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Challenging or Easy? Natural Uranium Availability to Fuel a Nuclear Renaissance

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Abstract

Current market tension is sometimes perceived as a proof of immediate scarcity for uranium resources. This is hopefully not the case, and one should avoid mixing short-term supplies tightening and long-term resource availability. While both timescales require adequate and timely preparedness, indeed there is a wide margin for further nuclear power development.

In order to show the uranium supply situation reality not only as of today, but well into the foreseeable future, this Paper is aimed at recalling the basics of uranium resources, exploration, development and ultimately mining. Published resource figures also require adequate explanations and comment to be fully understood and properly weighted.

For a corporation designing, building and selling nuclear power plants as well as exploring and mining uranium and also production of a wide variety of fuel services, reaching a balanced view on the particular topic of uranium resources is essential. We hope it will be also of interest for those in charge of deciding upon energy and environmental policies and ultimately the ordering power plants.

1. Introduction

Current uranium market tension is sometimes perceived as a proof of immediate scarcity for uranium resources. This is hopefully not the case, and one should avoid mixing short-term supplies tightening and long term resource availability. While both timescales require adequate and timely preparedness, indeed there is a wide margin for further nuclear power development, and this Paper is aimed at explaining the uranium resource facts on which can be built a large fleet of new nuclear reactors.

However, having said this, some key points require in-depth discussion. In particular, one can list the classic question of the ultimate resources, and we will try to shed some light on that. More important is the question of actions to be taken in the near term in the resource field to ensure that the burgeoning "Nuclear Renaissance" will turn into a strong and efficient answer to world population energy needs while addressing global warming issues.

2. Nuclear power scenarios: the challenges and their timing

Weighting the adequacy of uranium resources to future needs has some "chicken and egg" logic. In order to start at one side of the problem, it is easier to consider the current fleet of nuclear power plants, and from there to evaluate the future resource needs implied by scenarios that appear "credible" seen from today, and finally discuss the resource knowledge we have today and its adequacy. Thereafter we will discuss more ambitious scenarios for future nuclear power growth.

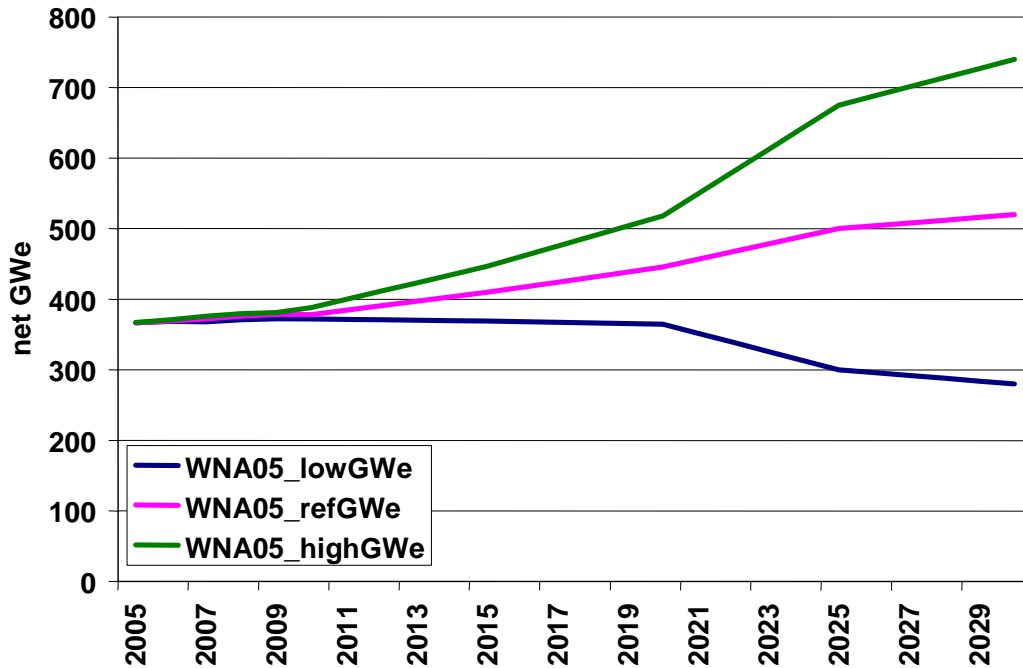
2.1. The Scenarios

In order to stay with well-known assumptions, we will use the WNA three scenarios prepared for the upcoming Market Report. From the current situation, i.e. a world nuclear power plant fleet of 438 operating reactors totaling 366 net GWe, the WNA developed

