URANIUM RESOURCES AND NUCLEAR ENERGY

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About the Energy Watch Group

This is the first of a series of papers by the Energy Watch Group which are addressed to investigate a realistic picture of future energy supply and demand patterns.

The Energy Watch Group consists of independent scientists and experts who investigate sustainable concepts for global energy supply. The group is initiated by the German member of parliament Hans-Josef Fell.

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Content

Summary

Any forecast of the development of nuclear power in the next 25 years has to concentrate on two aspects, **the supply of uranium** and the addition of **new reactor capacity**. At least within this time horizon, neither nuclear breeding reactors nor thorium reactors will play a significant role because of the long lead times for their development and market penetration.

The analysis of data on uranium resources leads to the assessment that discovered reserves are not sufficient to guarantee the uranium supply for more than thirty years.

Eleven countries have already exhausted their uranium reserves. In total, about 2.3 Mt of uranium have already been produced. At present only one country (Canada) is left having uranium deposits containing uranium with an ore grade of more than 1%, most of the remaining reserves in other countries have ore grades below 0.1% and two thirds of reserves have ore grades below 0.06%. This is important as the energy requirement for uranium mining is at best indirect proportional to the ore concentration and with concentrations below 0.01-0.02% the energy needed for uranium processing – over the whole fuel cycle – increases substantially.

The proved reserves (=reasonably assured below 40 $/kgU extraction cost) and stocks will be exhausted within the next 30 years at current annual demand. Likewise, possible resources – which contain all estimated discovered resources with extraction costs of up to 130 $/kg – will be exhausted within 70 years.

At present, of the current uranium demand of 67 kt/yr only 42 kt/yr are supplied by new production, the rest of about 25 kt/yr is drawn from stockpiles which were accumulated before 1980. Since these stocks will be exhausted within the next 10 years, uranium production capacity must increase by at least some 50% in order to match future demand of current capacity.

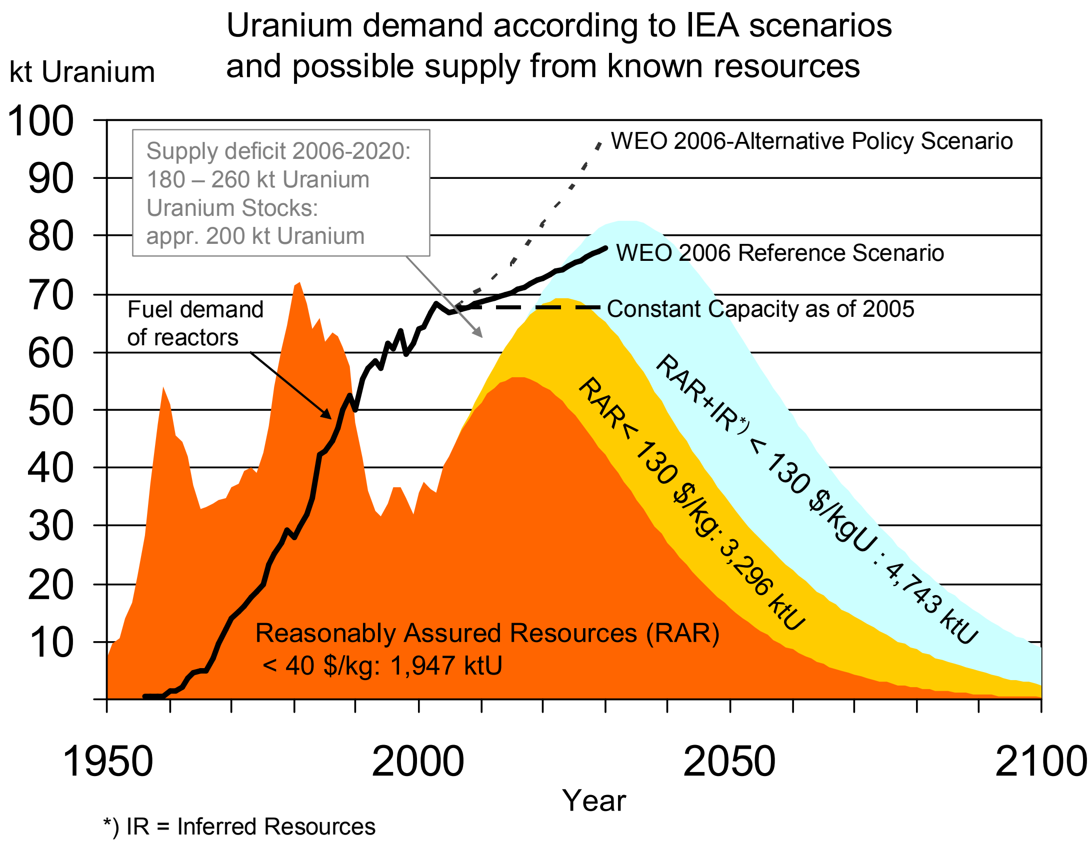
Recent problems and delays with important new mining projects (e.g. Cigar Lake in Canada) are causing doubts whether these extensions will be completed in time or can be realized at all??

In case only the proved reserves below 40 $/kt can be converted into production volumes, then even before 2020 supply problems are likely. If all estimated known resources up to 130 $/kgU extraction cost can be converted into production volumes, a shortage can at best be delayed until about 2050.

This assessment is summarised in the following figure. Possible uranium production profiles in line with reported reserves and resources are shown together with the annual fuel demand of reactors. The reserve and resource data are taken from the Red Book of the Nuclear Energy Agency (NEA 2006). The demand forecasts up to 2030 are based on the latest 2006 scenarios

by the International Energy Agency, a "reference scenario" which represents the most likely development, and an "alternative policy scenario" which is based on policies to increase the share of nuclear energy with the aim of reducing carbon dioxide emissions.

Figure: *Past and projected uranium production. Forecasts are based on reasonably assured resources below 40 $/kgU (red area), below 130 $/kgU (orange area) and additionally including inferred resources. The black line shows the fuel demand of reactors currently operating together with the latest scenarios in the World Energy Outlook (WEO 2006) of the International Energy Agency.*



Only if estimates of undiscovered resources from the Nuclear Energy Agency are included, the possible reserves would double or at best quadruple. However, the probability to turn these figures into producible quantities is smaller than the probability that these quantities will never be produced. Since these resources are too speculative, they are no basis for a serious planning for the next 20 to 30 years.

Nuclear power plants have a long life cycle. Several years of planning are followed by a construction phase of at least 5 years after which the reactor can operate for some decades. In line with empirical observations, an average operating time of 40 years seems to be a reasonable assumption. About 45% of all reactors world wide are older than 25 years, 90%

are now operating for more than 15 years. When these reactors reach the end of their lifetime by 2030 they must be substituted by new ones before net capacity can be increased.

At present, only 3-4 new reactors per year are completed. This trend will continue at least until 2011 as no additional reactors are under construction. However, just to maintain the present reactor capacity will require the completion of 15-20 new reactors per year. Today we can forecast with great certainty that at least by 2011 total capacity cannot increase due to the long lead times.

This assessment results in the conclusion that in the short term, until about 2015, the long lead times of new and the decommissioning of aging reactors perform the barrier for fast extension, and after about 2020 severe uranium supply shortages become likely which, again will limit the extension of nuclear energy.

As a final remark it should be noted that according to the WEO 2006 report nuclear energy is considered to be the least efficient measure in combating greenhouse warming: in the “Alternative Policy Scenario” the projected reduction of GHG emissions by about 6 billion t of carbon dioxide is primarily due to improved energy efficiency (contributing 65% of the reduction), 13% are due to fuel switching, 12% are contributed by enhanced use of renewable energies and only 10% are attributed to an enhanced use of nuclear energy. This is in stark contrast to the massive increase in nuclear capacity the IEA stipulates and the policy statements made when presenting the report.

URANIUM AND NUCLEAR POWER

This chapter is split into two subchapters: the first subchapter analyses the uranium supply basis and the second chapter analyses the statistics of construction and operation of nuclear power plants. Both subchapters close with a forecast about probable future developments.

Uranium Supply

The definition of Uranium resources differs from reserve classifications for fossil fuels in various ways. This is discussed in Annex 1. The classification into various categories (from discovered Reasonably Assured Resources (RAR) and Inferred Resources (IR) to undiscovered prognosticated and speculative resources) and cost classes (expected extraction cost below 40 $/kgU, below 80 $/kg U, and below 130 $/kgU) gives the impression of a high data quality and reliability which at present is not the case. Usually, only "reasonably assured resources" or RAR below 40 $/kgU or below 80 $/kgU extraction cost are comparable with proved reserves regarding crude oil. Other discovered resources (RAR between 80–130 $/kgU cost and inferred resources (IR)) have the status of probable and possible resources, while the undiscovered recources are highly speculative which forbids their use in serious projections of probable future developments.

At world level about 2.3 million tons of uranium have already been produced since 1945. Discovered available reasonably assured resources are somewhere between 1.9 and 3.3 million tons, depending on the cost class. Estimated additional resources (with lower data quality) are between 0.8 and 1.4 million tons. A summary table is provided below, the detailed country by country assessment is provided in Annex 3 and the historical assessment in Annex 2. The historical assessment shows that discovered resources were revised in the early years upward, but after 1980 a substantial downward revision by about 30% was performed which undermines the credibility of these data. This is discussed later on.

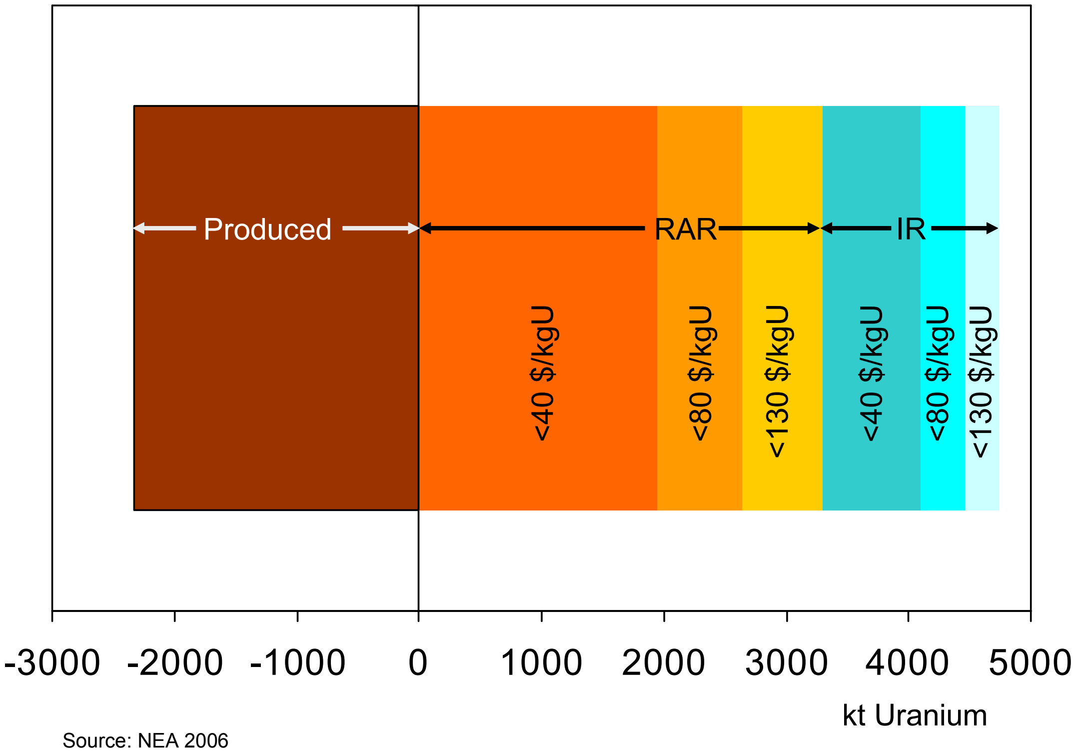
The Nuclear Energy Agency assesses also the undiscovered resources within each country and cost class. However, since these are highly speculative (and probably might never be converted into produced quantities) only the aggregated data are summarized in the following table together with the assessment for discovered resources. One should keep in mind that the data quality gets worse from top to bottom with the speculative resources having a much larger probability of never being discovered than of ever being converted into future production volumes.

Table 1: *Uranium Resources (Source: NEA 2006)*

Resource category		Cost range	Resource [kt]	Resource [kt] cumulative	Data reliability
Reasonably Assured Resources (RAR)		< 40 $/kgU	1,947	1,947	high
		40 – 80 $/kgU	696	2,643	
		80 - 130 $/kgU	654	3,297	
Inferred Resources (IR) - former EAR I		< 40 $/kgU	799	4,096	
		40 – 80 $/kgU	362	4,458	
		80 - 130 $/kgU	285	4,743	low
Undiscovered Resources	Prognosticated	< 80 $/kgU	1,700	6,443	
		80 - 130 $/kgU	819	7,262	
	Speculative	< 130 $/kgU	4,557	11,819	
		unassigned	2,979	14,798	very low

The reasonably assured (RAR) and inferred (IR) resources and the already produced uranium are shown in the following graph. About 2.3 million tons of uranium have already been produced. These amounts are shown as negative values at the left of the bar. Reasonably assured resources below 40 $/kgU are in the range of the already produced uranium. At present reactor uranium demand of about 67 kt/year these reserves would last for about 30 years, and would increase to 50 years if the classes up to 130 $/kgU were included. Inferred resources up to 130 $/kg would extend the static R/P ratio up to about 70 years.

