1994 following depletion of the only remaining shallow reserves. Priargunsky has also recently begun to evaluate the ISL potential of small sandstone deposits in the area surrounding its underground operations.

7.2.3. Future plans

Priargunsky will continue to be the cornerstone of Russia's production industry for the foreseeable future. However, ore grades are declining and costs are increasing at Priargunsky, so its future is by no means assured. By the year 2000, annual production is projected to total 3500 t U and to be about equally divided between conventional milling and surface and underground heap leaching.

Russia is evaluating the potential for ISL extraction in three areas outside the Priargunsky-Streltsovsk area: Zauralsky; western Siberia; and Hiagda-Vitimsk. An ISL pilot test has been completed at the Dalmatovsk deposit in the Zauralsky province, with ore depths ranging between 420 and 560 meters and an average grade of approximately 0.043% U. Because of depth and low ore grade, however, Russia has no immediate plans for full scale development at Dalmatovsk. Instead, it will accelerate evaluation of deposits in western Siberia, including Malinovsk, which has an average grade of approximately 0.07% U and ore depths ranging between 150 and 350 meters. Russia expects to gradually build its ISL production capacity to between 4500 and 5000 t U by the year 2005. It also has announced plans to reach 10 000 t U/year by 2010.

7.2.4. Reserves

Russia's resources (RAR+EAR I as in situ) at $80/kg U or less total 181 500 t U, of which 83 300 t are recoverable at $40 per kg U or less.

The resources in the Priargunsky area occur mainly as vein-stockwork deposits associated with volcanic rocks. Priargunsky has also begun to evaluate the ISL potential of sandstone deposits interbedded within the volcanics. The ISL-amenable resources outside the Priargunsky area occur as sandstone (valley-type) deposits.

7.3. UKRAINE

7.3.1. Historical production

Historical production figures are not available for Ukraine prior to 1992. Annual production from 1992 through 1996 averaged approximately 1000 t U.

7.3.2. Current operations

All of Ukraine's production is derived from underground mines in the Kirovograd province. The ore is hauled to the conventional mill in Zheltye Vody, which has an annual capacity of about 1000 t U.

7.3.3. Future plans

Ukraine has announced a goal of meeting all of its nuclear fuel requirements (estimated to average between 2500 and 3000 t U annually between 1997 and 2010) with Ukrainian uranium. Ukraine's goal of self sufficiency will require a 2.5 to 3 times increase in its current production capacity. The timing to reach its goal of self sufficiency is uncertain. The goal presents a formidable challenge given the fact that most of Ukraine's resources are associated with deep, low grade deposits, with relatively high production costs.

7.3.4. Reserves

Ukraine's resources (RAR+EAR I) total 131 000 t U of which 63 000 tonnes are projected to be recoverable at costs of $80/kg U or less. Approximately 75% of Ukraine's resources are hosted in a heterogeneous mixture of gneiss, granite and metasomatized albitites in the Kirovograd province. The uranium mineralization occurs as fault-related stockwork deposits along the periphery of a large gneissic dome. Ukraine also has minor sandstone hosted resources that may be amenable to ISL extraction. Aquifer contamination from past ISL projects in Ukraine has, however, heightened concern about ISL extraction. Therefore, future projects will have to demonstrate environmental viability prior to their being considered for development.

7.4. UZBEKISTAN

7.4.1. Historical production

Cumulative historical production in Uzbekistan through 1993 is at about 82 763 t U, of which 55 500 tonnes came from conventional open pit and underground mines and 27 175 tonnes came from ISL operations. The following table summarizes production from 1994 through 1996 (t U).

1994	1995	1996
1635	1644	1459

7.4.2. Current operations

Production in 1996 of 1459 t U was down 11% from 1995. Uranium production in Uzbekistan is now limited to ISL operations. High production costs forced the closure of conventional open pit and underground mines in 1994. Uzbekistan has three active ISL production centres, all located in the Kyzylkum geologic province in the central part of the country. Yellow cake slurry from the three ISL production centers is processed through the solvent extraction circuit at the Navoi mill. Capacity of the Navoi mill is reported to be at 3000 t U per year.

