World Nuclear Association Annual Symposium
5-7 September 2001 - London

Rocks to reactors: Uranium exploration and the market

Colin Macdonald

For the past several years, the uranium supply sector has, through a series of political, financial, and technical events, been dominated by secondary sources of uranium. The very low uranium prices this dominance has produced, along with a flat outlook for uranium requirements and the slower development path of new uranium mines during the market low, has displaced contemplation of the exploration and discovery of new uranium resources to the almost-geologically long term future. Yet for several reasons, this front-end segment of the uranium fuel cycle needs to be understood and considered in any long-term analysis of the uranium market.

A brief analysis of the discovery and production history of the Athabasca basin in northern Saskatchewan provides a useful illustration of how market dynamics influence uranium exploration investment, and how exploration discoveries in turn influence uranium markets. As in any such analysis, past behaviour may provide some insight into future patterns, which have considerable relevance today as nuclear power is once more coming under positive consideration as a source of reliable and clean energy.

Athabasca Basin Discovery History

The chronology of exploration discoveries in the Athabasca basin covers a period from about 1968, with the first major uranium discovery at Rabbit Lake just outside the basin, to the present. In detail, an early period of exploration discoveries (Figure 1), culminating in the discovery of the Key Lake deposit in 1975, was based largely on followup of uranium mineralization found by traditional prospecting on the land surface. These deposits, by 1977 called unconformity uranium deposits to denote their location at the contact between basement rocks and sandstone, were located close to the land surface. This allowed either direct observation of mineralized boulders, or detection of radiometric anomalies caused by uranium mineralization. This initial stage of "easy discoveries" can be grouped as Phase I of the exploration history.

A longer second phase of exploration discoveries, including the largest known deposits, Cigar Lake and McArthur River, followed from 1977 to 1992. From a technical perspective, Phase II was characterized by discovery of "blind" uranium deposits, those with no expression on the land surface. Knowledge of geological models derived from the Phase I discoveries, and increasing use of deep sensing geophysical techniques, were

the key success factors during Phase II. As of 2000, fully delineated and publicly announced discoveries in the Athabasca basin total about 1.4 billion lbs U_3O_8.

The Athabasca basin Phase I and II exploration periods, although different in terms of the methods of discovery, were nevertheless funded by a single continuous period of increasing exploration investment, peaking in 1980 at $CDN 77 million in annual expenditures. As such, the two phases can be combined and, using a long enough moving average, smoothed into a single curve (Figure 2), peaking in approximately 1984. The timing of this discovery peak is about four years after the 1980 peak in exploration expenditures, which in turn follows by three years the 1977 peak in uranium prices. As exploration commenced in this region in the late 60' s, there has been a roughly 17 year period between the beginning of exploration in this new region and the peak of discoveries.

It is important to remember that in 1966, when Athabasca basin exploration began, there was no geological knowledge that this style of large, high grade unconformity uranium deposits existed at all, certainly not in this new geological terrain. The discovery risk accepted by the initial explorers was exceptionally high. A look at the exploration investors at this time provides some insight into their motivation, as the largest funding levels were directed by state, crown, or utility-owned companies, such as the two Canadian crown corporations SMDC and Eldorado Nuclear, French companies Seru/Amok (later Cogema), and German explorer Uranerz. Japanese state- or utility-directed companies such as PNC also became major joint venture players. A contingent of oil companies were also active in the 70' s, including some major ones such as Shell and Texaco. However, some of the more important joint venture participants were smaller US and Canadian oil companies, taking advantage of the rapid rise in market interest in uranium. Thus, the majority of the initial exploration funding was sourced from companies who were either nuclear entities with interests in long-term supply security rather than short-term price, or exploration companies who were very aware of the price-driven upside of this growing commodity.

A rapid decline in exploration expenditures after 1985 closely followed the drop in uranium price. As expenditures declined, so did the discovery trend, especially when the typical 4-6 year lag between spending and proving reserves is taken into account. During this period, a large inventory of targets continued to exist in the Athabasca basin, but with significantly reduced drilling rates, and a gradual trend towards deeper targets (hence fewer tests per unit expenditure), the rate of target testing slowed significantly. Both Cameco and Cogema have announced new Athabasca discoveries occuring in the last five years [1, 5] but during the present market low, have been delineating these new prospects at a relatively slow rate.