Figure 1: *Reasonably assured (RAR), inferred (IR) and already produced uranium resources*

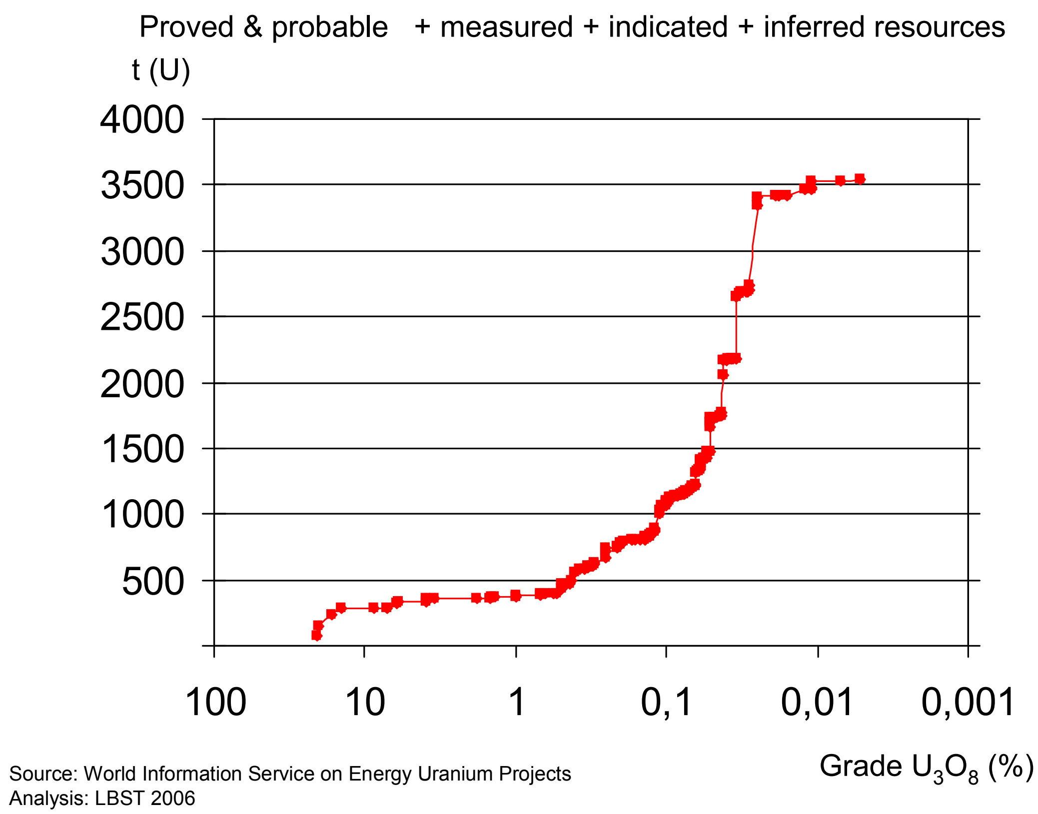


Among other criteria the ore grade plays an important role in determining whether uranium can be easily mined or not. The energy demand for the uranium extraction increases steadily with lower ore concentrations. Below 0.01–0.02% ore content the energy requirement for the extraction and processing of the ore is so high that the energy needed for supplying the fuel, operation of the reactor and waste disposal comes close to the energy which can be gained by burning the uranium in the reactor. Therefore, ore grade mining below 0.01% ore content makes sense only under special circumstances. This is discussed in more detail in Annex 4.

Today only one country, Canada, has reasonable amounts with an ore grade larger than 1%. The Canadian reserves amount to about 400 kt of uranium with highest concentrations of up to 20%.

About 90% of world wide resources have ore grades below 1%, more than two thirds below 0.1%. The following figure represents data of about 300 uranium mines which are listed in the WISE online database. It comprises measured, indicated and inferred resources (this is roughly equivalent with RAR + IR data in the previous figure – the difference might be due to some missing data on Russia and China and on different definitions).

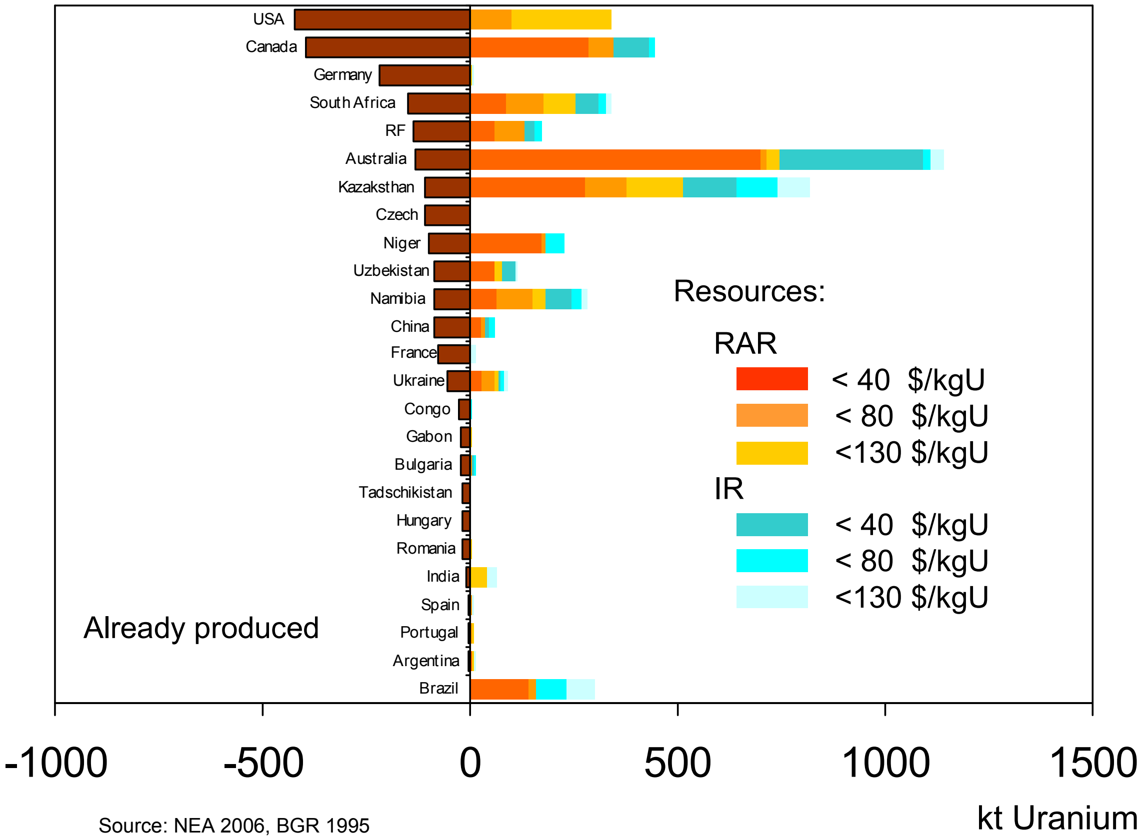
Figure 2: *Cumulative world uranium resources (without China, India and Russia) related to ore grade.*



The following figure shows the uranium resources and already produced uranium for individual countries. The countries are ranked in the order of volume of already produced uranium. The brown bar at the left shows the already produced uranium while the different colours of the bar at the right display the different qualities and cost classes of resources. As before, only reasonably assured and inferred resources are included in this figure as undiscovered resources are deemed to be too speculative.

It turns out that 11 countries have already exhausted their uranium resources since they depleted their resources over the last decades at a high rate. These are Germany, the Czech Republic, France, Congo, Gabon, Bulgaria, Tadshikistan, Hungary, Romania, Spain, Portugal and Argentina. The remaining resources with highest probability are in Australia, Canada and Kazakhstan which together contain about 2/3 of these resources below 40 $/kgU extraction cost. But again, it must be stressed that only Canada contains reasonable amounts of ore with more than 1% uranium content. Australia has by far the largest resources, but the ore grade is very low with 90% of its resources containing less than 0.06%. Also in Kazakhstan most of the uranium ore has a concentration far below 0.1%.

Figure 3: *cumulative produced uranium and reasonably assured and inferred resources of the most important countries.*

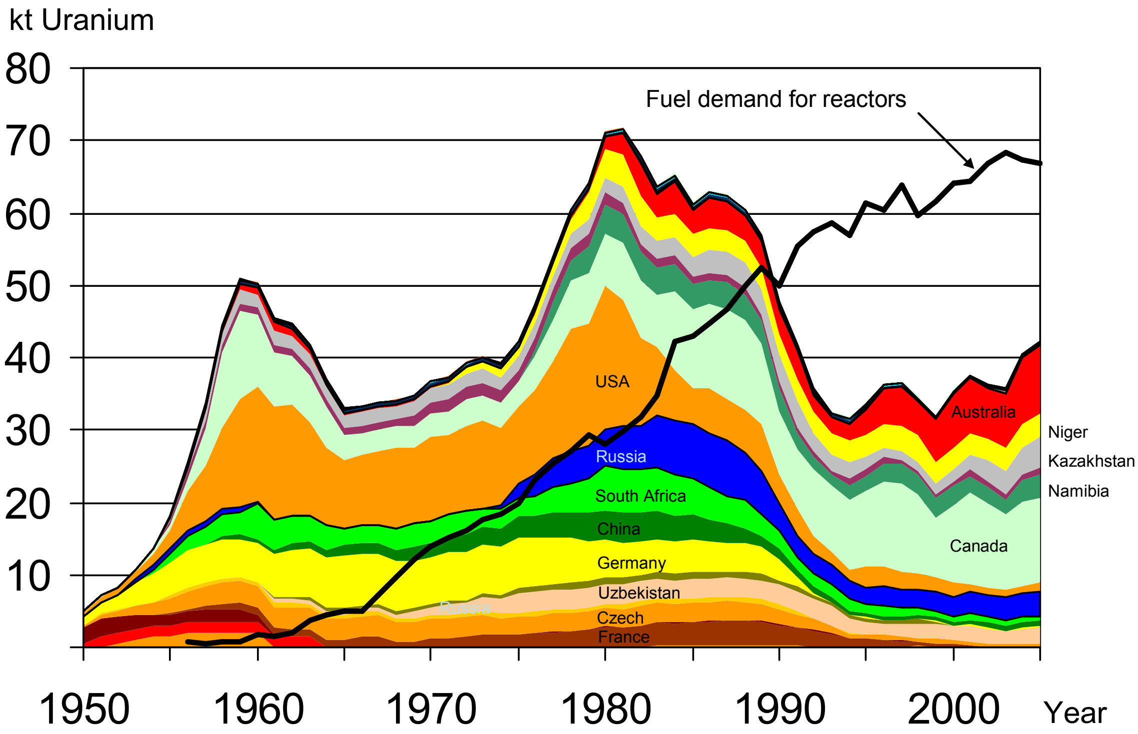


The production profiles and reported reserves of individual countries show major downward reserve revisions in USA and France after their production maximum was passed. This is analysed in detail in Annex 5 for France and in Annex 6 for the USA. These downward revisions raise some doubts regarding the data quality of reasonably assured resources.

A summary of the historical uranium production of all countries is shown in the following figure. At the bottom are those countries which have already exhausted their uranium reserves. The data are taken from NEA 2006 and for some Eastern European countries and FSU countries from the German BGR (BGR 1995, with additional data for subsequent years). The figure also includes the uranium demand for nuclear reactors (black line). In the early years before 1980 the uranium production was strongly driven by military uses and also by expected nuclear electricity generation growth rates which eventually did not materialise. Therefore uranium production by far exceeded the demand of nuclear reactors.

The break down of the Soviet Union and the end of the cold war led to the conversion of nuclear material into fuel for civil reactors and was at least partly responsible for the steep production decline at the end of the 1980ies and thereafter.

Figure 4: *Uranium production and demand*



At present, the production falls short of demand by more than 25 kt/yr. This gap was closed with uranium drawn from stockpiles. However, the total amount of these stocks is very uncertain, as they consist partly of stocks at reactor sites, of stocks at the mines, and of stocks resulting of the conversion of nuclear weapons and the reprocessing of nuclear waste. In 2002 it was estimated that about 390-450 kt of uranium could come from these sources (BGR 2002). This amount should in the meantime be reduced to about 210 kt of uranium or even less by the end of 2005.