7.4.3. Future plans

Though Uzbekistan's ISL production capacity is currently constrained by lack of capital for wellfield development, it has established a production goal of 3000 t U per year by the year-2000. Uzbekistan clearly has the reserves and mill capacity to realize this goal. It will, however, probably have to attract western capital to expand existing wellfields and to develop new deposits needed for the goal to become a reality.

7.4.4. Reserves

Resources (RAR+EAR I) <$80/kg U in Uzbekistan total about 105 570 t U, all of which are classified as recoverable at $40/kg U or less. Of the 132 200 t U recoverable at $130/kg U or less, 97 280 t U are occur in sandstone deposits.

8. URANIUM PRODUCTION INDUSTRY PROFILES — OTHER PRODUCERS

8.1. AUSTRALIA

8.1.1. Historical production

Uranium production in Australia began in 1954. Total production through 1993 is 56 399 t U. Production in recent years has been:

1994	1995	1996
2208	3712	4962

8.1.2. Current operations

The Australian production for 1996 was 4962 t U, an increase of 31% over 1995. This production came from the remaining two mines of the defunct « three mines policy ».

Ranger:	3 498 t U
Olympic Dam:	1 435 t U

8.1.3. Future plans

The Australian projects may be classified in three levels depending on their stage of development, permitting and licensing.

8.1.3.1. Advanced projects at existing mines

They are already on track and do not require substantial additional government approvals.

Ranger mill upgrade:

It will allow an increased production from the remaining broken ore stockpile from Ranger 1 and from freshly mined ores from the Ranger 3 open pit. ERA's expansion at the Ranger mine, will increase annual mill output from 3000 t U to 4300 t U by July 1997.

Olympic Dam mine & mill and uranium recovery plant expansion:

It will allow a very significant increase of concentrate production while maintaining about the same proportion between copper and uranium production.

WMC is conducting a AUS $1.48 billion expansion programme for its Olympic Dam copper-uranium-gold-silver operation. It will raise uranium production from 1995 levels of 1300 MTU to 3900 MTU by the end of 1999.

8.1.3.2. New mine sites near existing facilities

Jabiluka project:

This project represents the future of the Ranger Mill. It is subject to special approval. It has attracted opposition from environmentalists, as well as from aboriginal groups.

Koongarra project:

It is located not very far from the Ranger mill. This project could include a separate mill or not, depending upon future evolution of the uranium mining perspectives in this region.

8.1.3.3. Entirely new mine sites

Among various projects, those having reasonable chances for the foreseeable future are:

Kintyre:

After a strong promotion of this project, RTZ-CRA has reduced its efforts to support development.

Beverley:

Heathgate Resources (a General Atomics subsidiary) has started evaluating the South Australian Beverley uranium deposit; they plan to establish a production rate of 760 t U/year AR using ISL technology.

Honeymoon:

This 100% Canadian owned company Southern Cross Resources Inc. acquired this deposit located in South Australia from MIM Holdings Ltd. This project is undergoing testing for ISL mining. Pending technical results and completion of licensing and permitting the project could be put into production in the near term.

OTHERS:

Yeelirrie:

WMC's deposit in Western Australia. Not expected to be mined in the medium term.

Westmoreland:

CRA's deposit in Queensland. Not expected to be mined in the medium term.

Angela:

The uranium project of Noble Resources (now known as Uranium Australia NL (UAL) does not at this time appear to be very likely to be put into production.

Relationship between production costs and capacity

Australia reports resources (RAR+EAR-1) producible at $80/kg U or less, of 758 000 t U. This includes resources from Olympic Dam, with the largest amount of contained uranium of any known uranium deposit. Australia does not report resources recoverable at $40/kg U or less.

8.2. CANADA

8.2.1. Historical production

Canada is the 2nd largest producer having produced 266 847 t U through 1993. Recent production was (t U):

1994	1995	1996
9647	10 473	11 706

8.2.2. Current operations

Total 1996 Canadian production was 11 706 t U, a 12% increase from 1995. It was produced by 4 plants.

