Uranium Resources and Security of Supply

By Sophie Gabriel, Antoine Monnet and Jacques Percebois

INTRODUCTION

In order to study the possibilities for the future deployment of nuclear power plants, we have examined the long-term availability of uranium resources. We first defined a model to estimate the ultimate uranium resources (discovered and undiscovered resources and those already mined) (§ 2) and then studied the dynamics of the uranium market (§ 3). This allowed us to define a market model (§ 4). The modelling carried out allowed us to conduct prospective studies, with particular attention given to supply security issues (§ 5), introduced by changes of production in a particular region, for technical or political reasons. Our analysis was not based on modelling demand scenarios as this involved too many underlying assumptions, hence we adopted a literature review based approach [3]. Two demand scenarios were subsequently selected: scenario A3, representing high global demand for nuclear power (5,400 GWe installed capacity in 2100) with a consequently high-growth demand for natural uranium (810 ktU/year); and scenario C2, representing moderate-growth demand (2,100 GWe in 2100 and 340 ktU/year) (Figure 1).

The description of our study is given in [5] (in English) or with much more detail in [4] (in French).

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MODELLING ULTIMATE RESOURCES

Several bivariate and multivariate statistical models can be found in the literature to estimate the abundance and production costs associated with a non-ferrous metal such as uranium. These models are essentially used to estimate potential reserves within a specific region of the world.

Our methodology allows for an estimation of ultimate uranium resources based on a lognormal distribution of the grade and tonnage of deposits, on the use of an economic filter and on cost functions which take account of economies of scale and the type of mining involved.

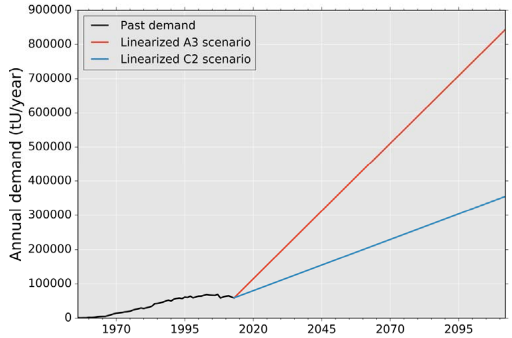

Figure 1 – Cumulative global uranium consumption scenarios [1]

The regional breakdown used to estimate ultimate resources (including both identified and undiscovered resources) consists of 6 subregions: **USA, Canada, Africa, Australia, Kazakhstan** and the **rest of the world.** These regions were selected on the basis of the following criteria:

- Representativeness: the top 5 subregions account for almost 85% of world production and close to 80% of reasonably assured resources (RAR) at <USD 130/kgU in 2013 [6].
- Availability of data on known deposits and recent mining projects.
- Minimal variability in the types of deposit encountered and a certain degree of standardisation of mining regulations within the regions to ensure relative consistency when estimating the costs of ultimate resources.

Our cost calculation method (cost-capacity relationship) was used for each subregion, taking account of the specific regional characteristics in terms of mining techniques.

Application of our model gave the ultimate resource estimates for each region illustrated in Figure 2. (The cumulative ultimate resources estimated is about 72 MtU at <USD 260/kgU). The results obtained in each region were compared with estimates from the NEA-IAEA published in the "Red Book" [6]. This comparison does have its limitations, however, bearing in mind that the resources (reasonably assured and inferred resources (RAR+IR)) identified in the Red Book do not, by definition, include any undiscovered or already-mined resources, whereas these are included in our estimate of ultimate resources.

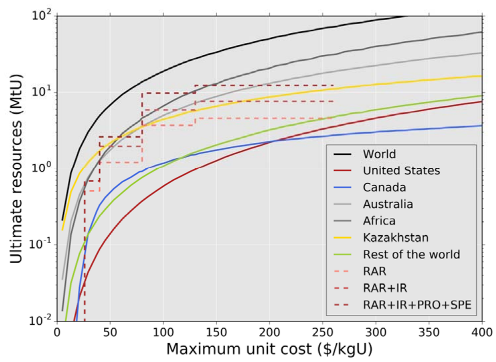

Figure 2 - Cumulative ultimate resources

It is important to note that the model developed only considers resources from the earth's continental crust and that uranium is considered to be a primary product. Hence, uranium resources dissolved in seawater are not taken into account.