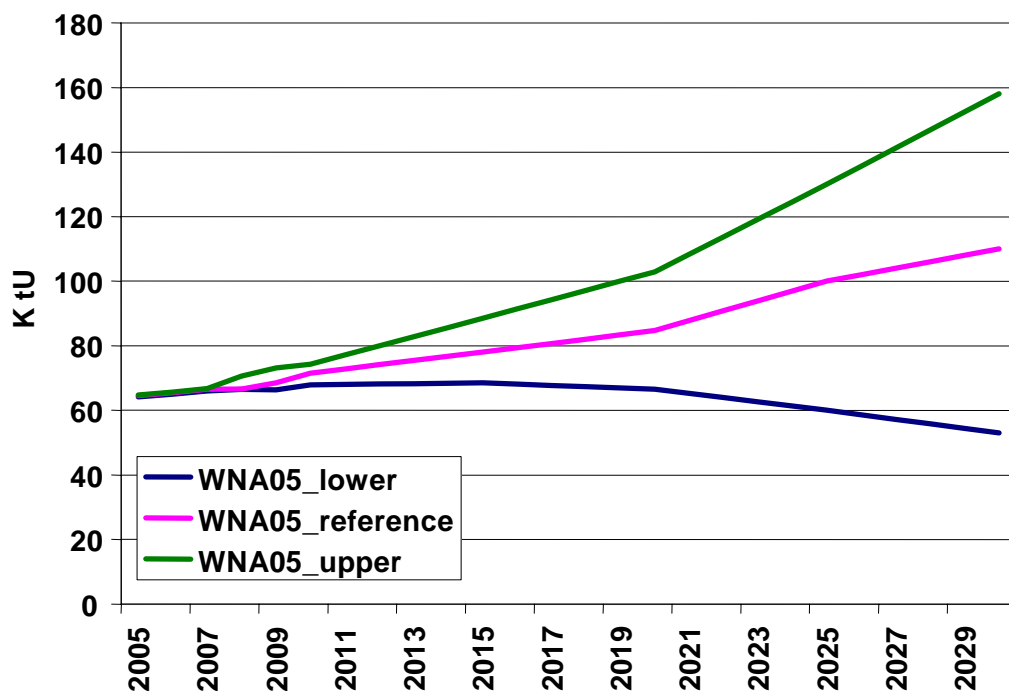
- **A Lower Scenario** with basically a steady amount of installed power until 2020, then a decline by closure at end-of-life-time to about 75% of today's figure by 2030. In this case, it is believed that nuclear power's share in world electricity production will fall from the current 16% to about 7% (mainly by dilution through other power production means). It is not the purpose of this paper to address the impact of this scenario on uranium supplies, as the resource topic won't be an issue. However, it is worth mentioning that the very existence of such a weak scenario, whatever its probability of occurrence, in an industry market appraisal is a reminder of some essential conditions to allow a "Nuclear Renaissance" occurring. There is a risk that it will act as a chilling warning for investors, delaying the necessary investments in new fuel cycle facilities and in uranium mining in particular.
- **A Reference Scenario** showing a slight increase to 2020, then a higher growth to reach 140% of current capacity by 2030. This will imply adding a net balance of 153 GWe, i.e. 120 to 160 reactors in the 1000 MWe size range, then producing about 13% of total electricity. We will discuss in detail the challenges set by this Scenario on uranium supplies and resources in the ground. In short, we can describe it more as a "NuclearWake-up" than a real "Nuclear Renaissance".
- **A Higher scenario** reaching a 140% increase as soon as 2020 and growing faster thereafter to a doubling of current capacity by 2030. This means a 18% share of nuclear power in total world electricity and the net addition of about 376 GWe, i.e. 300 to 400 reactors in the 1000

MWe size range. This scenario starts to be challenging enough, even if one can imagine more ambitious growth rate to help address more effectively the global warming issue.