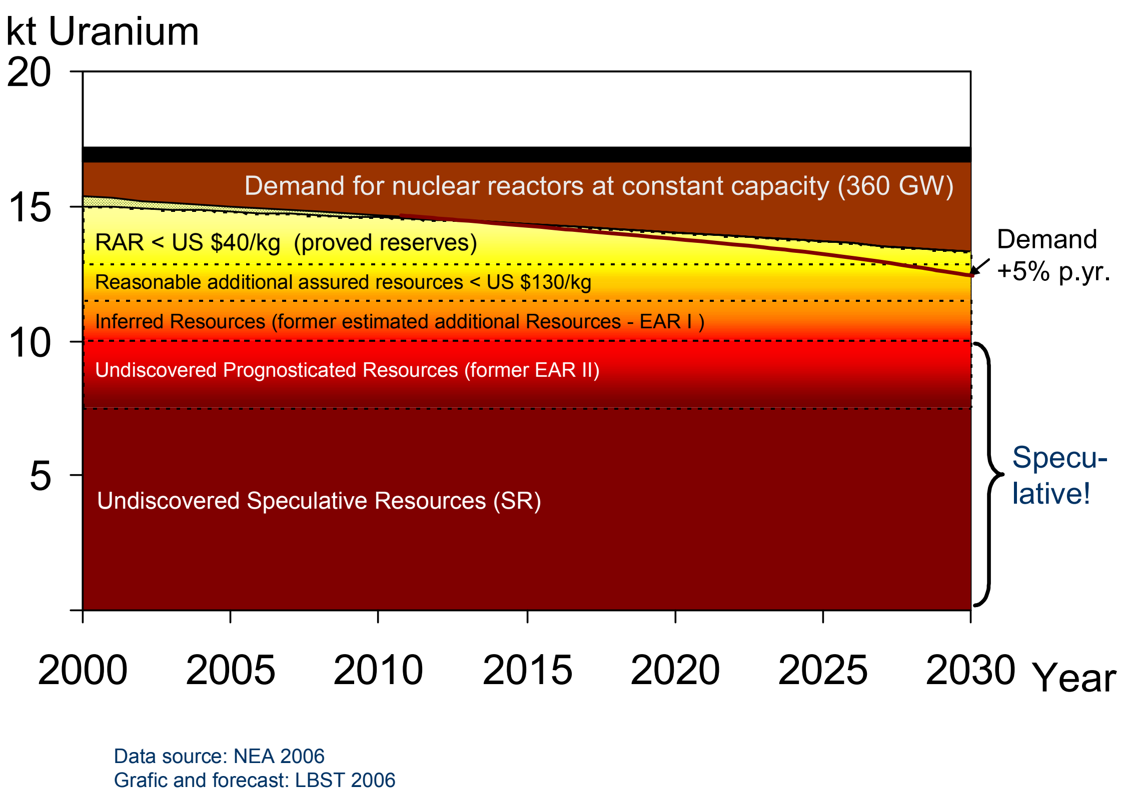
The following figure summarizes the uranium resource situation together with a forecast until 2030. Reflecting the usual reporting practice, the undiscovered prognosticated and speculative resources are included (at the bottom of the figure) though it is highly probable that these speculative resources will never be converted into real production volumes. On top of these speculative resources the inferred resources with expected extraction costs of up to 130 $/kgU are shown. On top of these the reported reasonably assured resources between 40 and 130 $/kgU and finally the reasonably assured resources below 40 $/kgU are shown. The latter category is seen by the German BGR as equivalent to "proved" reserves. The uppermost area represents the cumulative production of uranium of 2.3 million tons since 1945. This category is divided into material used for military purposes (estimated at 490 kt), uranium used in reactors (1.65 million tons) and addition to stocks (estimated at 210 kt in 2005).

If the present reactor capacity remains constant, the annual demand amounts to 67 kt/yr. If the annual production amounts to 45 kt and if 22 kt are taken from stocks, then stocks will be exhausted by 2015 (possible changes due to uranium enrichment and MOX fabrication are marginal). The continuing consumption of 67 kt/yr exceeds the reserves below 40 $/kgU by between 2030 and 2035. The inclusion of reasonably assured resources below 130 $/kgU would exhaust these resources by around 2050. Even the inclusion of the inferred resources below 130 $/kgU would lead to exhaustion of resources by around 2070.

Counting the reactors under construction and those which will be decommissioned soon (according to the IEA), indicates that nuclear capacity cannot be increased before 2011, at the earliest. If from then on the installed capacity would increase by 5% per year, uranium reserves below 40 $/kgU would be exhausted before 2030.

However, keeping in mind the many deficits of the reporting practice of reserves as outlined above it is very likely that even the reported reasonably assured and inferred resources are on the optimistic side. If so, this would imply that severe resource constraints will arise which will prevent the expansion of nuclear capacity – in addition to the problem of substituting ageing reactors.

***Figure 5**: Uranium resources and consumption 2000 – 2030*



In order to ensure the continuous operation of existing power plants, uranium production capacities must be increased considerably over the next few years well before the stocks are exhausted. Rising prices and vanishing stocks have led to a new wave of mine developments. Actually, various projects are in the planning and construction stage which could satisfy the projected demand if completed in time.

Annex 7 lists the mines which are planned to be in operation by the indicated years according to the Nuclear Energy Agency (NEA 2006). In total, about 20 kt/yr of additional production capacity are expected by 2010. This would increase the present capacity from about 50 kt/yr to 70 kt/yr, enough to meet the current demand once the stocks are exhausted.

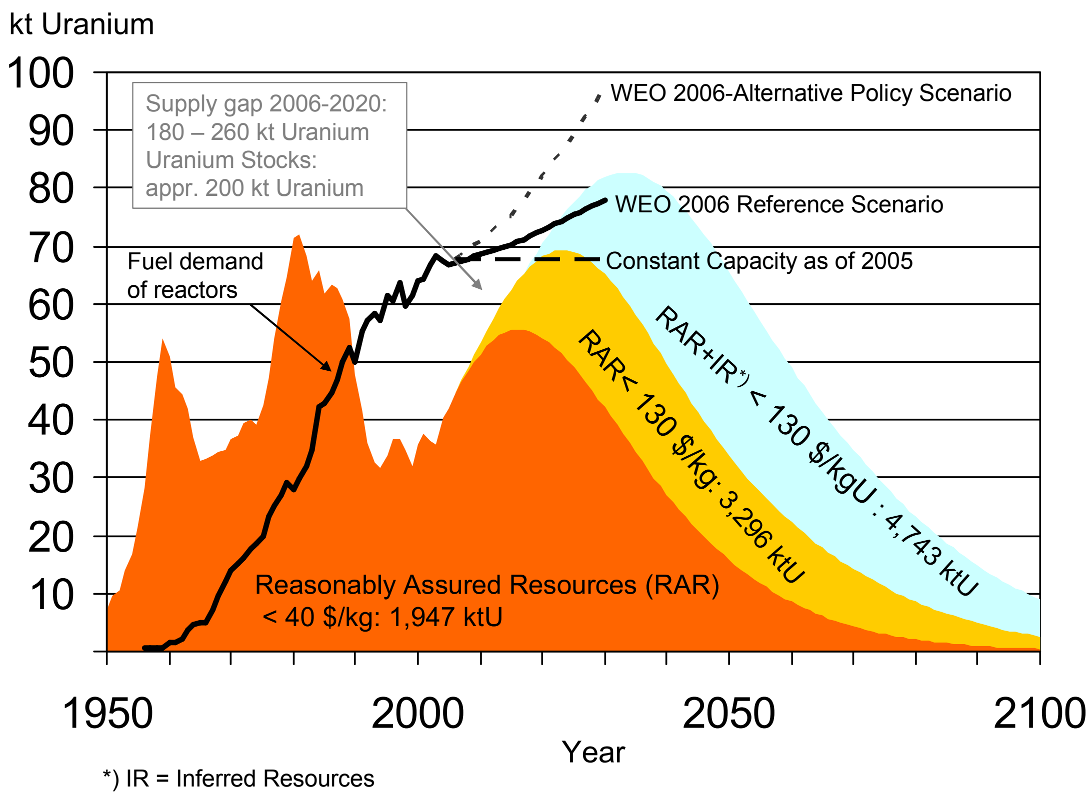
However, it is very likely that new mining projects experience cost overruns and time delays which raises doubts whether the production capacities can be extended in time. These problems can be observed e.g. at the development of the Cigar Lake project which is supposed to produce about 8 kt/yr U_3O_8 (equivalent to 6.8 ktU) starting in 2007. This mine will be the world's second largest high-grade uranium deposit containing about 100 kt proven and probable reserves. Its expected production capacity will increase the present world uranium production by about 17%. Therefore its development is a key element in expanding world uranium supply. In october a severe water inflow occured wholly flooding the almost finished mine. At present it is very unclear whether the project can be developed further (more details are given in Annex 8).

The following figure summarizes the present supply situation. The production profiles are derived by extrapolating the production for each country according to its available resource. The large data uncertainty is reflected by the different choices for still available uranium. The dark figure is based on proved reserves (reasonably assured resources below 40 $/kg U extraction cost), the light area above represents the possible production profile if reasonably assured resources up to 130 $/kgU can be extracted. These categories are more or less equivalent to so called probable reserves. The uppermost light blue area is in line with resources which include all reasonably assured and inferred resources. This roughly corresponds to possible reserves. The detailed country by country assessment is given in Annex 9.

The black line represents the uranium demand of nuclear reactors which in 2005 amounted to 67 kt. The forecast shows the uranium demand until 2030 based on the forecast of the International Energy Agency in 2006 in its reference case (WEO 2006). Taking account of the uncertainty of the resource data it can be concluded that by between 2015-2030 a uranium supply gap will arise when stocks are exhausted and production cannot be increased as will be necessary to meet the rising demand. Later on production will decline again after a few years of adequate supply due to shrinking resources. Therefore it is very unlikely that beyond 2040 even the present nuclear capacity can still be supplied adequately. If not all of the reasonably assured and inferred resources can be converted into produced volumes, or if stocks turn out to be smaller than the estimated 210 kt U, then this gap will occur even earlier.

Only when nuclear breeding reactors would operate in large numbers with adequate breeding rates, this problem could be solved for some decades. But there is no indication that this will happen within the next 25 years.

Figure 6: *History and forecast of uranium production based on reported resources. The smallest aera covers 1,900 kt uranium which have the status of proved reserves while the data uncertainty increases towards the largest area based on 4,700 kt uranium which represents possible reserves.*

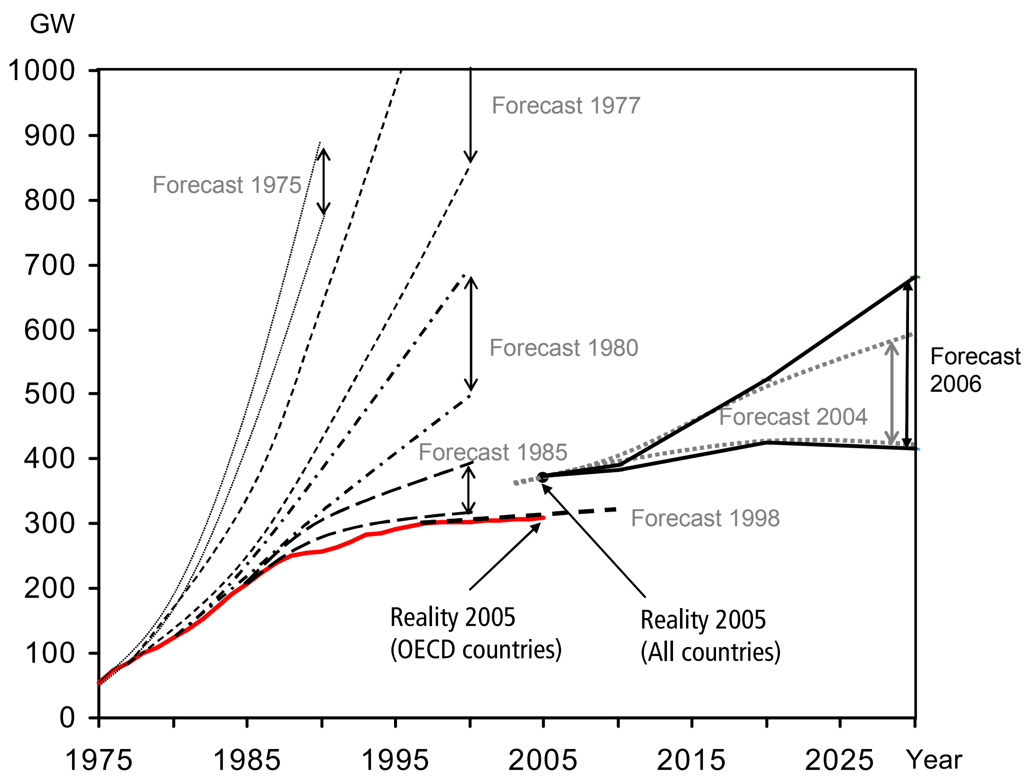


Nuclear Power Plants

History of nuclear power plants

Every two years the Nuclear Energy Agency (NEA) together with the International Atomic Energy Agency (IAEA) publish detailed data about existing reactors, reactors under construction, shut down reactors and also forecasts for the next 20–30 years. An early forecasts in 1975 predicted the nuclear capacity of OECD member countries to grow to between 772–890 GW by 1990. Based on such forecasts the uranium production capacities were extended. But in reality, the installed capacity grew to 260 GW falling far below the IAEA target range. The 1977 forecast was less ambitious, envisaging a range of between 860–999 GW by 2000. As the year 2000 came closer, the more modest the forecasts became eventually predicting a capacity ranging between 318–395 GW by 2000. Actually, a total of 303 GW were installed in the year 2000. Every forecast by the IAEA in the past eventually turned out as having been too optimistic. Even the most recent forecast foresees a growth of world wide installed capacity by 2030 to between 414–679 GW. The upper figure would almost double the presently installed capacity.