Are recent discoveries sufficient to reverse the decline observed in the discovery trend? With the limited drilling completed to date, these new discoveries have not yet demonstrated the size potential to equal the largest historic discoveries, McArthur River and Cigar Lake. Nevertheless, a second discovery cycle for the Athabasca basin is indeed possible, particularly considering the very small size of even the largest discovery targets. Such a second cycle will require a significant new influx of exploration funds to accelerate the rate of target testing, continued application of leading exploration technologies, and continued success in the deeper parts of the basin (>700 metres sandstone depth).

Discovery Determines Production

Leaving aside for the moment the impact of a second cycle of Athabasca basin discoveries, it is still useful, as the two largest uranium deposits are now in or approaching production, to look at the production trend that has so far resulted from the main discovery cycle. Figure 3 shows the smoothed discovery trend to date, along with the actual production trend to the present, projected to 2015 using announced production plans. At 2015, Cigar Lake and McArthur River will be the only known deposits still in production for a total of 36 Mlbs U_3O_8 per year. Eventual exhaustion of the presently known reserves for these two deposits necessarily requires that Athabasca production begins to decline sometime after 2020. How rapidly Athabasca production declines depends on future development of either currently uneconomic resources, or new discoveries.

The pattern consisting of a bell curve-shaped discovery trend and a similar but lagging production curve is well-known from the oil and gas literature. The production curves are also referred to as Hubbert curves, after the USGS geologist who first described them. There is little argument in the petroleum industry that these patterns exist and fairly represent naturally-occurring resource discovery and extraction trends for specific basins. The complete pattern forms a single exploration-discovery-production cycle. Production is inextricably linked to exploration, since the volumes produced must necessarily equal the volumes discovered, minus recovery losses. For major international petroleum basins, the average peak discovery to peak production lag is 30 years, which as it happens will be close to the equivalent peak-to-peak lag for Athabasca basin uranium. Globally, the accumulation of many regional Hubbert curves into a global oil production curve is still the topic of considerable debate, with numerous estimates placing the peak in global oil production sometime in the next ten years [3]. Should these estimates prove correct, the resulting changes in world energy sources could also impact nuclear energy.

Although the geology of petroleum lends itself to early identification of the largest producing fields, multiple exploration peaks have been documented, such as in the North Sea basin [2]. The physically tiny dimensions of unconformity-style uranium deposits, as well as the market-driven slowdown in targets tested as described above, suggest that a second cycle of Athabasca discoveries during the next ten years is possible, eventually producing a bi-modal discovery curve as with the North Sea oil example. But market-driven or not, there has been a significant hiatus in Athabasca basin discoveries. Given the long pre-production period necessary for large underground uranium deposits, larger new discoveries in the next ten years are more likely to extend the length of the Athabasca production curve than to significantly expand it. Smaller and shallower discoveries could perhaps be more rapidly developed if market and licensing conditions permitted, and to this extent the peak Saskatchewan production level could still reach a level slightly higher than that allowed by full production from McArthur River and Cigar Lake. Obviously, future production capacity increases at either of these two operations would also increase the total peak production level, but at the expense of more rapid production decline in future years.

Resources Determine Price

One of the insights gained from a resource depletion approach using Hubbert methodology is that short-term market events can influence the detailed shape of the

production curve from any single resource area, but that the long-term trend from each area will eventually show a peak and a decline – a decline that cannot be reversed through technology gains alone. Much of the price volatility typical of commodities stems from short-run events, which are usually well studied by analysts. The inexorable impacts of resource depletion trends on price are more stealthy effects, and are often not considered as market factors outside the petroleum sector. Exploration enters the equation because, as production from significant production areas declines, normally functioning price markets will have provided incentives for new cycles of exploration-discovery-production in new areas. Much of the current debate in the petroleum sector revolves around whether there are indeed new areas left on the globe to move to, at least with sufficient production potential to forestall a global peaking of oil production.