Nuclear generating capacity to 2030



Uranium requirements to 2030



2.2. The challenges

2.2.1. Defining a "sustainable competitive uranium supply"

In order to clear the path for nuclear power, one prerequisite is to offer enough confidence for a sustainable competitive uranium supply, meaning nuclear kWhs being cheaper than other environmentally acceptable sources. Because the costs of these other power sources are also evolving over time, it is difficult to set a precise reference figure for a competitive uranium price. Taking into account the limited share of uranium in total power production costs, it appears today that the \$80/kgU (\$30/lbU₃O₈) level used as a cost category limit in the well-known NEA-IAEA "Red-Book" is certainly affordable. Probably the upper limit of \$130/kgU (\$50/lbU₃O₈), also in use in the "Red-Book" will still allow the maintenance of a competitive margin for the nuclear kWh in future fossil fuels tighter markets.

2.2.2. The question to address

Clearly, decision makers having to order a new reactor today require certainty that it can be fueled for all its financial lifetime. For modern units such as the EPR, this period will last 50 to 60 years from first criticality. Let's take 60 years and analyze the consequences for a new reactor ordered now or just entering the construction stage. It is likely to go critical by 2010, and will have to be fueled until 2070. **Taking into account the overall requirements of the world fleet, do we have today the certainty of 65 years of forward uranium supply is the question to address.**

In theory, we have to cover only the lifetime needs of existing and firmly planned reactors, plus the needs for today's incremental reactor orders. However, an easier figure to get, providing a more dynamic outlook, is provided by simply cumulating the scenarios annual requirements figures. Let's start with the reference scenario. We don't have forecast figures for the period after 2030, so it is assumed that the installed power and the resulting requirements will go flat thereafter. **The cumulated gross requirements from 2005 to 2070 are evaluated at 6,48 MtU.** What are today the resources figures to balance these requirements will be discussed further on. **Convincing decision makers that the resource base is sufficient is our first challenge.**

Because we all hope to see new reactor orders in the coming years, we will have also to think about adding every year new resources, on average amounting to at least the yearly consumption. **Steadily adding new identified resources is our second challenge.**

3. Supplying 6.5 MtU: a discussion of today's uranium resource base

3.1. Available information on world uranium resources

There is a **single comprehensive source** of information addressing the world uranium resources issue, **the "Red Book"** published every two years under the umbrella of two international agencies, the Nuclear Energy Agency of the OECD, and the IAEA. This document collects and reports on the uranium resources data officially provided by the governments of the countries involved, regardless of whether they are producing uranium or not.

Without entering into details at this stage of the discussion, it is possible to say that the contained information is of good quality and certainly improving with time.

Obviously, the detailed data are not always as homogeneous and accurate as requested, but this has become a marginal concern.

There was an attempt at the Uranium Institute time (1998) to gather data more in line with "Industry definitions". According to the upcoming WNA Market Report 2005, the main finding was that "The results of the survey [...] were very close to the sum of the Red Book's Reasonably Assured Resources and the Estimated Additional Class 1, including only those assessed as having costs of extraction less than \$80/kgU." In other words, **the Red Book data are accurate enough to get a world picture**, there is no need to redo the work, but instead we have to explain and make known the meaning of its content.

3.1.1. Red Book figures are a snapshot of world uranium resources

Certainly, the first point to understand is that the **uranium resources published figures are a snapshot at a given date**. Some people do believe (or act as if) the numbers are the ultimate uranium endowment of the planet. This is totally wrong, and no doubt we will find more economically recoverable uranium in the future. This was achieved in the past, and it is an ongoing process despite still-limited exploration expenses.