Figure 7: *Historical forecasts*

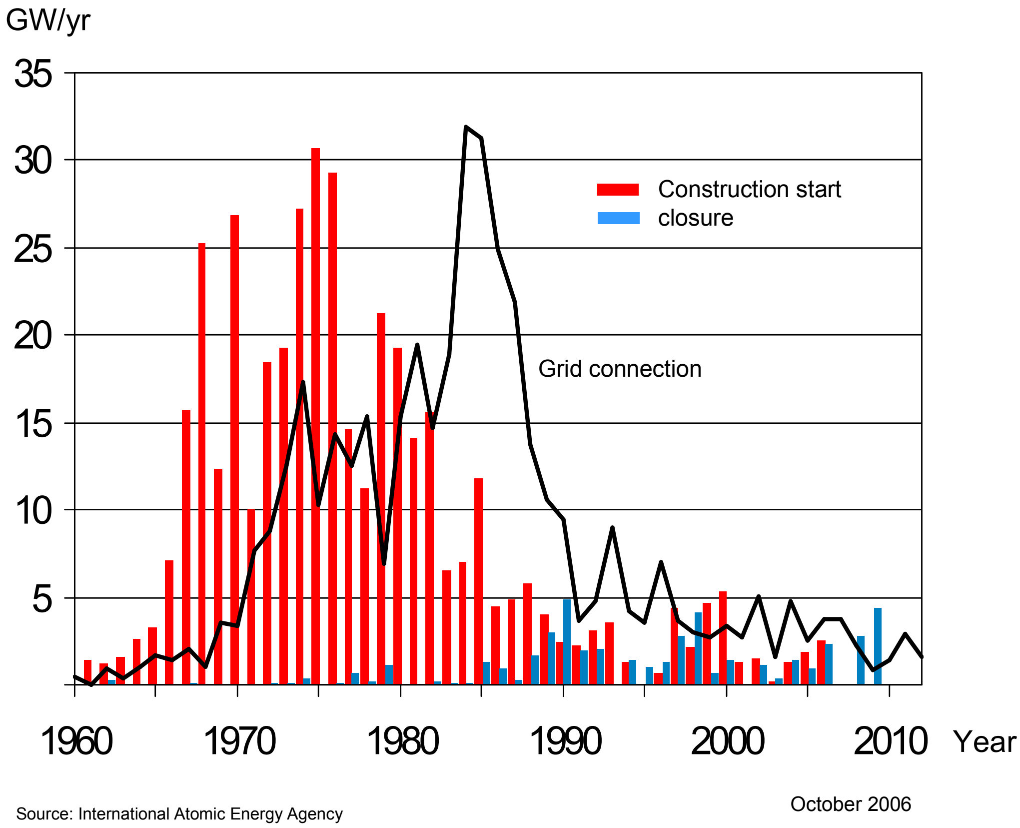


Data Source: IAEA; Grafics: LBST

Even the International Energy Agency fell behind these very optimistic forecasts in the past assuming 376 GW of installed capacity by 2030 and intermediate capacities of 385 GW by 2010 and 382 GW by 2020 (WEO 2004). However the latest IEA report (WEO 2006) states that nuclear capacity should be increased in order to avoid energy shortages and to reduce greenhouse gas emissions. The reference case sees a growth of 0.5% per year between 2004 and 2030 and the alternative policy scenario a growth of 1.4% per year. But according to our analysis this IEA forecast is much too optimistic as in the short run until 2015 the necessary lead times are too long, not allowing for a capacity increase of about 15%. In addition, existing reactors are ageing and almost 60–80% of existing reactors will be decommissioned within the next 25 years.

The following figure shows the net capacities of started constructions of new reactors (red bars) and the grid connections of new reactors (black line) between 1955 and 2006. As a general trend, most reactors were constructed between 1965 and 1975 when on average the construction of about 20 new reactors started each year. The peak of grid connections was in 1985, indicating an average construction time of about 10 years.

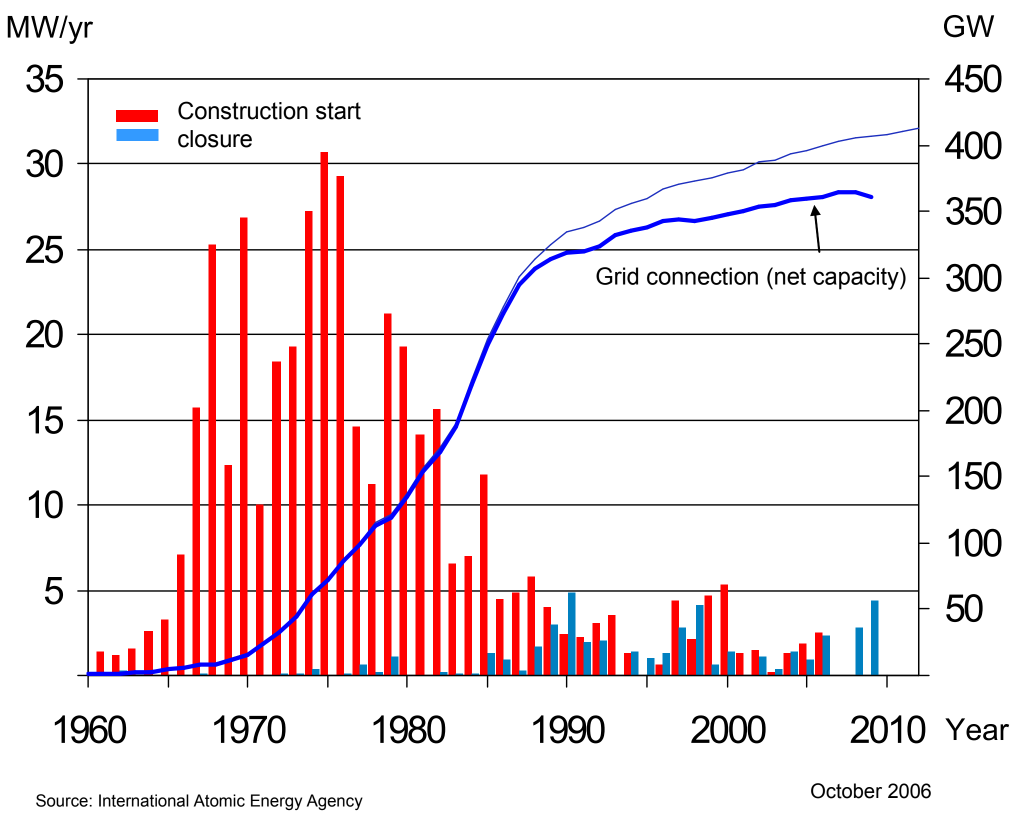
Figure 8: *Construction start and decommissioning of nuclear power plants at world level*



At present, a total of 28 reactors are under construction worldwide (see the table in Annex 10). However, 11 of these reactors are already under construction for more than 20 years of which almost all are located in countries of the former eastern bloc. Construction of the reactors in these countries stopped at the beginning of the economic transition. It is therefore highly questionable whether these reactors ever will be completed – anyway, a scheduled date is not available. If construction of these reactors were to continue now this would amount to a completely new construction. Consequently the black line in the figure includes only those future grid connections which can be expected by 2011 if everything proceeds according to schedule. This adds up to a total of 13.7 GW by 2011 (or 6.7 GW by the end of 2009). If completion of some of these reactors will be delayed then this number will be smaller.

The blue bars in the figure show the reactors already shut down and also the probable shut downs of reactors for the period between 2006 and 2009 as expected by the IEA (see table in Annex 10). This adds up to a total capacity of shut down reactors of 9.3 GW by the end of 2009. Balancing annual reactor capacity additions and shut downs gives the resulting grid connected net capacity for the period 1950 to 2009 as shown in the following figure. The thin blue line shows the gross cumulative capacity additions and the thick blue line the cumulative net capacity. The net capacity presumably will peak in 2008 and will then decline in the following years.

Figure 9: *Cumulative installed capacity until 2011*



Based on this analysis a maximum capacity of 367 GW can be expected by 2011, probably even less if more reactors are shut down due to their ageing. A net capacity of 391 GW by 2015 as expected by the IEA in the WEO 2006 ("reference scenario") is simply not possible. This would require the grid connection of appr. 24 additional reactors by 2010 which have not yet seen their start of construction. Even more unrealistic is the "alternative policy scenario" in the WEO 2006 which projects a nuclear reactor capacity of 412 GW by 2015. This would require the construction start of 45 new reactors within the next 5 years at the latest!

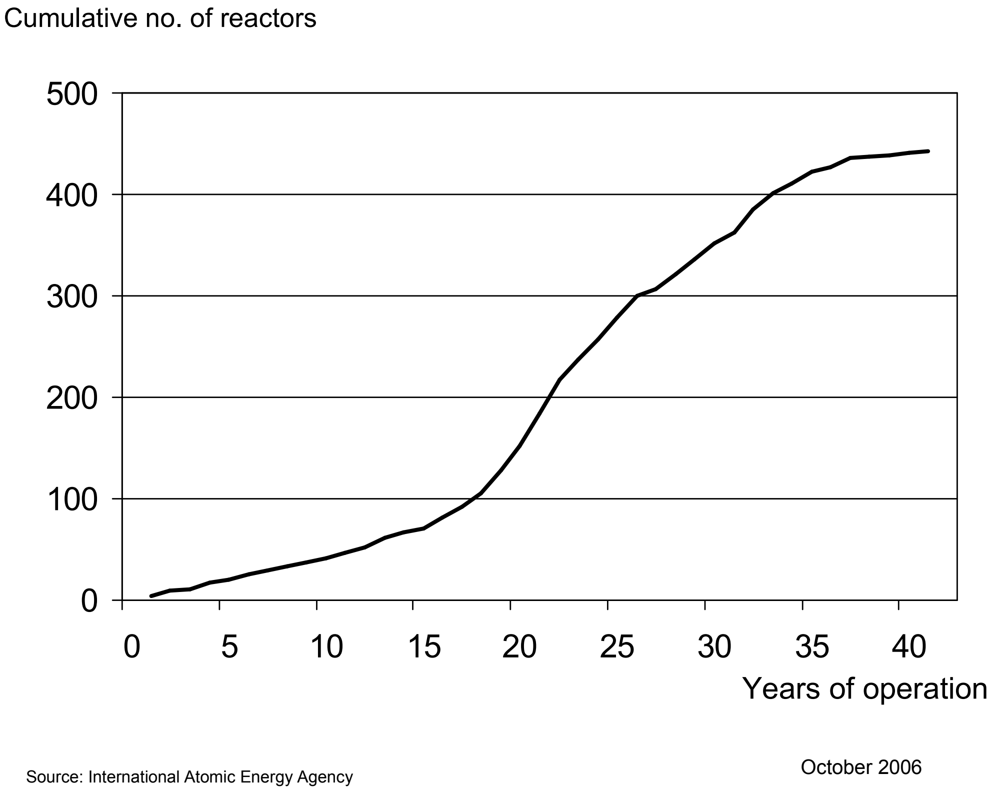
Forecast of nuclear power capacity until 2030

During the last 50 years a total of 214 reactors with a net capacity of 148 GW were built in Europe. The average construction time was seven years. About 30% of these reactors - 63 reactors - have already been shut down after an average operation period of 24 years. The latest reactor under construction is the EPR reactor in Finland, another one is in the planning stage in France. The planned time schedules of these reactors are summarised in Annex 11 because they provide an insight into the necessary lead times. Every construction delay makes it more difficult to achieve a capacity increase as the decommissioning of ageing reactors has to be compensated. After one year of construction, the new Finnish reactor is almost one year behind schedule.

For a worldwide scenario of future nuclear reactor capacity it is assumed that the average construction time of new reactors will be 5 years after start of construction.

About 85% of the operating reactors worldwide are now operating for more than 15 years. The age structure of these reactors is shown in the following figure. About 90 reactors are operating since at least 1975 having a net capacity of 62 GW. These reactors are expected to be decommissioned during the next 10 years by the end of 2015.

Figure 10: *Age of nuclear reactors*



Over the last 15 years the average construction rate was between three to four reactors per year. If this trend continues, only half of the decommissioned capacity would be substituted by new reactors and installed capacity would decline by about 30 GW. This scenario is represented in the following figure by the blue line. The red bars indicate the construction start of already existing reactors with an extrapolation of the present trend – i.e. start of construction of three reactors per year. If this trend were upheld until 2030 then installed capacity would decline from 367 GW at present to 140 GW.