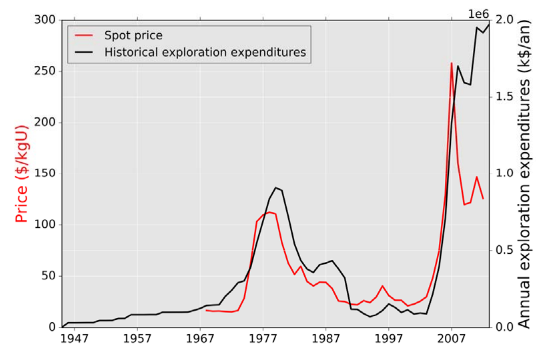

Figure 3 – Uranium spot price (yearly average of month-end prices) and exploration expenditure (1940-2013)

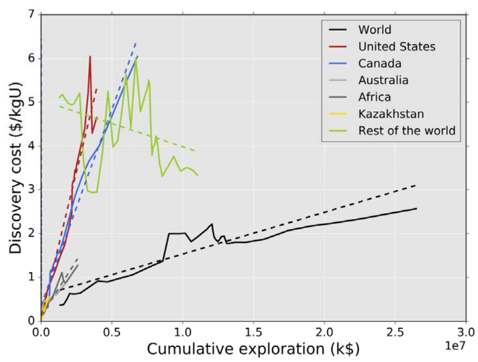

Figure 4 - Correlation between discovery cost and cumulative exploration expenditure

Moreover, sensitivity analysis showed significant uncertainties on the ultimate resource estimate. The most sensitive parameters include the discount rate, the depth of the earth's crust considered and the price of uranium representative of current economic conditions. (In order to take into account this high level of uncertainty, we will also consider an estimate of 36 MtU at <USD 260/kgU.)

It can now be noted that a very limited number of regions gather a large part of current resources and production which raises questions about security of supply. We will see later how the variation of production of a single region can influence the market.

DYNAMIC CONSTRAINTS ON URANIUM SUPPLIES

Analysis of exploration activity and associated discovery costs allow the introduction of two key relationships.

- Market prices and exploration expenditure

Like many other mineral raw materials, uranium shows a clear correlation between its spot price and exploration expenditure (see Figure 3).

- Discovery cost and cumulative exploration expenditure

As a territory is explored, more and more difficulties in identifying new resources are encountered, which results in an increase in the discovery cost. We have estimated the correlation between discovery cost and cumulative exploration expenditure per region.

Besides, the reserves-to-production ratio (R/P) is an indicator of availability of a non-renewable resource used primarily in the oil and gas industry [2]. We propose two original interpretations of the R/P ratio. On a global level, R/P is a simple indicator of scarcity, which can represent a constraint associated with the anticipation of global demand. On a regional level, this ratio can be interpreted further as the result of the producers' technical, budgetary and financial constraints or a regional strategy. If the perceived scarcity of the resource exceeds a critical value, a retroactive increase of the price is applied until the additional exploration expenditure is sufficient to satisfy this constraint. This type of modelling introduces the notion of **scarcity rent**.

MODELS OF THE URANIUM MARKET

Based on the supply constraints described earlier, which may be short-term (such as the causal link between price and exploration expenditure) or longer term (such as the anticipation of demand), we study the long-term availability of uranium using a succession of short or medium-term economic balances.

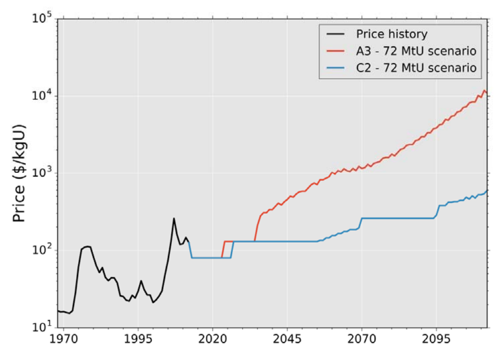

Figure 5 - Price trends (A3 and C2 72 MtU)

The market is modelled as an oligopoly of 6 regions with exploration and anticipation constraints (the market players are combined and modelled together in these regions), but no rent other than the scarcity rent or the differential rents is included in the market price to represent a possible dominant position of any player.

Figure 5 and Figure 6 show the price and resource rent trends for demand scenarios A3 and C2.

Two marked trends can be seen in prices for scenario A3: the price remains fairly stable in the short and medium term (around the 2013 levels), then increases significantly after 2035 (Figure 5). In fact, this change occurs when the global R/P ratio reaches its 60-year threshold. In this situation, the market mechanism introduces an increasing scarcity rent to keep the R/P ratio at its minimum level (Figure 6).