Cluff Lake production was 1930 t U (a 60% increase due to a temporary capacity increase, linked to new operations).

Key Lake production was 5423 t U (little change from 1995; decreasing by 0.7%).

Rabbit Lake production was 3960 t U (a 26% increase).

The remaining output came from Rio Algom's Stanleigh mine (422 t U) before its *definitive shutdown* in April 96.

8.2.3. Future plans

Canada will be able to maintain its position as a world leader through development of its new project. The annual capacity of the McClean/Cigar lake, and Key Lake/McArthur projects are 9230 t U and 6920 t U respectively.

The *McClean Jeb* mill construction is almost completed on schedule for its first stage, and stripping and production at the JEB pit are also on schedule.

In February 1997, Cogema received a green light for starting operations of a second open pit, Sue C-1. Licensing problems related to technical aspects of tailings disposal are likely to delay the first concentrate production initially expected in the second half of 1997.

The public hearings for the *Cigar Lake* project were conducted in 1996, and additional hearings were scheduled for 1997 in connection with a change of method of tailings management. The ores are to be milled at the Jeb mill. Subject to regulatory approvals, production could start in 2000 at Cigar Lake.

The completion of public hearings to review the *McArthur* project, and the positive recommendation of the panel seems to give a very strong likelihood to this project, scheduled for production by 1999.

Key Lake reserves will to be depleted at the turn of the century. The Key Lake mill will then process McArthur ores as mill capacity is expanded to 6920 t U/year.

Rabbit Lake orebodies are likely to be depleted at the turn of the century or shortly after. At this time, the future of the mill will depend upon the likelihood of other mines in the region, and therefore upon market conditions.

Cluff Lake future is well assured until at least 2005, and with a good probability for ten additional years.

Other production centres:

The Kiggavik and related deposits are not scheduled for production.

Recent staking of new Canadian exploration properties by various junior companies are unlikely to lead to operations before 2020.

Canada's RAR+EAR-1 total 430 000 t U in the $80/kg U, or less production class. Canada keeps confidential resources in the $40/kg U, or less class. With the closure of the high cost Stanleigh production centre all of Canada's production is from unconformity type deposits. Key Lake has long been known as either the lowest, or among the lowest cost producers in the world. The other operating projects continued production throughout the lowpriced market of the 1980s and 1990s.

8.3. CHINA

8.3.1. Historical production

The annual uranium production information for China is a state secret [12]. Therefore China's total uranium production is not known. China's estimated uranium production as reported in the Red Book is summarized below for 1993 through 1996 (t U):

1993	1994	1995	1996
780	460	500	560

8.3.2. Current operations

Starting in 1990 China shifted its emphasis from granitic, volcanic and carbonaceous schist hosted uranium targets located in south China, to focus its exploration on sandstone hosted deposits in northern and northwestern China. The sandstone targets are expected to be amenable to low cost ISL mining.

In recent years China has also made major efforts to improve the efficiency and lower the cost of its uranium production. This has been accomplished by closing high cost producers and reducing industry manpower, while adopting more effective technology at existing mines. It has also started up new mines based on lower cost technology. The total uranium production staff was reduced from 45 000 in about 1985 to 8500 in 1996.

In 1996 about 260 t U came from 3 new mines: the Yining ISL facilities in the Yili Basin, Xinjiang Autonomous Region, northwest China; the conventional Benxi mine/heap leach operation in northeast China; and the conventional Lantian mine/heap leach operation near Xi'an, central China [13]. The latter 2 mines are developed on granite hosted uranium deposits. China also operates the small Tenchong ISL facility in Yunnan Province, south-central China. Other conventional mines continue to operate in south China. Use of both heap, and in-stope leaching following blasting, have become important in China. In 1996 two-thirds of China's production came from heap and stope leaching, together with ISL mining.