Just to maintain the present capacity would require much more ambitious investments into nuclear power as can be observed today. The World Nuclear Association frequently updates its overview of reactors in operation, under construction, on order or planned and proposed. At the end of September 2006 about 28 reactors were under construction (including the 11 reactor "ruins" which are now under construction for more than 20 years), 62 are on order or planned with a net capacity of 68 GW and 160 reactors with a net capacity of 119 GW are listed as "proposed". Assuming (1) that the reactors under construction (except the already discussed 11 permanent construction sites) will be grid connected by 2011, (2) that all of the reactors "on order or planned" will be grid connected within the next 10 years by 2016 and (3) all "proposed" reactors will be built within the next 15 years by 2021, then total new capacity would sum up to 190 GW. By 2021 about 164 of the present reactors with a total capacity of 130 GW will be older than 40 years. Additionally the shut down of 13 GW is scheduled in Germany. Therefore, if these plans materialise, the net capacity could increase by 2021 at best by 50 GW to 420 GW i.e. 13%, despite probable fuel supply problems as discussed earlier.

If all the proposed reactors will only be completed within the next 20 years (instead of the next 15 years) then total capacity would still decline. Therefore, maintaining present capacity until 2030 seems to be an ambitious goal even when assuming a revival of nuclear projects. The figure below sketches the necessary effort needed to meet various scenario requirements.

An average construction time of 5 years is assumed. The red bars indicate the present trend of the annual construction start of three new reactors on average with 3 GW. The red line gives the trend of grid connected capacity. New reactors are grid connected after 5 years of constrution time. After 40 years of operation, old reactors are decommissioned. Therefore, the net capacity will decline by about 70% until 2030 if present trends continue. German reactors are decommissioned after 32 years of operation. The broken red line provides the results if their operation time is extended to 40 years.

The dark green bars indicate the necessary annual construction start-ups in order to maintain the present capacity of about 367 GW which is represented by the dark green line. A tiny decline at the end of this decade is unavoidable as too few reactors are under construction at present.

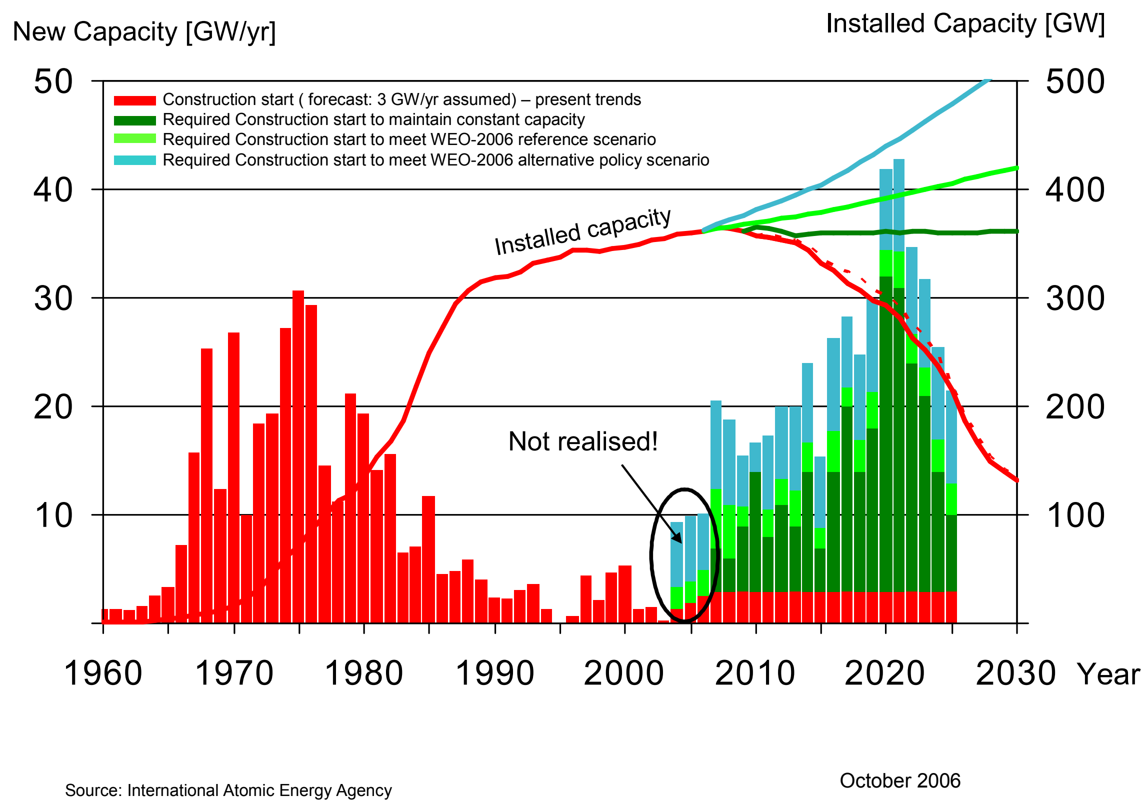
The light green bars indicate the necessary annual construction start-ups in order to meet the projection of the International Energy Agency in its "reference scenario" in the world energy outlook 2006. The light green line provides the corresponding total capacity.

The blue bars indicate the necessary annual construction starts in order to meet the projection of the International Energy Agency in its "alternative policy scenario" in the WEO 2006. The blue line provides the corresponding total capacity

Over the last few years too few reactors started their construction in order to meet the IEA scenario until 2012. In order to meet these scenarios beyond 2012, between 5 to 10 times more reactors must be annually constructed than at present. This will need skilled manpower for the construction which is not yet available. In addition, the long lead times and the huge investments of more than 1 billion Euro per GW together with the high financial risk make it hard to believe that these investments will be performed in liberalised markets. For instance, in the UK nobody invested into new nuclear power plants for at least the last 18 years, thought this was not forbidden and the electricity demand was there.

Summarising the results of this chapter, in the short term until 2012 the world nuclear capacity will rather decline than increase due to ageing reactors and too few new reactors under construction. In the long term beyond 2030 uranium shortages will limit the expansion of nuclear power plants. However, even to meet the demand until 2030 the present uranium production capacities must be increased by at least 30%. Due to the delays in new projects and the severe problems at the new Cigar Lake mine, the largest mine under development, probably these uranium supply restrictions will limit the available nuclear capacity way before 2030.

Figure 11: *Projections of nuclear capacity*



When presenting the WEO 2006 report the IEA said it was a major argument in the development of the "Alternative Policy Scenario" that the extension of nuclear power plants would be an efficient instrument to combat climate change. This is in striking contrast to the results in the report because according to the report nuclear energy is considered to be the least efficient measure in combating greenhouse warming: in the "Alternative Policy Scenario" the projected reduction of GHG emissions by about 6 billion t of carbon dioxide is primarily due to improved energy efficiency (contributing 65% of the reduction), 13% are due to fuel switching, 12% are contributed by enhanced use of renewable energies and only 10% are attributed to an enhanced use of nuclear energy.

ANNEX

Annex 1: Various Definitions of Uranium Reserves

The reserve classifications of uranium differ from the reserve definitions of oil and gas. Most national or international institutions use a slightly different scheme for the listing of uranium reserves. But even within the same institution these definitions change from time to time. The most common classifications are summarized in the following figure.

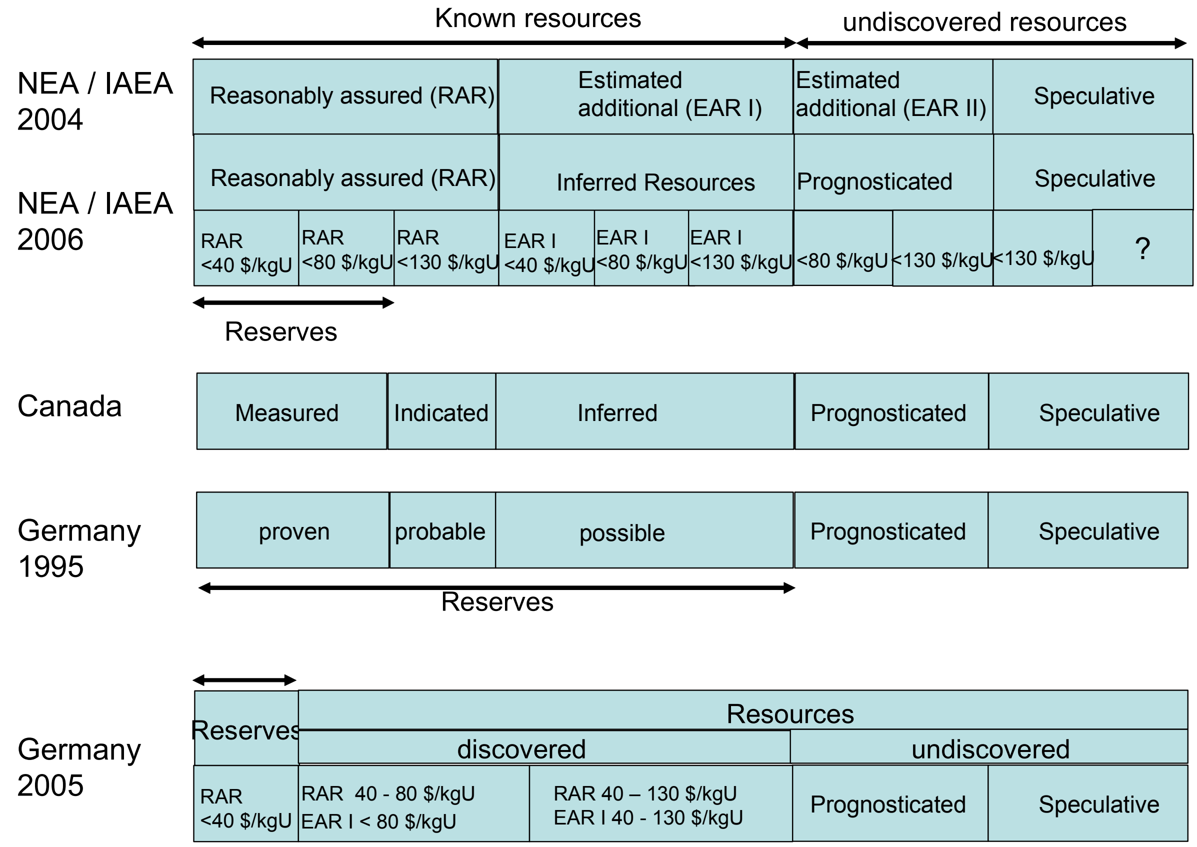
The reference scheme introduced by the Nuclear Energy Agency and the International Atomic Energy Agency is frequently used. According to this classification resources are split into “known resources” and “undiscovered resources”. “Undiscovered resources” are divided into “prognosticated” and “speculative” resources. Prior to the last resource update the phrase "Estimated Additional Resources of category 2", or in short EAR II, was commonly used for describing prognosticated resources.

“Known resources” are divided into the groups "Reasonably Assured Resources" (RAR) and "Inferred Resources" (formerly denominated as "Estimated Additional Resources, category 1"). The categories are internally divided into various cost classes according to suggested extraction costs. The definition of these classes also changed from time to time. The classes “below 40 $/kgU”, “below 80 $/kgU” and “below 130 $/kg U” are the most widely used.

The data quality declines from "reasonably assured resources" to "speculative resources" and from low to high extraction cost estimates. Very often resources of type “RAR < 80 $/kgU” are regarded as being equivalent to "proved reserves", e.g. by the German Federal Agency for Geosciences and Minerals (BGR) until 2002. In Canada this category is known as "measured reserves". The category of RAR between 80 and 130 $/kgU is defined as "probable reserves" in Germany, but as "indicated reserves" in Canada. The whole group of "Estimated Additional Resources of category 1" or "Inferred Reserves" (IR) is defined in Germany as "possible reserve". Compared with the classification of oil and gas reserves, a "possible reserve" is something which might be turned into a "proven reserve" with 5 to 10% probability. Recently, the German BGR has changed its classification scheme and has reduced the range of "proved reserves" to “RAR < 40 $/kgU”. While “discovered resources” are grouped into “RAR between 40 and 80 $/kgU” and “IR below 80 $/kgU” at the one hand – this might correspond to "probable reserves" – and “RAR between 80 and 130 $/kgU” and “IR between 80 and 130 $/kgU” at the other hand – this might correspond to "possible reserves", “undiscovered resources” are always treated similar.

This long discussion of definitions shows that these definitions are only indications of proved reserves. The high level of disaggregation of the data into four groups, each of them subdivided into different cost classes, gives the impression of a high level of data quality which in actual fact is not justified. Each class might include speculative amounts which never might be turned into produced volumes. This is demonstrated below by giving some examples.