3.1.2. The "Red Book" reports "Resources", not "Reserves"

It is essential to underline that the "Red Book" is reporting "Resources", not "Reserves". The two words are frequently utilized to speak about approximately the same thing; "uranium in the ground". This is unfortunate because they have each a different and precise definition for the industry, not only for geologists and miners, but also for accountants and stock market regulatory bodies. Detailed instructions for reporting Reserves and Resources are available, and their assessment requires a recognized, specialized and graduated "competent person". To make a short distinction, the main difference is that "Reserves" necessarily implies a positive feasibility or a detailed pre-feasibility study, when this is not the case for "Resources". Therefore, **Reserves are the only part of the Resources that are ready for production or close to it**.

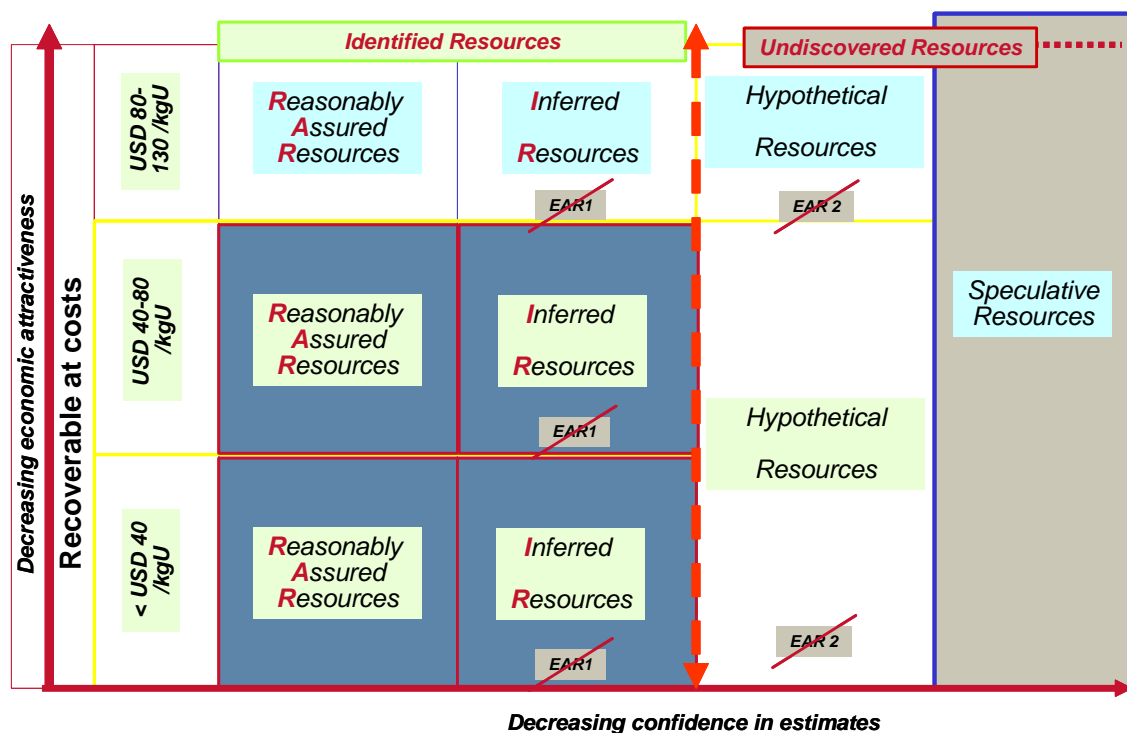
3.1.3. Red Book Resources classification: the two axes: knowledge and cost

Before detailing the classification scheme, it is worth recalling that the Red Book distinguishes **Conventional Resources** where uranium is either a primary product, co-product (typically copper or vanadium) or an important by-product (gold or copper), and **Unconventional Resources**, where uranium is either a marginal by-product (phosphate rocks) or at very low grades (black shists...) or under forms that do not allow an easy and currently economic recovery. Detailed studies and data collection on unconventional resources are not done on a regular basis.