8.3.3. Future plans

China intends to meet its own reactor uranium requirements, as well as any sales contracts. In recent years the contracts have involved up to about 1000 t U/annum [12]. China's reactor requirements are projected to be 600 t U in 2000, increasing to: between 900 and 1500 t U in 2005; 2400 and 3000 t U in 2010; and 3200 and 4000 t U in 2015. To supply these levels a major effort will be required to expand uranium production by 5 to 8 times over the next 15 years.

China has indicated it plans to increase annual output of the Yining ISL facility to 400 t U by 2000. This will be done by expanding existing, as well as development of new facilities in the area. China has been evaluatilng other basins for ISL amenable sandstone deposits and is expected to primarily increase its capacity by using this technology.

To reach the projected production levels significant new resources will have to be discovered. China has a aggressive exploration programme conducted through the Bureau of Geology (BOG) of the China National Nuclear Corporation. The BOG has a total staff of 45 000, including 14 000 technical personnel, working out of 5 district offices.

8.3.4. Reserves

A total of 64 000 t U are reported in the Red Book. The resources are in-place and not classified by production cost. Some additional resources related to individual deposits are reported in various reports. No complete inventory exists, however, as China's total uranium resources are a state secret. It is not known if sufficient uranium resources with a low production cost are available to meet China's production targets.

8.4. GABON

8.4.1. Historical production

Since its startup in 1961 Gabon has produced 22 831 t U through 1993. Production in recent years was:

1994	1995	1996
650	652	565

8.4.2. Current operations

The 1996 production was 565 t U, a 10% decrease from 1995. The reason for this decrease is depletion of resources. The inventories are limited to a working stockpile.

8.4.3. Future plans

Production is scheduled to stop by 1999, due to resource depletion. As of 1 January 1997 the resources in the Okelobondo mine, the only operating mine were 700 t U.

8.5. MONGOLIA

8.5.1. Historical production

Uranium production in Mongolia began in 1988. Cumulative production between 1988 and 1995, when operations were suspended at the country's only production center, is reported at approximately 533 t U. The production history in t U/year follows:

1989	1990	1991	1992	1993	1994	1995	1996
94	89	101	105	54	72	20	0

8.5.2. Current operations

Extensive mine development has been completed at two deposits in the Dornod geologic province in northern Mongolia. Open pit mining of the Mardai deposit began in 1988 and continued through mid-1994. (The 1 year lag between mining and production reported above allows for transport and processing of the ore.) Ore from the Mardai operation was hauled by rail to the

Priargunsky mill in Russia for processing. Extensive mine development has been completed in Ore Body No. 7 of the Gurvangulag deposit complex, but the mine was never put into production because of lack of capital.

ISL pilot testing of the Haraat sandstone deposit in Choir basin in central Mongolia was conducted during 1995 and 1996. Both the Dornod and Haraat programmes are controlled by joint ventures that involve western companies and Mongolian and Russian government organizations.

8.5.3. Future plans

Operations were suspended at the Mardai open pit operation in 1994 to conduct pit optimization plans. When operations are resumed, heap leaching of the Mardai ore will be implemented to reduce transportation and processing costs. Ammonium-uranyl-tricarbonate crystals from the heap leach-ion exchange operations will be transported by rail to the Priargunsky mill for final processing. Schedules for resumption of production at the Mardai mine and further development of the Ore Body No. 7 mine are not available. Estimated production capacity of the Mardai operation will range between 230 tonnes and 310 t U.

Evaluation of Mongolia's ISL potential will continue with pilot testing at the Haraat deposit. Future production plans will depend on results of the pilot test and expansion of reserves through additional exploration and development drilling.

8.5.4. Reserves

Mongolia's estimated resources (RAR+EAR-I) total approximately 83 000 t U. Included in this total are 11 000 t U in the Haraat area that are amenable to ISL extraction and are projected to be recoverable at a cost of <$40/kg U.