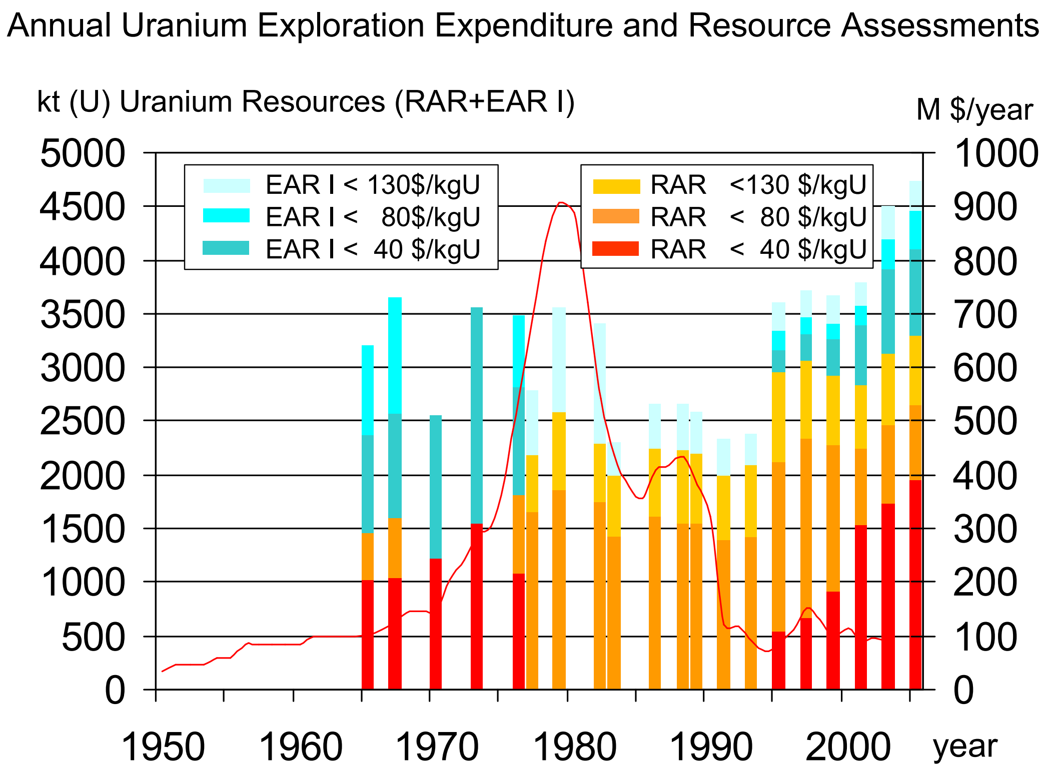
Figure A-1 : *Different classification schemes of uranium reserves and resources which are commonly used*



Annex 2: Historical Development of Uranium Resources

The historical development of the resource estimates is illustrated in the following figure. So-called "undiscovered resources" are not included. However, the different cost classes are listed individually. For the time period between 1977 and 1995 no separation of the cost class "below 40 $/kgU" was available – this explains why these data are missing. The red curve in the background of the figure indicates the exploration expenditures of the mining industry which show a marked peak around 1980. It seems that the level of expenditures did not influence the exploration success since no growth of resources can be attributed to this time period. Vice versa, "Estimated Additional Resources" declined in the early 1980ies by almost 1 million tons of uranium, about 30% of total resources. As will be shown later, this is almost completely due to the downward revision of resource assessments in the USA.

Figure A-2: *Historical development of uranium resources of categories RAR and EAR I between 1965 and 2005, and estimated annual expenditures for exploration. The resources are split into different cost classes as indicated in the figure.*



Annex 3: Country by Country Assessment of Uranium Resources

The following table lists the detailed assessment of "reasonably assured" and "inferred" resource data for each country as of end year 2004 as provided in the latest report (NEA 2006). A question mark indicates that no comment by the reporting body was made relating to the respective cost class.

The first two columns show the latest available annual production rate and the estimated cumulative production data. The next columns state "reasonably assured" and "inferred" resources while each category is disaggregated into the cost classes "<40 $/kgU", "<80 $/kgU" and "130 $/kgU". One should note that the values given for the high cost classes include the values for the lower cost classes.

Table A-1: *Cumulative uranium production as of end 2005, "Reasonably Assured Resources" and "Inferred Resources" of uranium as of end 2004 [kt Uranium] (NEA 2006) (BGR 1995, 1998, 2001, 2006)*

Country	**Production in 2005**	**Cum. production end 2005**	**Reasonably Assured Resources (RAR) end 2004**			**Inferred Resources (EAR I) end 2004**		
			< 40 $/kgU	**< 80 $/kgU**	**< 130 $/kgU**	**< 40 $/kgU**	**< 80 $/kgU**	**< 130 $/kgU**
Algeria	0	0	?	19.5	19.5	0	0	0
Argentina	0	2.6	4.8	4.9	7.1	2.9	2.9	8.6
Australia	9.51	132	701	714	747	343	360	396
Brazil	0	1.9	139.9	157.7	157.7	0	73.6	121
Bulgaria	0	16.7	1.67	5.9	5.9	1.7	6.3	6.3
Canada	11.6	394	287.2	345.2	345.2	84.6	98.6	98.6
CAR	0	0	?	6	12	0	0	0
Chile	0	0	?	?	0.6	?	?	0.9
China	0.75	80	25.8	38	38	5.9	21.7	21.7
Congo	0	25.6	?	1.4	1.4	?	1.3	1.3
Czech Rep	0.4	110	0	0.5	0.5	0	0.1	0.1
Denmark	0	0	0	0	20.3	0	0	12

Finland	0	0	0	0	1.1	0	0	0
France	0.007	76	0	0	0	0	0	11.7
Gabon	0	25.6	0	0	4.8	0	0	1
Germany	0.077	220	0	0	3	0	0	4
Greece	0	0	1	1	1	?	6	6
Hungary	0	20	0	0	0	0	0	0
India	0.23	9	?	?	42.6	?	?	22.3
Indonesia	0	0	0	0.3	4.6	0	0	1.2
Iran	?	?	0	0	0.4	0	0	1.1
Italy	0	0	?	4.8	4.8	0	0	1.3
Japan	0	0	0	0	6.6	0	0	0
Jordan	0	0	30.4	30.4	30.4	48.6	48.6	48.6
Kazakhstan	4.36	111	278.8	378.3	513.9	129.3	228.4	302.2
Malawi	0	0	?	8.8	8.8	0	0	0
Mexico	0	0	0	0	1.3	0	0	0.5
Mongolia	0	0.7	8	46.2	46.2	8.3	15.8	15.8
Namibia	3.147	85	62.2	151.3	182.6	61.2	86.3	99.8
Niger	3.093	98	172.9	180.5	180.5	0	45	45
Pakistan	0.045	1	0	0	0	0	0	0
Peru	0	0	0	1.2	1.2	?	1.3	1.3
Poland	0	1	0	0	0	0	0	0
Portugal	0	3.2	0	6	7	0	1.2	1.2
Romania	0.09	18	0	0	3.2	0	0	3.6
Russian Fed.	3.431	136	57.5	131.8	131.8	21.6	40.7	40.7
Slovenia	0	0	0	1.2	1.2	0	2.8	5.5
Somalia	0	0	0	0	5	0	0	2.6
South Africa	0.674	158	88.5	177.1	255.6	54.6	71.6	85
Spain	0	6.1	0	2.5	4.9	0	0	6.4
Tadchikistan	0	20	0	0	0	0	0	0

Sweden	0	0	0	0	4	0	0	6
Turkey	0	0	0	7.4	7.4	0	0	0
Ukraine	1.039	56	28	58.5	66.7	6.5	17.3	23.1
USA	1.219	423	?	102	342	0	0	0
Uzbekhistan	2.3	87	59.7	59.7	76.9	31	31	38.6
Vietnam	0	0	?	?	1	?	0.8	5.4
Zaire	0	23	0	0	0	0	0	0
Zimbabwe	0	0	?	1.4	1.4	0	0	0
World	**41.952**	**2,347**	**1,947**	**2,643**	**3,297**	**799**	**1,161**	**1,446**

Annex 4: Uranium Mining and Energy Demand for Mining

About 10% of the uranium is mined as by-product of the mining of gold, copper or other minerals (e.g. in South Africa). But most reservoirs contain only uranium. At these mines the mining effort increases dramatically with decreasing ore grade. This is due to two reasons:

1. The materials throughput (and therefore the energy demand) is indirectly proportional to the ore grade: To extract 1 kg of uranium out of 1% ore containing material needs the processing of 100 kg. Extracting the same amount from 0.01% ore needs the processing of 10,000 kg.

2. The separation of the uranium ore from the waste material can only be achieved with some losses. These losses are negligible if the ore grade is high, but at low ore grades the extraction losses set a lower limit on the accessible ore quality.

These relations are discussed in detail in a publication by Storm van Leeuwen and Smith, 2005. According to this study the energy demand for uranium mining increases according to the formula:

$$\text{Energy demand} = E_0 / (\text{yield}*G),$$

with 'E_0' being the energy demand at 1% ore grade, 'yield' being the amount of extracted uranium and 'G' being the ore grade in percent. The detailed assessment provides the following results for the increasing energy demand relative to the energy demand of 1% ore grade.

Ore grade (G) [% U_3O_8]	**Energy demand (theoretical)**	**Yield (theoretical)**	**Yield (empirical)**
1%	E_0	0.98	0.98
0.10%	11 times E_0	0.91	~0.9
0.05%	23 times E_0	0.86	~0.85
0.03%	41 times E_0	0.81	~0.75-0.8
0.015%	90 times E_0	0.74	~0.5
0.010%	143 times E_0	0.7	?? (probably 0)

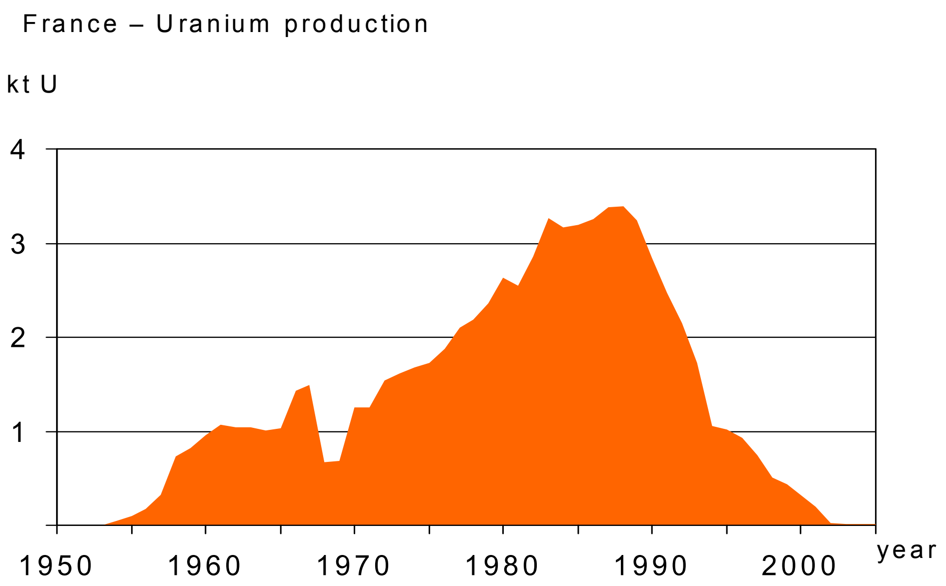
The full calculation – including energy needs covering the whole fuel path with the steps "ore mining", "yellow cake processing" and "transport to the power plant" – shows that below an ore grade of 0.02–0.01% the net energy balance becomes negative. The upper limit is applicable for hard ores and the lower limit for soft ores. From these considerations it can be concluded that the ore grade sets the lower limit for uranium ores that can be regarded as possible resources (this limit does not hold for by-product mining). It is very likely that most of the undiscovered prognosticated and speculative resources might refer to ore grades of below 0.02%. If so, these resources would not be available as an energy resource due to their negative mining energy balance.

A more recent Life-Cycle Energy Balance analysis by the university of Sydney does not question the approach by Storm/Smith but critisizes some details (ISA 2006). As a result it is out of question that the energy demand increases substantially with declining ore grade, but the final limit at which ore grade the net energy balance becomes negative might differ. Their calculations are based on 0.015% ore grade as present average for Australia. Based on this ore grade and present state-of-the art technologies for reactors and uranium processing facilities, the overall energy intensity of nuclear power is calculated to vary within 0.16 – 0.4 kWh_{th}/kWh_{el}. This amounts to 16-40% at when electricity is counted as primary energy, or to 6 – 16%, wenn electricity is converted into primary energy with an efficiency of 40%.

Annex 5: Uranium Mining in France

Mining of uranium started very early in France in the context of military and electricity generation applications. The production rate gradually increased until the end of the 1980ies and declined sharply thereafter. Production ceased in 2002. Between 1956 and 2002 about 76 kt of uranium have been mined.