Not departing from what is done in other classifications, **the first axis of the resource classification is the level of knowledge** for a given resource.

«Red Book» NEA-IAEA new Classification Scheme for Uranium Resources

- ▶ Wording change of Estimated Additional Resources 1 for Inferred Resources
- ▶ And of Estimated Additional Resources 2 for Hypothetical Resources



Two very clear-cut categories are now in use.

- **"Identified Resources"** (replacing previous "Known Conventional Resources") refers to resources that are precisely positioned geographically (between the meter to the hectometer scale or at the shovel scale!). In the Red Book, this category is reported **as tonnes of recoverable uranium**, instead of *in situ* uranium. This category covers

- the "**Reasonably Assured Resources**" that have a high assurance of existence according to the tonnages, grades, recoverability of the uranium and cost assessment.
- The "**Inferred Resources**" (previously Estimated Additional 1) that are basically geometrically less known extensions (larger drilling patterns) of the previous (RAR) but are likely to have similar geological, technical and economic characteristics.
- "**Undiscovered Resources**" refers to resources that are not necessarily positioned at a mine scale (at the kilometer scale or even larger). Because of the uncertainty of potential mining and ore processing methods, **Undiscovered Resources are reported as *in situ* uranium**. This category covers
- "**Hypothetical Resources**" that are evaluated on the basis of indirect evidences within known uranium bearing areas, and
- "**Speculative Resources**" that are thought to exist in geologically documented but poorly explored areas with respect to uranium "on the basis of indirect evidence and geological extrapolations".

This recently-proposed distinction introduces a very sharp limit between the Identified and Undiscovered Resources categories. It is to be implemented for the 2005 Red Book issue, and will require from a few countries some work to adapt their data to this new system.

The second **axis of the classification is the economic attractiveness** defined through cost categories limits. To allow gathering the data in single tables, all the costs are converted in US dollars at a fixed date. **The costs are typically "forward marginal cost"**, not taking into account sunk costs nor any profit margin and return on invested capital.

The costs limits considered in the Red Book are

- less than \$40/kgU (about \$15/lbU₃O₈)
- \$40 to \$80/kgU (about \$30/lbU₃O₈)
- \$80 to \$130/kgU (about \$50/lbU₃O₈)

The last published Red Book (2003 issue) mentioned that "known conventional resources" now labeled "Identified Resources" recoverable at cost of <USD\$80/kgU are distinctly important because they support most of the world's EXISTING and COMMITTED production centers". This statement is consistent with above-mentioned WNA findings.