Civilian uranium markets are still relatively young compared to most other commodities, as the rapid rise in uranium demand did not begin until significant nuclear generation capacity had been constructed in the mid-70's. During this period, the early Saskatchewan discoveries, such as Rabbit Lake, Cluff Lake, and Key Lake, were quickly seen to be of sufficient size and quality to pre-empt most other known sources of uranium on the cost curve, as all could be produced for under $US 12 per lb U_3O_8 operating costs. High-cost (and already-depleting) uranium production areas, such as Elliot Lake and Uranium City in Canada, and much of the sandstone-hosted conventional production in the US, began to close down during the time that Saskatchewan production increased. The replacement of higher-cost production with lower-cost Saskatchewan and Australian production thus contributed to lowering the cost curve for primary uranium through the 80's and 90's.

Along with flattening of demand and increased secondary supplies, the new low-cost production sources from Saskatchewan helped to produce the climate of flat to declining nominal uranium prices which remains to this date. One of the interesting ironies of the Athabasca exploration history is that state- and utility-controlled exploration firms primarily interested in security of supply were the key contributors to a lower production cost curve and lower commodity prices. As it happened, reduced costs and lower prices were ultimately of more value in sustaining the competitive economic basis for nuclear power. But how long can declining real prices continue?

Although a popular school of economic thought holds that real commodity prices decline in perpetuity [6], it can equally be argued that prices only decline because they follow a period of discovery of new resources of superior quality and lower production cost than those previously depleted. The Athabasca basin history described above is an excellent example. Even secondary uranium supplies can be described as a "newly discovered" source of uranium with lower cost characteristics than the supply replaced. Outside the uranium sector, mineral exploration for numerous metals through the last 50 years has proven extremely effective in discovering both new geographic areas for resource extraction and new deposit types with lower extraction costs. When combined with mining and processing technology improvements, these large "inventories" of lower cost resource discoveries have been perhaps the most significant reason why many commodity prices have shown declines in real terms over the lengthy (but not infinite) periods necessary to begin to show depletion of these resources.

Extending this argument to the uranium market, the timing of the uranium production peak for the Athabasca basin resources remains an estimate, but based on the exploration

history summarized above and announced production plans, seems likely to occur near, and possibly before, 2020. Secondary supply "resources" will also follow a Hubbert curve, since this category represents the sum of numerous finite quantities of contained uranium. The final secondary supply curve will not likely be smooth, as annual supply will continue to be determined by business and political events, constrained by the market and in some cases by processing capacities. Still, it is important to recognize that secondary supply, too, will reach a point of decline.

Numerous uranium market analyses in recent years have highlighted a likely gap in uranium supply, usually within the next five years, and usually incorrectly. One possible reason for this difficulty is that two of the largest supply sources, the Athabasca basin and the secondary resources, have been on the upwards portion of their Hubbert curves while these forecasts were made. Even in the petroleum sector, accurately forecasting the production peak for any given producing region has proven difficult when production is still rising, although M. King Hubbert himself did get it right in 1956, when he forecast that the lower 48 US states oil production would peak about 1970 [actual was 1971 – ref. 2]. The absence of accurate information about the quantities of secondary uranium supplies has clearly been another problem in forecasting.

While short-term price forecasting will continue to be prone to errors from various uncertainties as well as the small volumes typical for the uranium market, long-run predictions based on the inevitability of depletion patterns are a sound basis for looking at future supply price trends. Without generating a specific long-term uranium supply forecast, which is beyond the scope of this paper, it can be noted that two opposite (but not necessarily equal) resource drivers of future uranium price will be as follows:

1. presently known but undeveloped uranium resources have a higher cost basis – commodity prices must rise from present levels to bring these into production, or:

2. new exploration-discovery-production cycles, perhaps in concert with new technology, succeed in generating new supply sources equal or better in cost terms than those replaced – commodity prices may stay the same, or even decline.

From both a cost and security of supply basis, the long-term interest of the nuclear industry would be to see the second price driver healthy and active, but when will this begin?