8.6. NAMIBIA

8.6.1. Historical production

Namibia's historical production was 54 679 t U through 1993. All of this production has come from the Rossing deposit which started production in 1977. Rossing is the lowest grade conventional mine with an average grade of about 0.035% U. The mine is the world's largest open pit uranium mine. Recent production (t U) has been:

1994	1995	1996
1895	2116	2447

8.6.2. Current operations

1996 production was 2452 t U (a 22% increase from 1995). An additional small increase was planned for 1997. The recent reorganization of the management of uranium assets within Rio Tinto/RTZ-CRA (69% of Rössing) makes evolution less certain.

According to Mining Journal, the increase during 1996 was the "result of higher grades and improved recoveries from ores mined in a new area of the open pit on a trial basis".

8.6.3. Future plans

The probability of developing an additional production center in Namibia (as indicated in the 1995 Red Book) appears to be of lower priority than the goal of keeping Rossing operating under the present difficult market conditions. There are sufficient resources available if market conditions justify continued operation.

Namibia reports RAR of 156 124 t U recoverable at $80/kg U or less. This includes 74 089 t U recoverable at $40/kg U or less. An additional 90 815 t U of in situ EAR-1 producible at $80/kg U or less are known. This includes 70 546 t U in the $40/kg U, or lower class.

8.7. NIGER

8.7.1. Historical production

Since the start of production in 1970 Niger produced 59 490 t U through 1993. Recent production in t U has been:

1994	1995	1996
2975	2974	3321

8.7.2. Current operations

1996 production was 3321 t U (a 12% increase from 1995). A further small increase was anticipated for 1997, and future years depending upon market conditions. The production increase to nominal plant capacity has been achieved mainly by enhancing selective mining methods which allow a higher average mill feed grade. Stockpiles are limited to working stockpiles.

8.7.3. Future plans

Essentially all of Niger's known resources are comprised RAR of 69 958 t U recoverable at $80/kg U or less. This includes 41 800 t U producible at $40/kg U or less. Additional known resources are limited to only 1200 t U of EAR-1 recoverable at $40/kg U or less.

8.8. SOUTH AFRICA

8.8.1. Historical production

South Africa's uranium production started in 1952. A total of 145 108 t U were produced through 1993. Production in t U through 1996 was:

1994	1995	1996
1671	1421	1436

8.8.2. Current operations

In 1996, the South African production was 1436 t U, an increase of 1% over 1995. The production was recovered as a byproduct of 3 gold and 1 base metal mines. The gold mines are NUFCOR partners, and they produced the bulk (1374 t U) of the production.

Vaal Reefs (912 t U) - Anglo American
Hartebeestfontein (248 t U) - Angloval
Western Areas (214 t U) - JCI

The product from Palabora, which is primarily a copper mine, was about 100 t U.

Installed capacity:
Palabora: The theoretical capacity of Palabora is 200 t U/year but production is completely driven by the output of a heavy minerals recovery plant.

NUFCOR:
The Nufcor central finishing plant had a large capacity (5000 t U/year). It is believed to have been substantially reduced in the recent years. The limitation is at the mine sites, where tailings are reprocessed. The total available capacity for the three mines still producing uranium slurries is reported to be 2800 t U/year (1997 Red Book). The 5000 t U/year reported by the Uranium Institute appears to be high. The dismantling of nine uranium production plants eliminated the potential of restarting these facilities. The conversion of the Randfontain (Cooke) plant to a gold extraction plant also removed this capacity.

8.8.3. Future plans

Gold production as a whole is declining in South Africa, due to the continually increasing depths and working costs. Uranium production in South Africa is mainly done through reprocessing of tailings, and thus without the direct link with present gold production which will create the amount of available resource for the future. However, the gold market has a strong influence on the uranium recovery economics, as gold is a significant byproduct of the tailings reprocessing.

Palabora is expected to startup an underground mine by 2002 with a mine life of 20 years. Open-pit operations will cease by 2002.