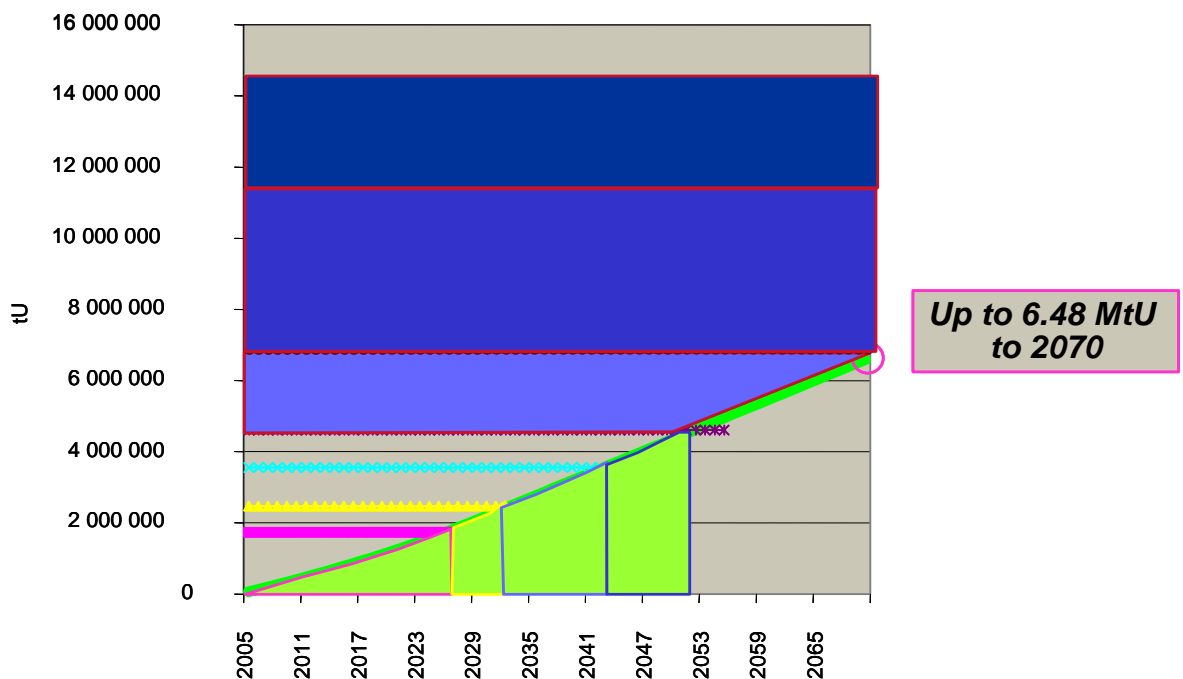
3.2. The Uranium Resources figures and the Reference Scenario demand coverage:

The numbers; World Uranium Resources Figures as of 2003

MtU	Conventional Resources				Unconventional Resources.
	RAR	Inferred or EAR-1	Hypothetical	Speculative	
US\$/kg U \$/lbU308					
< 40 <15	1,7	0,8	1,5	4,4	Around 15 to 25 Costs unknown
40 – 80 15 - 30	0,8	0,3			
80 – 130 30-50	0,7	0,3	0,8	3.1	
> 130 > 50	?	?			
	3,2	1.4	2.3	7.5	
TOTAL	4,6	14.4	9,8		15 – 25

Source: Red Book OECD-NEA - IAEA; issue 2003

WNA Reference case cumulated world (gross) uranium requirements



3.2.1. RAR < \$40/kgU: they are totaling about 1.8 MtU in which the first contribution is Australia with 0.7 MtU (39%), likely to increase. Year 2003 Top 10 uranium producing countries (94% of world production) cover at least 95% of the total (the US did not provide information for this

category). Clearly, these were the core resources used by producers in the depressed market period that characterized the years from 1998 to 2002. With regard to our demand scenario, this **will allow fueling the NPP fleet until 2026**, about 20 years, not taking into account any inventory and so called "secondary supplies". One can comment that 20 years of visibility is quite a nice outlook for mining companies. These RAR are actually real "Reserves" meaning they were found, defined, assessed, acquired, licensed at significant costs that their owners are now willing to recover at a profit. On the other hand, such a figure is clearly not sufficient to reassure decision makers willing to order a new reactor. Indeed \$40/kgU is not a suitable level to get access to sufficient quantities of uranium resources.

3.2.2. RAR < \$80/kgU: they total about 2.5 MtU (+0.8 MtU). With 28%, Australia remains the number one, but the Top 10 producers represent a little less (89%). One can observe that the increment is only +43% for a doubling of the cost, contrasting with some optimistic assertions that a doubling of the cost is likely to multiply the resource quantities by up to 10 fold (just to recall that a prudent approach is required). This will **allow pushing our supply limit to 2033 at costs that are close to current market levels**. This is not bad, but still insufficient.

3.2.3. RAR + Inferred <\$80/kgU : all together, the identified resources at current market level total 3.6 MtU (+1.1 MtU).Australia's share and Top 10 producers share remain unchanged. The **supply limit reached is now 2043** under the same conditions.