The Next Uranium Exploration Cycle

To provide the rewards that allow exploration companies to justify the risks involved in exploration, a healthy price outlook and a strong future for the nuclear industry are both required. While we are now seeing signs of the latter, the price outlook remains overwhelmed by secondary supplies. In the past five years, low uranium prices, largely caused by the increase in secondary supply sources, have masked what would otherwise be the beginnings of market signals to exploration companies. Only as price begins to show real gains can the market conditions necessary to provide incentives to uranium exploration, and the next exploration-discovery-production cycle, begin. If this does not happen within the next five years, there may not be sufficient time even with higher exploration investment levels to avoid the need to develop much of the existing

undeveloped uranium resource base described by IAEA and others, most of which is now understood to require higher uranium prices.

The next exploration cycle will differ in some ways from the first, as most of the utility- and state-owned exploration companies that funded the 1970's exploration cycle are now gone. Publicly traded resource companies such as Cameco and Rio Tinto represent the new model in the uranium industry for capital formation. Cogema is the remaining utility-linked firm, although this company is also undergoing significant changes. Although a small number of Canadian and Australian junior exploration companies remain patiently in uranium, a price recovery would stimulate many more. In general, these ownership changes in the industry mean that the majority of the current uranium explorers will not, or simply cannot, make large investments in the next exploration cycle ahead of a price recovery. This was not the case through the first exploration cycle.

Once a price recovery has begun, other potential investors in a new uranium exploration cycle may be newly-merged large utilities that perhaps have the most to lose from instability in future uranium supply. Petroleum companies looking to re-invest earnings from rising oil prices may once again re-enter the nuclear energy world.

So primary uranium supply today occupies a kind of paradoxical dilemma, as follows:

- long-term prices can only remain low if a new exploration-discovery-production cycle, or several, are commenced soon; but,

- new exploration-discovery-production cycles cannot be started and sustained while prices remain low.

When market conditions finally do allow the next uranium exploration cycle to begin, the prospects for discovery of new uranium resources that would be superior to many of those now undeveloped appear to be excellent. Although many geological regions have been explored for uranium, it is important to recognize that much of this early exploration was similar to Phase I in the Athabasca basin: it involved using direct observation and radiometric prospecting to discover exposed or easily found uranium resources. In the Athabasca basin, it was the application of more advanced geophysical techniques and geological knowledge during Phase II exploration that led to the largest discoveries, a pattern consistent with that seen in other metal discovery histories. In much of the world, Phase II exploration for uranium, using the most up-to-date geological models and exploration technology, has not been seriously undertaken – it has not needed to until now.

Conclusions

- Successful worldwide exploration for uranium during the first major cycle of exploration-discovery-production, primarily in the 1970's and early 80's, has played a critical role in creating the large, flexible production sources and lower cost curve that have characterized uranium supply over the past two decades. Nuclear energy has been a principal benefactor of the resulting lower prices.

- Today's improving outlook for nuclear power is advancing the day when a new cycle of uranium exploration-discovery-production will need to begin. Although

the players will be different from those present in the first exploration cycle in the 70' s, the prospects for discovery of new uranium resources of superior quality to some of the now-undeveloped resources is excellent.

- Security of uranium supply, in the sense of absolute scarcity of resources, is not a foreseeable constraint to reasonable further development of nuclear energy [5]. However, security of ***low-cost supply*** is not possible without investment in the source of the low prices – this is the role that exploration plays.

- Short-term uranium prices will need to rise to allow producing uranium companies to afford additional exploration, and encourage new junior and major company investment in exploration. Whether long-term prices also rise depends on whether a new uranium exploration cycle can begin soon enough to discover low-cost resources in time to replace depleting supply areas.

REFERENCES

[1] D Jiricka, *Geology and Uranium Mineralisation at La Rocque Lake, Saskatchewan.* Saskatchewan Geological Survey Open House, 2000.

[2] J Laherrere, *1999 World oil supply: What goes up must come down: when will it peak?* Oil and Gas Journal Feb 1, p 57-64 and in Letters of OGJ March 1, March 15 & March 29, 1999.

[3] J Mackenzie, *Oil as a finite resource: When is global production likely to peak?* World Resources Institute paper, March, 2000, www.wri.org/wri/climate/jm_oil_001.html.

[4] J C Rippert, E Koning, R Koch, J Robbins, D Beaudemont, *The Shea Creek Project, West Athabasca Basin, Saskatchewan.* Saskatchewan Geological Survey Open House, 1999.

[5] G Pauluis, *The global nuclear fuel market to 2020,* Proceedings of the Uranium Institute Annual Symposium, 1998.