Relationship between production costs and capacity in South Africa is complex. As reported in the 1997 Red Book "the major influences on South Africa's uranium resources are the gold price, mining working costs, the dollar/rand exchange rate, and the uranium prize". Furthermore, the doubling of uranium spot price from 1994 to 1996 resulted in only a 10% increase in total revenue per tonne of ore. South Africa reports 218 300 t U RAR in the $80/kg U in less category. This includes 110 500 t U in the $40/kg U in lower category.

8.9. UNITED STATES OF AMERICA

8.9.1. Historical production

Historical production in the USA through 1995 totaled approximately 344 060 t U. Annual production reached a peak of 16 800 t U in 1980, and steadily declined to a low of 1180 tonnes in 1993. Production in 1994 through 1996 was (t U):

1994	1995	1996
1289	2324	2431

Production in 1995 totalled 2324 t U with estimated production from the following sources:

Extraction method (t U)	1995 t U
In situ leach	1 297
Milling of stockpile ore	572
By-product from phosphate production	395
Mine water treatment	60
TOTAL	2 324

8.9.2. Current operations

US production in 1996 totaled 2431 t U. The estimated distribution by extraction method was:

Extraction method	No of operations	t U
In situ leach	6	1688
Conventional milling	1	263
Phosphate by-product	2	423
Mine water treatment	1	57
TOTAL	10	2431

US in situ leach (ISL) producers began to expand operations in 1996 by adding wellfields and modifying central processing plants and adding satellite ion exchange facilities to accommodate increased production. Even with these expansions, however, production was still only about 75% of nominal capacity. There were no conventional mines operating in the USA in 1996. Therefore, operations at the only licensed mill were limited to processing industrial waste streams from which uranium was recovered. Phosphate by-product facilities operated at near nominal capacity in 1996.

8.9.3. Future plans

ISL production will continue to dominate the US uranium industry for the foreseeable future. Current ISL operations will expand to 2120 tonnes U by 1998. New operations have been announced with capacities totaling 2540 t U, which, if developed, will more than double US ISL production to 4660 t U by the year 2000. There is no assurance, however, that market prices and demand projections will justify all of these projects being developed according to the schedules announced by their owners.

Plans have been announced to resume production at two conventional mills that have been on standby status since the early 1980s. Nominal capacity of these two mills totals 2465 t U. Mine development in support of restarting these two mills is currently underway. In addition, mine development will resume in 1998 that will allow the currently operating mill to increase production. Total nominal capacity of conventional mills that have announced operating plans totals 4000 t U. Actual output from these operations could total 2465 t U by the year 2000. With proper market incentive, nominal capacity (4000 tonnes) could be achieved in 2003.

Phosphate by-product production is expected to continue at nominal capacity of 430 t U at two facilities currently in operation. In addition, feasibility studies are underway to evaluate resumption of production at two facilities with nominal capacity of 530 t U that are currently on standby. Therefore, phosphate by-product capacity could total 960 t U by the year 2000.

Following is a summary of projected US production capacity in the year 2000 for all projects with announced operating plans. Conventional mining and milling capacity has been adjusted for projected mine development limitations.

Extraction method	Projected capacity (t U)
In situ leach	4660
Conventional mining & milling	2465
Phosphate by-product	960
Mine water treatment	80
TOTAL	8165

8.9.4. Relationship between production costs and capacity

Following is a summary of US production capacity considered technically achievable in the year 2000 that falls within the three cost categories:

	<$33.80/kg U (t U)	$33.80-$52/kg U (t U)	>$52/kg U (t U)
In situ leach	2505	2155	-
Conventional mine & mill	-	770	1695
Phosphate by-product		960	
Mine water treatment		80	
TOTAL	2505	3965	1695

Current ISL production in the USA ranks among the lowest cost production in the world. Therefore, expansion of existing facilities is likely to proceed. New ISL projects generally fall in the medium cost range, and they will also likely proceed with planned development.

Phosphate by-product production costs are at the high end of the medium cost range. Current facilities are expected to continue production, but based on demand projections, it is much less likely that projects currently on standby will return to production within the next five years. Production costs for conventional mining and milling projects scheduled to restart production are projected to be in the high-cost category. Therefore, these projects will have a difficult time competing in the demand/market price environment projected for at least the next five.

