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LONG TERM URANIUM DEMAND AND SUPPLY IN CANADA

by

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ABSTRACT

Many projections of world demand for uranium have been made in the past. A general feature of these projections is that they decrease with time; the later the projection is made, the lower is the projected demand. The long term uranium supply has not been given the same attention. However, the supply picture is affected by real delays and industrial momentum in the same way as the demand picture and for this reason I believe it is useful to develop a model, however crude, to provide perspective on the long term uranium supply-demand situation. This report suggests such a model and examines the supply-demand situation in Canada. The results presented are not a projection; a parametric survey presents instead a range of possible developments.

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INTRODUCTION

Many projections of world demand for uranium have been made in the past.[1][2] A general feature of these projections is that they decrease with time; the later the projection is made, the lower is the projected demand. The long term uranium supply has not been given the same attention. However, the supply picture is affected by real delays and industrial momentum in the same way as the demand picture and for this reason I believe it is useful to develop a model, however crude, to provide perspective on the long term uranium supply-demand situation. This report suggests such a model and examines the supply-demand situation in Canada. The results presented are not a projection; a parametric survey presents instead a range of possible developments.

Perhaps the best analogy to use as a guide in developing a model is the petroleum industry.[3] Initially, commercial energy in Canada came mostly from wood. Later coal with its greater energy density supplanted wood. Shortly after, the low cost and convenience of oil and hydroelectricity led to their very rapid growth, and the roles of both wood and coal have declined dramatically in recent years even though coal resources, at least, are far from being exhausted. The most recent primary energy sources are natural gas and nuclear power, both of which are penetrating the market rapidly. The timing and extent of these substitutions of one energy source for another in Canada are shown in Figure 1.[4] During this period petroleum has advanced from a new and expanding source of energy to a situation where production is being affected by resource depletion.