3.2.4. RAR + Inferred < \$130/kgU: waiting for additional investments that will turn "undiscovered" resources into "identified", we have to consider tapping higher cost identified resources. Remember that in the late 1970's prices jumped above \$110/kgU in real dollars, about \$280/kgU in today's dollars. The total Identified Resources represent 4.6 MtU. Australia still leads with 23%, followed by Kazakhstan (18%), and the Top 10 producers cover 87% of the total. **Taken alone, all today's identified resources enable the power plants in our scenario to be fed to 2052, and this with a very high probability**, without taking into consideration any other source of fuel. If we add a 5% savings through further enrichment tails assay reduction, 2200 tU /year of recycling Pu and RepU (it would be easy to do more, as this is just about today's level) and using 200 ktU from HEU and other stockpiles (again a low figure), then these identified resources will be sufficient to 2058.

3.2.5. Identified Resources + Hypothetical Resources < 130\$/kgU

From here, we enter a less certain world. Globally, the top 10 producers share 88% of a total of 6.9 MtU. Australia falls at the third rank (15%) simply because it does not report "Undiscovered Resources". This prominent absence gives confidence in the likelihood of more available uranium in the future, and we know today that a single Australian deposit, Olympic Dam, conceals at least about 1.3 MtU of total Resources. On the other hand, the US takes the first rank with a huge figure of a mixed Estimated Additional Resources, falling mainly in the Hypothetical

category as a result of an evaluation program achieved during the 1980's (the so called NURE program).

3.2.6. Speculative Resources and others

To supply our reference scenario, there is no need to go beyond the limit of Hypothetical Resources, as we have identified enough uranium to claim that there won't be any problem to fuel our NPP fleet until 2070. Nevertheless, it is worth exploring the Speculative Resource category, likely to add a further 7.5 MtU, more than doubling our previous figure, not even speaking about Unconventional Resources believed to add also very large quantities, mainly from phosphate rocks.

3.2.7. So Easy!

When directly balancing the total resource figures with cumulated requirements, it appears that fueling a large reactors fleet will not meet any difficulty.

In theory, we can even do more, for example covering the needs of a more ambitious scenario such as the above mentioned Upper scenario WNA 2005, likely to require 8.8 MtU (+2.3 MtU) to 2070.

However the Resources are one thing, i.e. uranium in the ground, and fuel supplies are another thing, i.e. uranium in the fuel elements. The other challenge is thus to produce the uranium concentrates often referred to as "uranium in the can", and before that, to prepare the resources for mining in a timely fashion.

4. Turning Resources into production

4.1. Raising production to unprecedented levels: challenging or easy?

4.1.1. Huge production increase needed for the next 25 years

In our reference scenario, yearly requirements levels will rise from today's 65ktU/year to 110 ktU/year by 2030, a 69% increase.

For uranium mines production the increase looks even higher. Due to a lengthy period of excess inventories reduction, it represented only about 40 ktU in 2004 (about 60% of requirements). **Therefore, the increase needed for mine production would be in the range of 170% by 2030 for the Reference Scenario, including a 50 to 60% increase within the next decade just to cover the consumption after full exhaustion of excess inventories.**

It is time to recall that past production has never reached levels beyond 68 ktU/year (record year 1980), and that currently existing mining and milling capacity is now far less the 60 ktU/year level (about 45 ktU).

The already mentioned tightness in today's market is the result of this situation.

4.1.2. Steps toward production increase

4.1.2.1.1. Production increase potential from existing mines

All the existing mines and mills are producing, with a few exceptions with a limited capacity (mainly in the US). Furthermore, the producing ones are today almost running at full speed. Some of them have the ability to increase their mining and milling output, in general to some extent only. Therefore **starting new mines as soon as possible is necessary.**

4.1.2.1.2. From reserves to production

Current practices all around the world require many licensing steps before uranium production can start. In other words, it takes years to bring a perfectly known deposit to fruition. To give an idea, let's say a minimum 2 years to get a construction license, then 2 years to build the necessary infrastructure and facilities and obtain the production license, add one year in average to deal with various uncertainties, and you get **a 5 years incompressible time lag between a "market signal" and a supply response... for fully feasible projects.**

However, projects of significant size already cleared for feasibility are just a handful or so. As a result, bringing reserves to real production is less a matter of price than a matter of time.