[6] J Simon, *Forecasting the Long-Term Trend of Raw Material Availability,* International Journal of Forecasting 1, 1985.

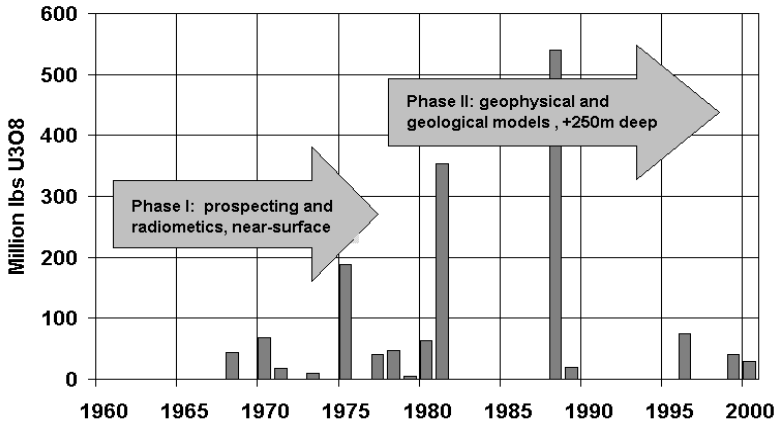

Figure 1: *Saskatchewan uranium discoveries*

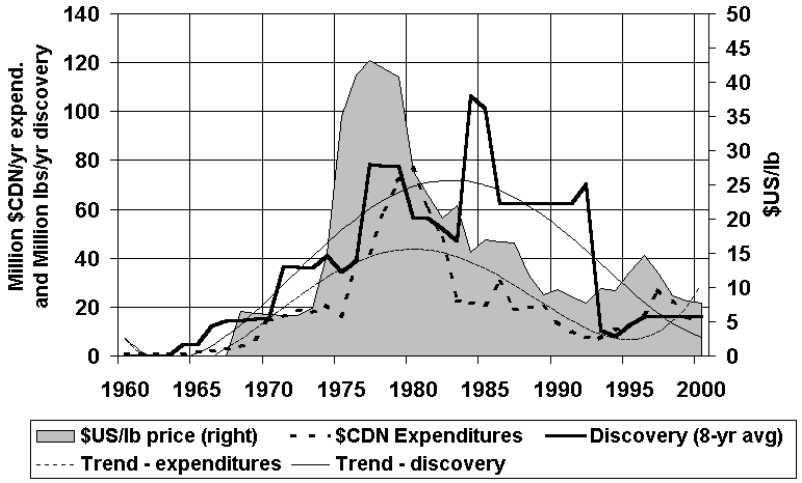

Figure 2: *Saskatchewan uranium exploration discovery and expenditure trends*

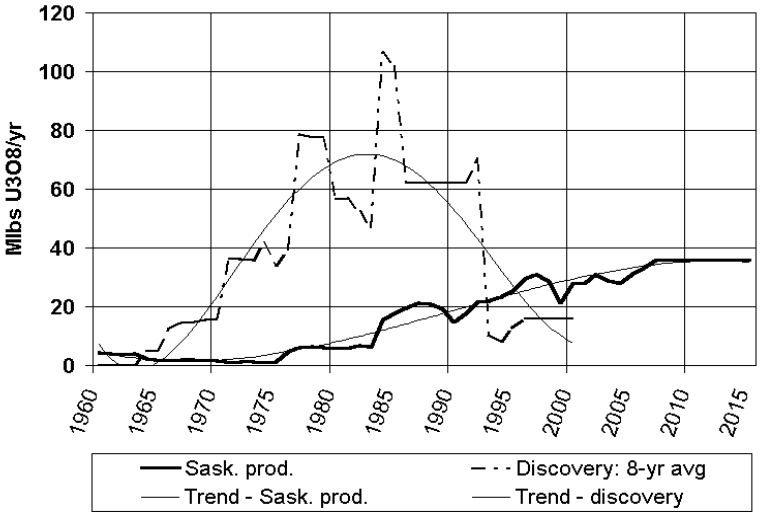

Figure 3: *Saskatchewan uranium discovery and production trends*