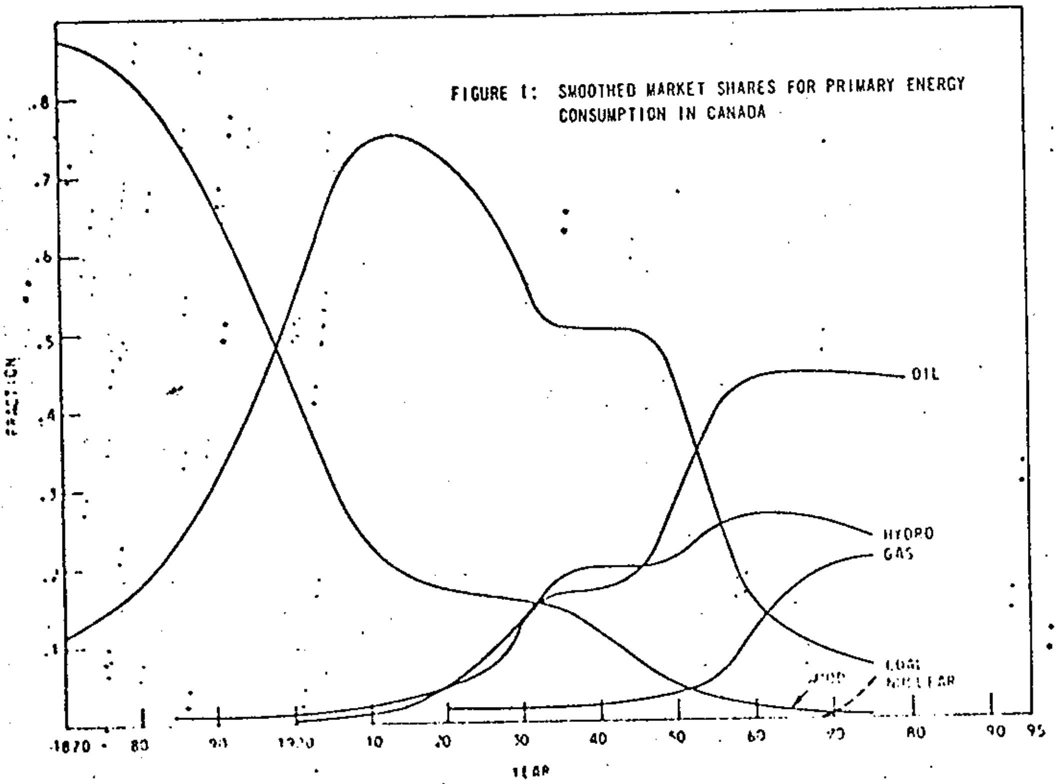


FIGURE 1: SMOOTHED MARKET SHARES FOR PRIMARY ENERGY CONSUMPTION IN CANADA

The use of "conventional" petroleum as a primary world energy source increased rapidly during this century. However, the discovery rate has fallen off, while production is still increasing, so that reserves are now declining.(3) In the United States from 1918 to 1948 cumulative discoveries were increasing at an exponential rate. From 1949 to 1975 the growth was linear. Since the ultimately recoverable resources are finite this trend suggests a gradual reduction in discovery rate so that cumulative discoveries will converge to the ultimately recoverable resource. A saturating law which fits the U.S. case well is

$$\frac{df}{dt} = \alpha f(1-f)$$

where

$$f = \frac{\text{cumulative discoveries}}{\text{ultimately recoverable resource}}$$

and

$\alpha \doteq$ initial exponential discovery rate when f is small.

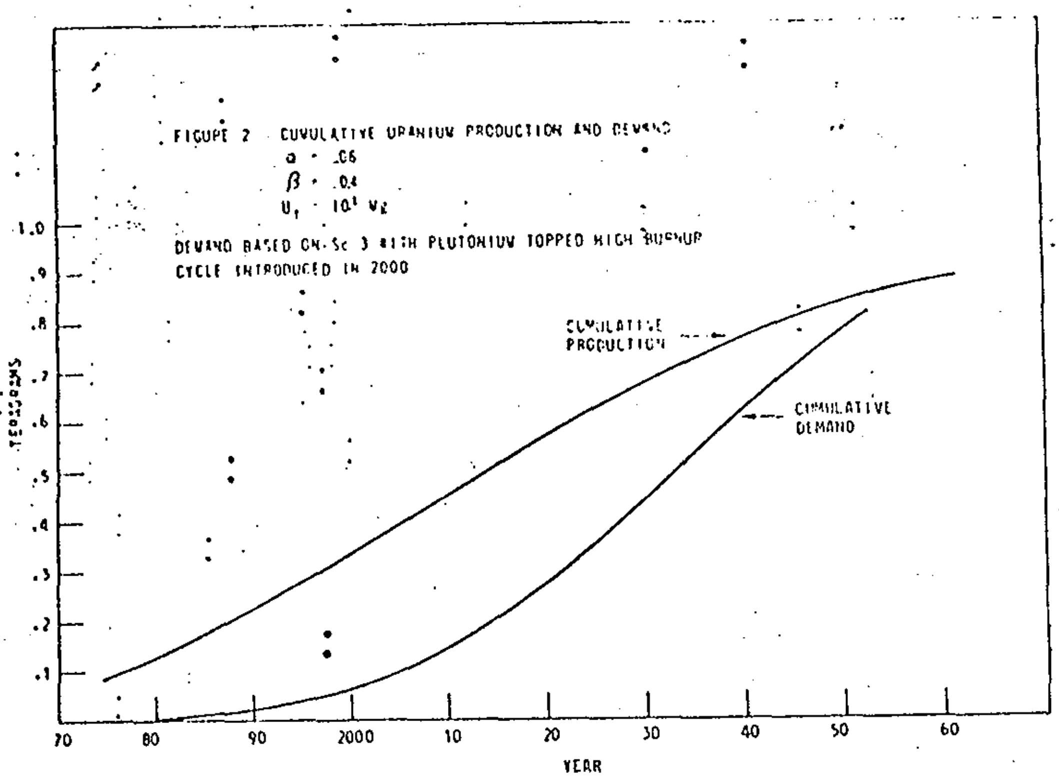
A similar picture probably applies to uranium. Initially when the discovery rate is low and improved prospecting techniques are being developed, the discovery rate will increase exponentially, reach a peak and eventually decline as more and more of the commercially interesting deposits are discovered.