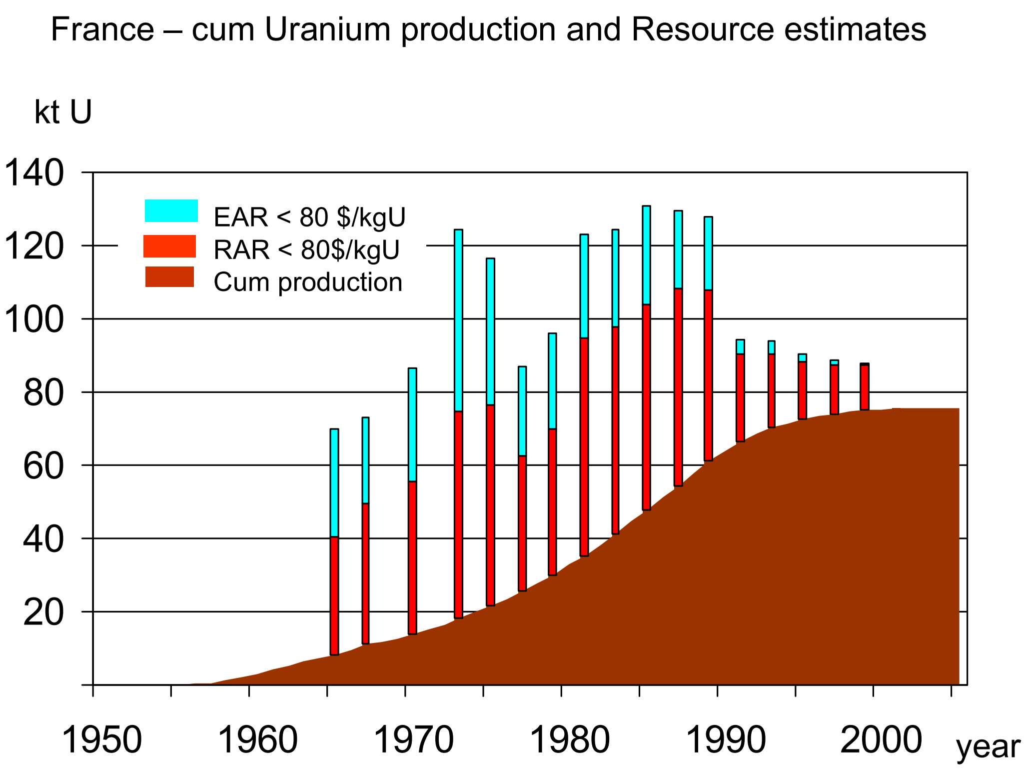
Figure A-3: *Uranium production in France*



According to the latest NEA statistics the "inferred resources between 80 and 130 $/kgU" still amount to about 11 kt. This is in accordance with the resource estimates up to 1970 stating "reasonably estimated and inferred resources" of about 70 kt while about 10 kt have already been consumed (see the following figure). The red bar indicates "reasonably assured resources below 80 $/kgU" and the blue bar estimates "additional or inferred resources below 80 $/kgU" which in these early years coincided with "resources up to 130 $/kgU". In later years the reported resources remain that high or were increased up to 82 kt by end 1985 (and even up to 112 kt if "resources up to 130 $/kgU" are included). At that time already 50 kt have been produced.

In the following years the "reasonably assured" and "estimated" resources were successively downgraded with a steep dip from 67 kt to 28 kt in 1991 and a second big downgrading from 13 kt to 0.19 kt in 2001. At present, "reasonably assured" and "inferred" resources below 80 $/kgU are zero. It is interesting to notice that the resource estimates were increasing as long the production was increasing, but were followed by significant downgradings as soon as production had peaked and started to decline.

Figure A-4*:* *Cumulative uranium production and quality of resources in France*

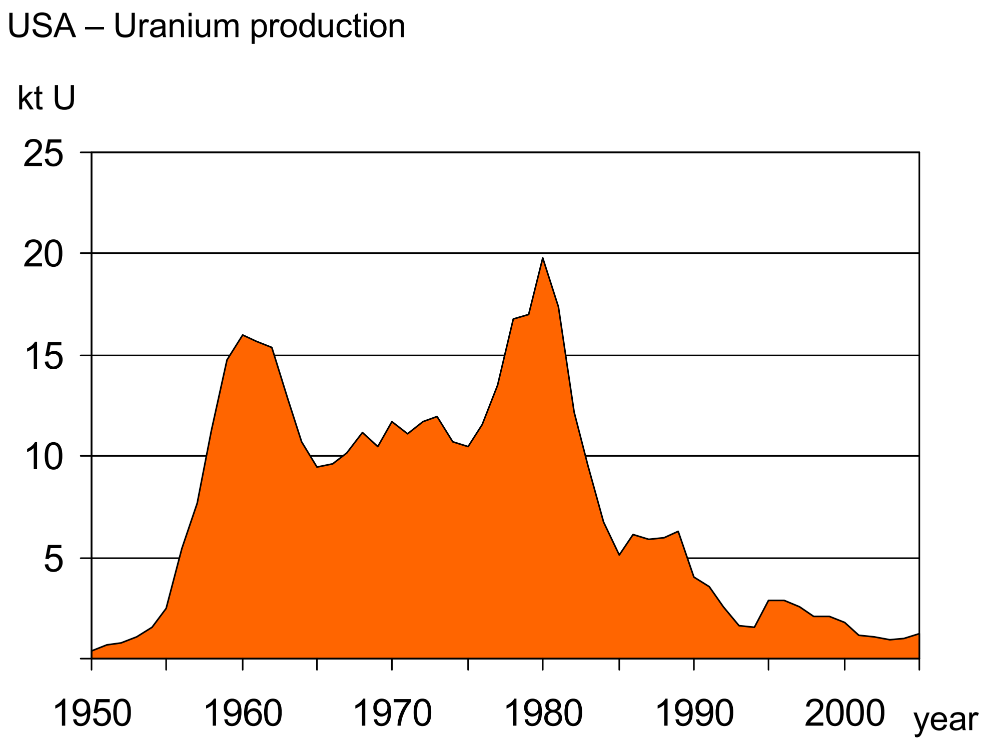

France – cum Uranium production and Resource estimates
kt U
140
120
100
80
60
40
20
EAR < 80 $/kgU
RAR < 80$/kgU
Cum production
1950
1960
1970
1980
1990
2000
year

Annex 6: Uranium Mining in the USA

The history of the uranium production in the USA provides a prominent example of falsely reported "reasonable estimated and assured resources".

Commercial uranium production in the USA started in 1947 growing fast to reach 15 kt/year in 1960. Peak production close to 20 kt was reached in 1980 which was followed by a steep decline. At present, the production amounts to about 1.2 kt, almost 18 times below peak production (see the following figure). By the end of 2005 about 420 kt have already been produced. The present NEA report still states “reasonably assured reserves below 80 $/kgU” of 102 kt and additionaly 240 kt “between 80 and 130 $/kgU”. “Inferred resources” are zero, but “undiscovered prognosticated resources below 80 $/kgU” are reported at 839 kt and “below 130 $/kgU” at 1,273 kt, plus “undiscovered speculative resources” of 1,340 kt (whatever the difference between “undiscovered prognosticated” and “undiscovered speculative resources” might be).

Figure A-5: *Uranium production USA*

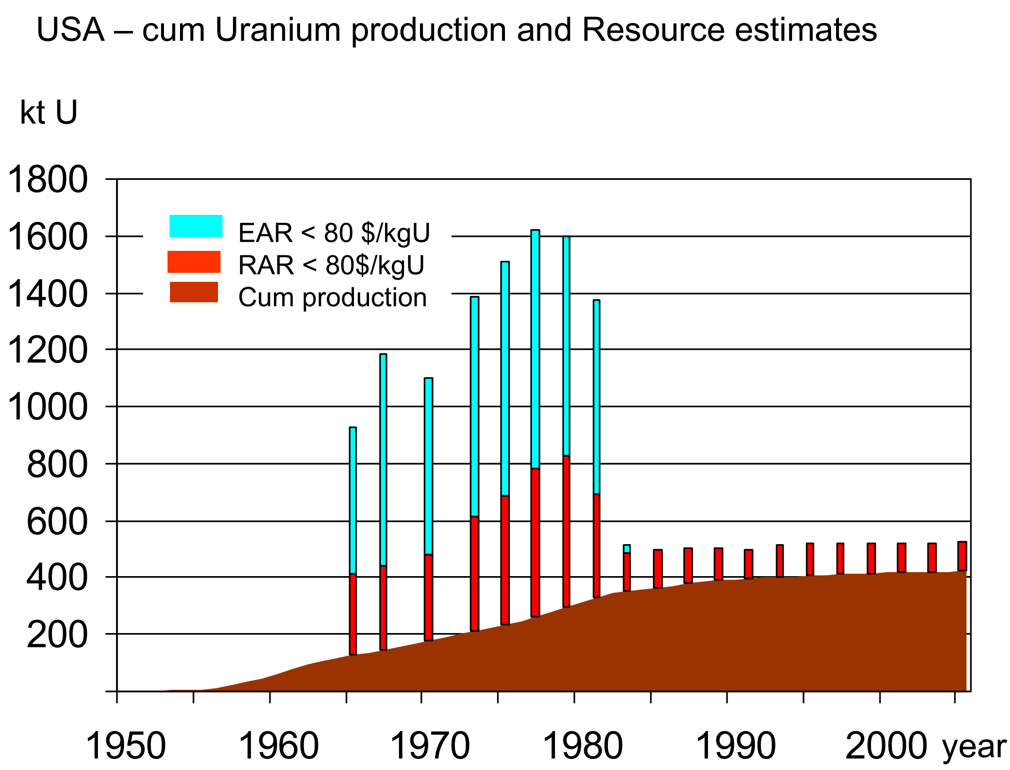


The analysis of historical resource reports reveals similar patterns like the ones shown for France before (see the following figure).

In 1977 "reasonably assured and additionally estimated resources below 80 $/kgU" were at 1,361 kt when 200 kt were already produced at the time. By extending the extraction cost class to 130 $/kgU the reported resources amounted to 1,800 kt. In 1983 the "reasonably assured and inferred resources" where downgraded by 85%, a decline of almost 1,000 kt. This happened at a time when exploration expenditures reached their highest level. This drop of US uranium resources by 1,000 kt was the reason for the decline of "reasonably assured and inferred resources" at world level at that time (see text and figure above). At present "reasonably assured resources below 80 $/kgU" are still at 100 kt, while at the same time the production declined steeply.

Though the reasons for the production decline in the USA could be manifold, this strong correlation between declining production and downgraded resources is at least interesting. Therefore it is possible that production was declining because of a lack of resources. Apart from this observation, a decline of "reasonably assured resources" is hard to understand – this is to say that in fact the formerly stated resources were not "reasonably assured" after all. A known discovered resource was converted into an unknown undiscovered resource: this does imply that the reporting practice of known resources is highly questionable and unreliable. A decline of 1,000 kt is a relevant quantity which reduces the static R/P-ratio (at 50 kt production) by 20 years.

Figure A-6: *Cumulative uranium production in the USA and resource estimates*



Annex 7: Uranium Mining Projects (Planned or under Construction)

The following table is based on a report by the NEA (NEA 2006)

Table A-2: *Planned uranium mines*

Year	Country	Mine	Projected capacity
2005	Iran	Bandar Abbas	0.021 kt/yr
	Russia	Khiagda	1 kt/yr
	Total		**1.021 kt/yr**
2006	India	Banduhuran Lambapur	0.15 kt/yr 0.13 kt/yr
	Namibia	Langer Heinrich	1 kt/yr
	Niger	Ebba	2 kt/yr
	Kazakhstan	JV KATCO – Tortkuduk	1 kt/yr
	Total		**4.28 kt/yr**
2007	Brazil	Itataia	0.68 kt/yr
	Canada	Cigar Lake	6,9 kt/yr
	Iran	Ardakan	0,05 kt/yr
	Kazakhstan	JV Kendala – Central Mynkuduk	2 kt/yr
	Total		**9.63 kt/yr**
2008	Kazakhstan	LLP Stepnogorskiy Mining – Semizbai LLP Kyzylkum – Kharasan-1 Southern Inkai Irkol JV Karatau – Budenovskoye 2	0.4 kt/yr 1 kt/yr 1 kt/yr 0.75 kt/yr ??
	Total		**3.15 kt/yr**

2010	Canada	Midwest	2.3 kt/yr
??	Australia	Honeymoon	0.34 kt/yr

Annex 8: The Development of Cigar Lake in Canada

The Cigar Lake deposit was discovered in 1981. Test mine development began in 1987 and was completed in 2000. An environmental impact statement was filed with the relevant regulatory authorities in 1995. After a thorough environmental assessment, in April 1998 the federal and provincial governments accepted the recommendations of a joint-review panel and authorized the project to proceed to the regulatory licencing stage. In 2003, a further screening level environmental assessment was required by the regulations before construction and operating licences could be issued. In February 2004, the Environmental Assessment Study report was filed and accepted by the regulatory authority (CNSC) in July 2004 allowing the project to proceed to construction licensing (quotations from CAMECO 2004).