As previously noted, if all projects currently being considered for development proceed as planned, US production in the year 2000 could total 8165 t U. However, at least 2225 tonnes of this total are estimated to have high production costs which may not be supported by market price and demand projections until 2004. In addition, even some of the lower cost production may be deferred if demand and market price projections fall short of expectations.

8.9.5. Reserves

Estimated US resources (RAR+EAR) recoverable at $80/kg U or less total 949 000 t U. Resources are considered adequate to sustain production estimates projected in this report for all extraction methods.

APPENDIX

The *Uranium Supply Analysis System* (USA System) is an interactive computer system developed by NAC International for modeling technical and financial information in the uranium production industry. The system includes two main components:

(1) A comprehensive database of technical and financial information on uranium production centres throughout the world; and
(2) Interactive programmes for analyzing a broad spectrum of uranium industry supply and demand issues.

The cornerstone of the USA System is a database that includes technical and production cost information on approximately 130 of the world's operating, planned and potential uranium production centres. Planned production centres are those facilities which are either under development or those with announced development plans and/or production schedules. Potential producers include uranium deposits with proven and/or probable reserves (RAR and/or EAR-1). Production schedules for potential projects are based on technical feasibility — what is the shortest possible time frame that a project could begin operations considering practical permitting and construction schedules. Also included in the potential category are speculative or undiscovered resources that have that have been identified in highly favorable geological provinces such as the Athabasca Basin in Saskatchewan, Canada, and the Arnham Land region, Northern Territory, Australia. However, no speculative resources were included in the present IAEA study.

Reserves/resources in the USA System total 3 354 180 t U. Distribution of this total by country or region is as follows:

	1000 t U
Australia	410
Canada	420
Central and Western Africa	290
Kazakhstan	470
China and Mongolia	90
Namibia	110
Russia	340
South Africa	190
Ukraine	60
United States of America	350
Uzbekistan	230
Other	390

Technical parameters stored in the data base for each project include: reserves; average grade; production capacity; and mill recovery factor. For practical reasons, the USA System is limited to a 30-year life. Capital and operating costs are input into the System according to production activity. Capital cost line item categories include: mine development; mill construction; and infrastructure. Operating cost line item categories include: mining; haulage; milling; production and severance taxes; royalty; and environmental monitoring and reporting. Production costs are calculated on a forward cost and full cost basis, both with and without a rate of return (ROR). The ROR varies depending on project status. Operating projects are presumed to have lower risk and are assigned a 10% ROR. Projects under development and potential projects carry increased risk, and are assigned required rates of return of 12% and 15%, respectively. Amortization of capital costs is based on a units of production schedule.

The USA System includes primary uranium and uranium produced as a by-product of gold, phosphate and copper production. Uranium derived from weapons-grade highly enriched uranium (HEU) from Russia and the USA is also included in the System. The reserve/resource total includes 172 000 tonnes HEU. Modeling routines in the USA System are interactive. Therefore, the schedule for entry of HEU-derived U_3O_8 into the market can be varied to evaluate its impact on supply-demand relationships and market prices.

The market analysis model in the USA System has been used in the present IAEA analysis to help identify the supply sources that will most likely fill demand through the year 2020. This model provides a rigorous analysis based on the assumption that annual demand will be filled by the lowest cost producers. The lowest cost producer operating at full capacity will fill the first increment of demand. Remaining demand is filled by progressively higher cost producers until is annual demand is filled. Production from higher cost projects is deferred until it is cost competitive. Modifications have, however been made to the market analysis model results to accommodate higher cost operations that continue production because of contracting obligations and/or social and political responsibilities.

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CONTRIBUTORS TO DRAFTING AND REVIEW

Capus, G.	COGEMA, DEES/EM, France
Kidd, S.	Uranium Institute
McMurray, J.M.	United States of America
Underhill, D.H.	International Atomic Energy Agency

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