For scenario C2, the R/P ratio reaches its threshold later and the price increase is lower.

The sensitivity analysis has shown that anticipation of demand and the need for visibility for consumers, represented by the constraint on the global R/P ratio, directly affect price trends, by influencing the scarcity rent (Figure 7). Maintaining a minimum R/P ratio is necessary to avoid a shortage. It can also be seen that the higher the anticipation constraint, the sooner and the stronger the price increase.

Some parameters introduced in our model tend to increase production costs as resources are depleted and new resources discovered. Yet, these trends are secondary compared with the long-term uranium price trends since the scarcity rent is the first determining factor when demand rises according to scenarios A3 or C2.

These results show that in the case of increasing demand for uranium, low market prices that do not favor exploration threaten long-term security of supply, whether by a shortage of identified resources if there is no anticipation of the risk, or if not, by a very large price increase linked to the appearance of a scarcity rent.

PROSPECTIVE STUDIES OF SUPPLY VARIATIONS

In order to test the robustness of our model and to go further in the analysis of security of supply over the long term, we considered three cases of variation in supply. First of all, we study the effect of the uncertain estimation of the ultimate resources on price trends and then situations in which production is suddenly stopped or doubled in one region.

Effect of the ultimate resources

Figure 8 shows the price trends with two supply scenarios, 72 MtU and 36 MtU at <USD 260/kgU, for the two demand scenarios A3 and C2.

The following observations can be made:

- Uranium demand is the first-order variable which influences uranium price trends.
- The estimation of the ultimate resources affects price trends more in the medium terms than in the long-term (the characteristic medium and long-term timescales depend on the growth of demand).
- Increasing the ultimate resources, in the medium term, delays the price increase associated with the differential rents, which limits exploration and, in the longer term, brings forward the date when a scarcity rent appears, and therefore the significant price increase.

Thus, at the first order and over the long term, the uncertainties about the quantities of ultimate resources are not responsible for the rise in prices. The rise in prices is linked to the anticipation of demand (R/P ratio), that is to say the quantities of identified resources (R) since in our model production (P) corresponds to demand and is exogenous.

Effect of stopping production in one region

We simulate stopping Australia's production in 2050 and analyse its effect on price trends. Australia was chosen because this region plays an important role in global production and past political choices have already restricted or suspended its production for several years. In a context where some countries decide to stop exploration and production of hydrocarbons, it is conceivable that a country decides to stop its exports of nuclear fuel only for political reasons.

The results obtained (Figure 9) show that stopping production in a country such as Australia would result in a period of price fluctuation followed by a residual price variation in relation to the reference situation. This variation continues in the long-term. Furthermore we have shown that the earlier production is stopped, the greater the variation.

These results suggest that the political decision to stop uranium production in a region like Australia may threaten the global security of supply and have long-term consequences.

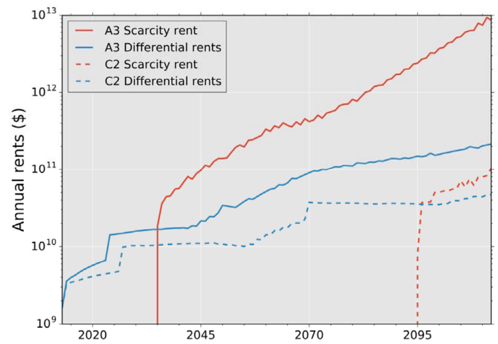

Figure 6 - Resource rent trends (A3 and C2 72 MtU)

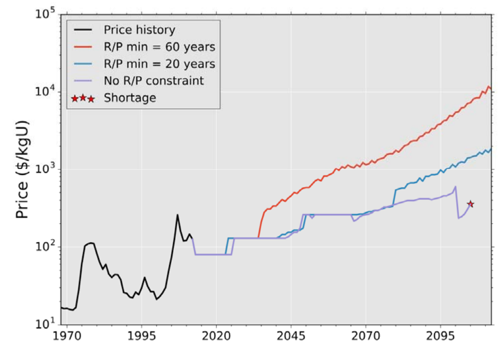

Figure 7 - Effect of the anticipation of demand constraint (A3 72 MtU)