Approval for start of construction of Cigar Lake was given in December 2004. At that time construction was expected to start early in 2005 and production was scheduled to start after 27 months of construction by early 2007. According to the plans, then there was to follow a rampup period of three years before the mine would reach its full production.

The Cigar Lake mine consists of an ore deposit about 450 m below surface between basement rock and overlaying water-saturated sandstone. This makes the extraction difficult requiring the freezing of the ground to allow for safe mining. In April 2006 a first water inflow occured. The repairs of this accident were expected to delay the work for six months and to increase costs by 10–20%. On October 23, 2006, Cameco reported a second inflow at Cigar Lake following a rock fall in a future production area that had previously been dry. This second more severe water inflow will cause a substantial delay for at least another year. A remediation plan is still being developed and at present there are a number of unknowns, such as changes (if any) to the development and/or mining plan, production schedules and additional capital expenditures. According to the latest qarterly report, after a clarification of these uncertainties the mine owner Cameco will be in a better position to evaluate whether the reserves in Cigar Lake will need to be reclassified from proven to probable.

This example shows that the process of bringing new mines into production needs long lead times and is by no means straight foreward. Delays due to technical problems and cost overruns are common.

Source: Company reports and press releases by Cameco (www.cameco.com)

Annex 9: Country by Country Assessment of Future Production Profiles Based on Resource Restriction (According to NEA 2006)

Figure A-7: *Future uranium production profile*

If all "Reasonably Assured Resources < 40 $/kg U" are producible, this corresponds to "Proved Reserves".

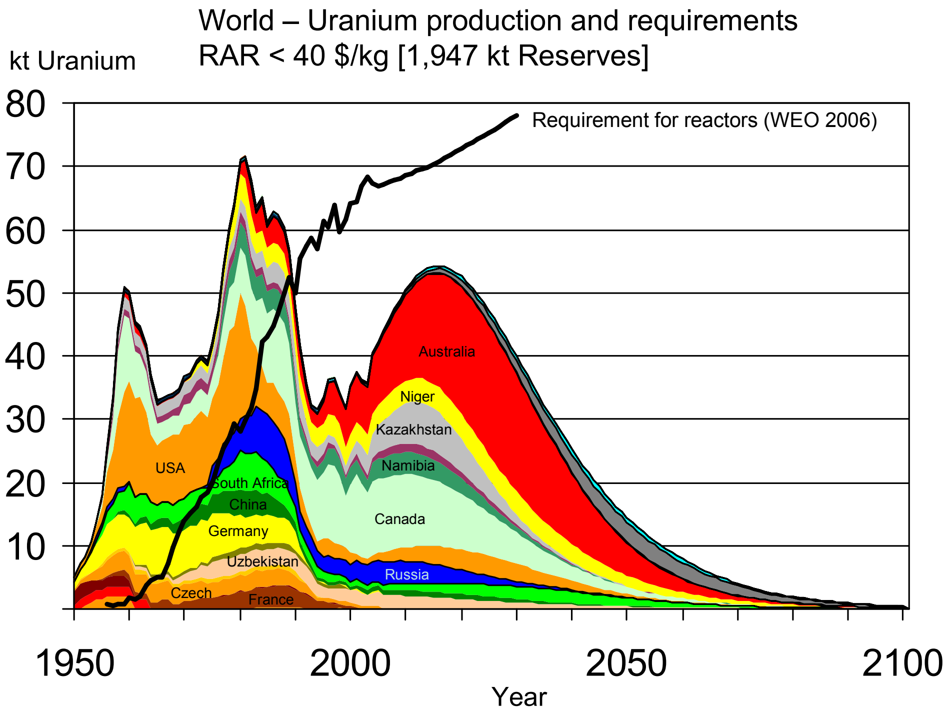


Figure A-8: *Future production profile*

If all "Reasonably Assured Resources < 130 $/kg U" are producible, this roughly corresponds to "Probable Reserves".

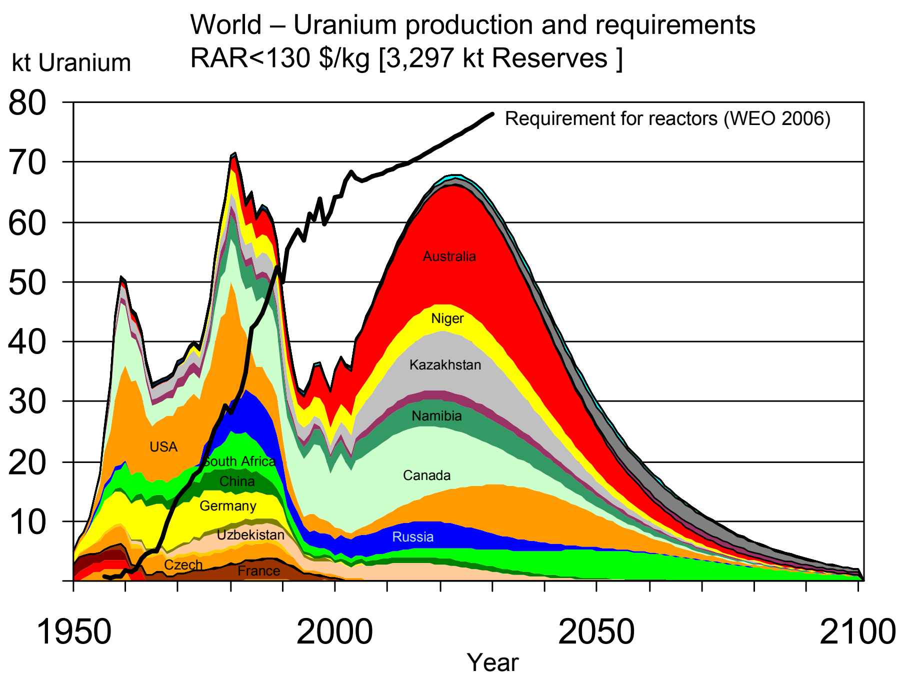
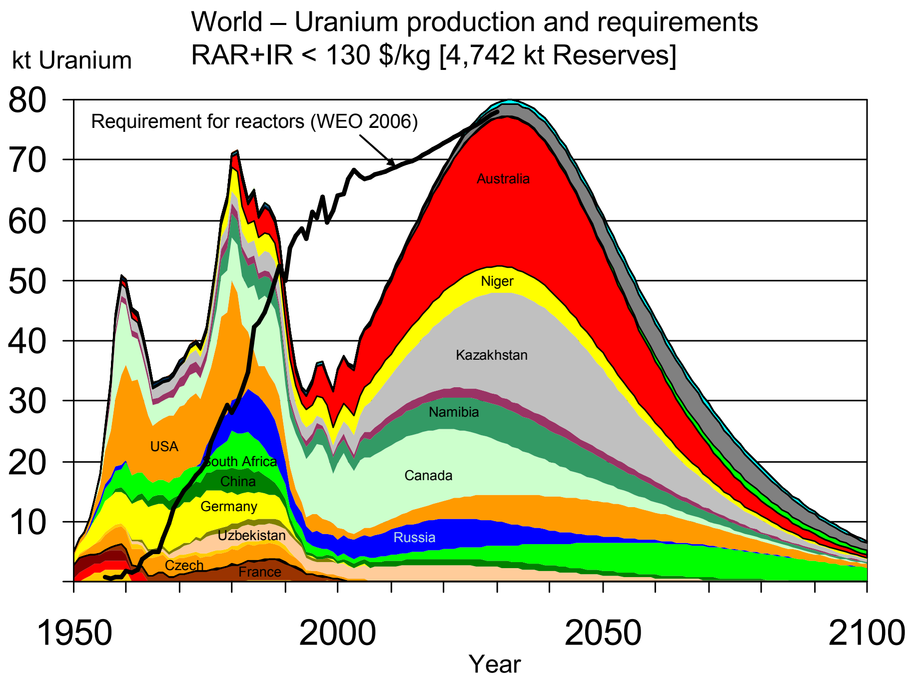


Figure A-9: *Future production profile*

If all "Reasonably Assured Resources" and "Inferred Resources < 130 $/kg U" are producible, this roughly corresponds to "Possible Reserves".



Annex 10: Nuclear Power Plants Under Construction

Table A-3: *Nuclear power plants under construction (Status October 2006, Source: PRIS)*

Country	Name	Net capacity	Construction start	Expected start of operation
Argentina	Atucha-2	692	1981	?
Bulgaria	Belene-1	953	1987	?
	Belene-2	953	1987	?
China	Lingao 3	1000	2005	2010
	Lingao 4	1000	2006	2010
	Qinshan 2-3	610	2006	2010
	Tianwan-2	1000	2000	2006
Finland	Olkiluoto-3 (EPR)	1600	2005	2009
India	Kaiga-3	202	2002	2007
	Kaiga-4	202	2002	2007
	Kudankulam-1	917	2002	2007
	Rajasthan-5	202	2002	2007
	Rajasthan-6	202	2003	2008
	Kudankulam-2	917	2002	2008
	PFBR	470	2004	2010
Iran	Bushehr-1	915	1975	2006
Japan	Tomari-3	866	2004	2009
Korea	Shin-Kori-1	960	2006	2010
Pakistan	Chasnupp 2	300	2005	2011
Romania	Cernavoda-2	655	1983	2007
Russia	Volodonsk-2	950	1983	?
	Kursk-5	950	1985	?
	Kalinin-4	950	1986	?
	Balakovo-5	950	1987	?
Taiwan	Lungmen-1	1350	1999	2010
	Lungmen-2	1350	1999	2010
Ukraine	Khmelnitski-3	950	1986	?

	Khmelnitski-4	950	1987	?
World	All reactors Only those with schedule	16893 13703		? by 2011

Table A-4: *Anticipated worldwide reactor closures before 2010 (Source IEA, according to US-EIA 2006)*

Country	Name	Net capacity	Operation start	Expected closure
Bulgaria	Kozloduy 3	408	1973	2006
	Kozloduy 4	408	1973	2006
France	Phenix	233	1974	2009
Germany	Biblis A	1,167	1974	2008
	Neckarwestheim	785	1976	2008
	Biblis B	1,240	1976	2009
	Brunsbüttel	771	1976	2009
Lithhuania	Ignalina 2	1,185	1987	2009
Slovakia	Bohunica 1	408	1978	2006
	Bohunice 2	408	1980	2008
UK	Dungeness A1	225	1960	2006
	Dungeness A2	225	1960	2006
	Sizewell A1	210	1961	2006
	Sizewell A2	210	1961	2006
	Oldbury A1	230	1962	2008
	Oldbury A2	230	1962	2008
	Wylfa 1	490	1963	2009
	Wylfa 2	490	1963	2009
World		9,323		2009

Annex 11: Time Schedules for the New EPR Reactors in Finland and France

The following examples demonstrate the long lead times from the first applications until the reactor starts to operate:

Example Finland: (Source: Nuclear Energy in Finland, UIC briefing paper#76, September 2005 (www.uic.au/nip76.htm) and Areva (www.areva-np.com))

- November 2000: Application by Finnish Utility TVO.
- May 2002: Finland's parliament voted 107-92 to approve the building of a fifth nuclear power plant, to be in operation by about 2009.
- January 2003: Approval by the government.
- March 2003: Tenders were submitted by three vendors for four designs.
- October 2003: The site of the new unit was decided to be at the existing Olkiluoto plant. In the same month, TVO indicated that Framatome ANP's 1,600 MW_e European Pressurised water Reactor (EPR) was the preferred design.
- December 2003: TVO signed contracts with Areva and Siemens for the construction of a 1,600 MW_e EPR unit effective on 1 January 2004. In January 2004 licence for construction was applied for and granted in January 2005. Construction started in mid 2005 and the reactor was scheduled to start commercial operation in 2009.
- In April 2006 it was reported that construction of the reactor was already 9 months behind schedule. The reactor is now expected to start commercial operation in 2010 (Source: AFX Paris, Finanznachrichten, 24.4. 2006, see at http://www.finanznachrichten.de/nachrichten-2006-04/artikel-6320902.asp).
- 2009: Scheduled start of operation.

Example France:

- Reactor site for EPR was decided to be Flamanville on 21st October 2004.
- 2005 – 2006: Administrative procedures.
- 2007: Scheduled start of construction.
- 2012: Scheduled start of operation.

The lead time from the first application by the utility to the expected start of operation of the new plant will amount to at least 9–10 years in Finland.

The French reactor has been planned at least since 2004. This would result in at least 8 years until operation can start.

LITERATURE

AFX 2006 Areva reactor construction in Finland 9 months behind schedule, AFX news , 24 april 2006, see at www.finanznachrichten.de

AREVA 2006 Finnish EPR Olkuoto 3, the first reactor of the third generation under construction in the world

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BGR 1998 Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen 1998, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, 1998

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Breuer 2006 Th. Breuer, Reichweite der Uranvorräte der Welt, Greenpeace, Hamburg 2006

Cameco: The following press releases are the basis for the description of Cigar Lake:

21 December 2004: Cameco Proceeds with Cigar Lake Mine Construction
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