4.1.2.1.3. From Known Resources to Reserves

Because new projects are needed, re-stating resources for new feasibility assessments must be started now. This will imply not only paperwork, but also additional drilling, sampling, testing...and in some cases ad hoc licensing. This process also requires time (a few more years; typically 2 to 5) that will have to be added to our previous time lag, meaning that what we start today is likely to translate into fresh production by 2015.

This is probably the most urgent step, because only one producing deposit enjoys a reserves endowment allowing to produce beyond the 2050 window, Olympic Dam, and only at current production rates.

4.1.2.1.4. From Undiscovered Resources to known Resources

As explained above, it is necessary to compensate production by new discoveries, in order to maintain a credible amount of known resources to allow the ordering of new reactors. Therefore, financing a steady and significant exploration effort is required, with the goal of adding at least a half Cigar Lake a year. This means exploration money, (in the range of MUSD 200 to 300 yearly or more) in addition to all the investments needed by previously mentioned steps.

4.2. Prerequisites for making available the uranium that is under our feet

To summarize what was just said, one can observe that financing is involved at each mentioned step of the process:

- investments in new mining capacities,
- financing ore-bodies development to transform resources into mineable reserves, and finally,
- investments in exploration to identify new resources.

Clearly, money is one of the prerequisites, and, thanks to the ongoing price rise, "market forces" seem to be at work according to the skyrocketing number of uranium exploration companies.

We believe it is fair to warn market participants once again that two other prerequisites are also unavoidably needed, and probably more challenging than finding money. They are time and expertise.

Time is a very difficult parameter to handle. First, there is the time required to discover an ore body worthy of development. This is not a simple task, and some might say that the "low hanging fruit" has already been picked in this regard. Secondly, in our modern societies, industrial activities, and especially nuclear industry, are under scrutiny of many supervisory authorities including individual citizens. Licensing processes take time, and accelerated funding can't help to reduce this time.

Expertise is likely to be another bottleneck. Experienced geologists, mining engineers and metallurgists in the field of uranium exploration and production are now very few, after more than 20 years of depressed markets worldwide. The last ones are working for the "surviving producers", and while easy to achieve overnight with stock market money, the multiplication of uranium companies is unlikely to multiply the specialists at a similar speed. To some extent, expertise and time are closely linked parameters. We believe this fact is commonly underestimated by market participants.

As a result, the three prerequisites classified by order of decreasing importance are Time, Expertise and Money.

We, at AREVA, are accustomed to work with the time parameter, and a long time frame is clearly a characteristic of the nuclear industry at large. Our expertise in the field of uranium exploration and mining is also based upon a unique worldwide history and a unique mix of technical cultures. Finally, we do have a large financing capability ready to address future challenges if they appear economically sound.

5. Conclusions

The first and very important finding is that there are enough uranium resources to fuel very significant nuclear power programs based upon light water reactors, enough to speak about a real Nuclear Renaissance.

For a corporation like AREVA, designing, building and selling nuclear power plants, but also exploring and mining uranium besides production of a wide variety of fuel services, such a finding is already reassuring. Our real challenge is to convey this finding to decision makers.

But we have an even more ambitious vision. In order to really address global warming issues, nuclear power should represent more than 20% of total electricity production. This implies finding large additional resources, then raising the question of "the ultimate uranium resources", and/or shifting to reactor designs able to burn more efficiently the available uranium and other fissile material.

Regarding the "ultimate uranium resources" there is no way to get the numbers through a credible method, despite attempts and statements. So let's use the "Speculative" figures as they are published, and modestly add to the "Identified Resources" year after year by investing in exploration, more expensive, but more efficient than crystal balls and other magic formulae.

We believe this is a balanced view on uranium resources. We hope that, together with the other benefits and advantages of nuclear power, it will ultimately convince people in charge of setting energy and environmental policies that it is sound enough to allow them to order new nuclear power plants.