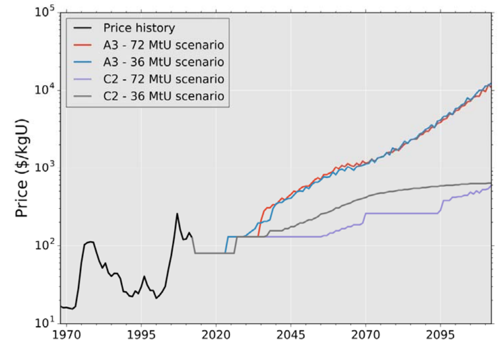

Figure 8 - Effect of the supply and demand scenarios

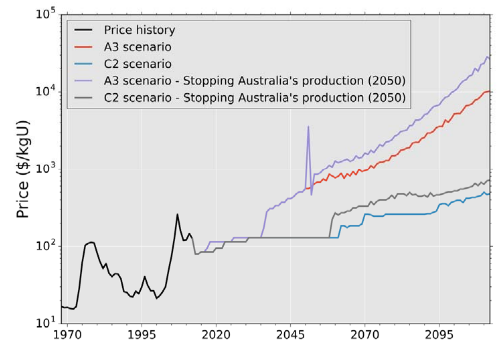

Figure 9 - Effect of stopping Australia's production in 2050

Effect of doubling the production in one region

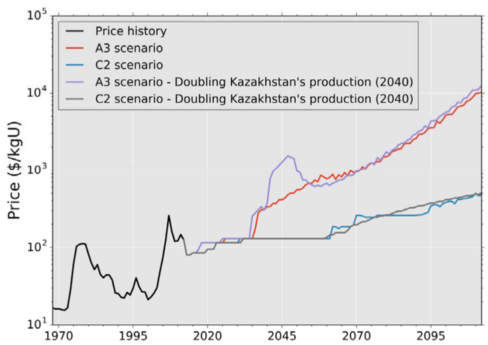

Figure 10 - Effect of doubling Kazakhstan's production in 2040

We now look at the effect on price trends of doubling Kazakhstan's production in 2040. Kazakhstan was chosen because this region has already proved, at the start of the 21st century, that it is capable of rapidly increasing its production.

According to the results (Figure 10), doubling the production of a country such as Kazakhstan would introduce price fluctuations in the short and medium term, but would have little long-term effect.

CONCLUSION

This analysis of uranium resources and security of supply is based on modelling the ultimate uranium resources (discovered and undiscovered resources and those already mined) and modelling the market.

A new methodology for estimating the ultimate resources and their associated production costs has been developed using available data on known uranium deposits. The model incorporates the specific economic and geological characteristics of each region in the best possible way by calibrating the deposit distributions and cost functions differently.

Despite significant uncertainties, the results obtained have shown that, due to some regions' specialisation in particular mining techniques and/or their specific economic and geological characteristics, the ultimate resources of uranium are distributed unevenly throughout the world. The discount rate, the depth of the earth's crust taken into account or the price of uranium representative of current economic conditions are all particularly decisive parameters in the estimation carried out. However it has also been shown that the estimation of ultimate resources only has a second-order influence on long-term uranium price trends and security of supply.

The analysis of the structure of the market and its dynamic constraints has enabled us to define a new model to investigate market mechanisms. This is a deterministic model which calculates a series of short-term economic balances in order to carry out a long-term prospective study. This model takes into account the causal link between price and exploration expenditure. It also accounts for increases in discovery costs and anticipation of demand. The regionalisation of the market players (modelled by an oligopoly with no collusion) introduces differential rents which have a limited short and medium-term effect in the increasing demand scenarios that have been studied. At the same time, the demand anticipation constraint introduces a scarcity rent. This contributes to maintain security-of-supply margins, but also leads to a significant increase in the price of uranium in the long-term.

A sensitivity study has revealed the particular importance of the demand scenarios, the demand anticipation constraint and even the regionalisation of the discovery costs: they all have a significant effect on price trends by influencing the scarcity rent.

Our results have shown that, without anticipating demand, prices are not high enough to encourage exploration and the discovery of new resources needed to offset production and rising demand. This leads more or less rapidly to a shortage.

Only an anticipation of demand ensures security of supply over the long term. This anticipation is made via a scarcity rent and translates into a sharp rise in prices.

Further analysis of security of supply should take account of the limited number of producing regions. Geopolitical analyzes of the producing countries, but also of the uranium-consuming countries, would be very relevant, but the time horizon to be considered is a major difficulty for these analyzes.

References

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