As new mines are discovered, they will be exploited. Some will be developed rapidly and other larger lower grade deposits will be developed more slowly. Cumulative discoveries less cumulative production represents the reserves which are being exploited at any given time. The, ratio of annual production to these reserves represents what I will call the exploitation rate, β. This rate will depend on the type of mine, the ore grade, size of the deposit and other technical features of the deposits being exploited. Economic considerations suggest that a reasonable average for this ratio would be in the range of 4-6% representing roughly a 16-25 year forward supply of uranium.

These considerations form the components of the model. The parameter α is estimated from the initial discovery rate when cumulative discoveries are growing exponentially. The total recoverable resource is of course, not known. It is treated as a parameter. The discovery rate and exploitation rate are assumed to be constants. Thus, the annual production depends only on the technical capacity with no constraints due to demand or political considerations.

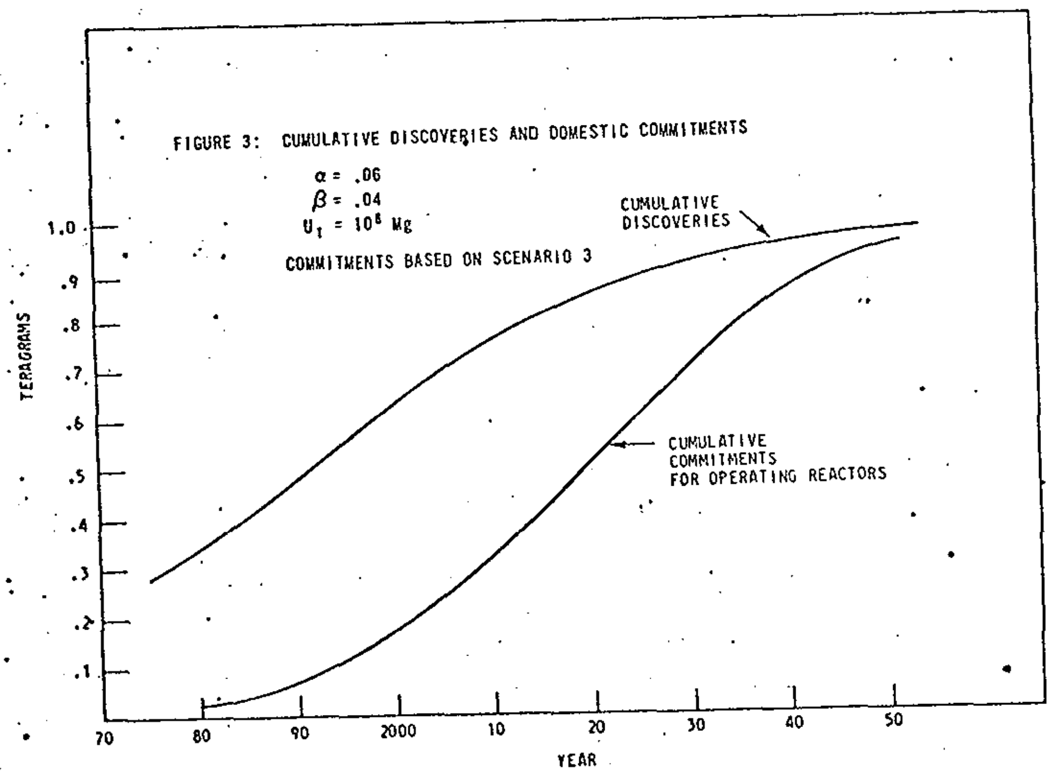
APPLICATION TO CANADA

Canada's Reasonably Assured Resources[5] increased by about 15% from the end of 1974 to June 1977. Allowing for production during the interval this represents an annual increase of about 6%. Continuation of this trend suggests that Reasonably Assured Resources would amount to about 210,000 megagrams in 1980. Cumulative production to 1976 was 112,000 megagrams and production to 1980 is expected to be about 130,000 megagrams. Estimated additional resources amount to 600,000 - 700,000 megagrams suggesting that something of the order of 1 million megagrams might be a reasonable estimate of the ultimately recoverable resources, U_T. Using these round numbers for initial values, cumulative uranium production can be calculated as a function of time. Results for particular values of α, β and U_T are compared in Figure 2 with the cumulative demand corresponding to that generated using scenario 3 from AECL-6202. A description of this scenario is given in the Appendix.

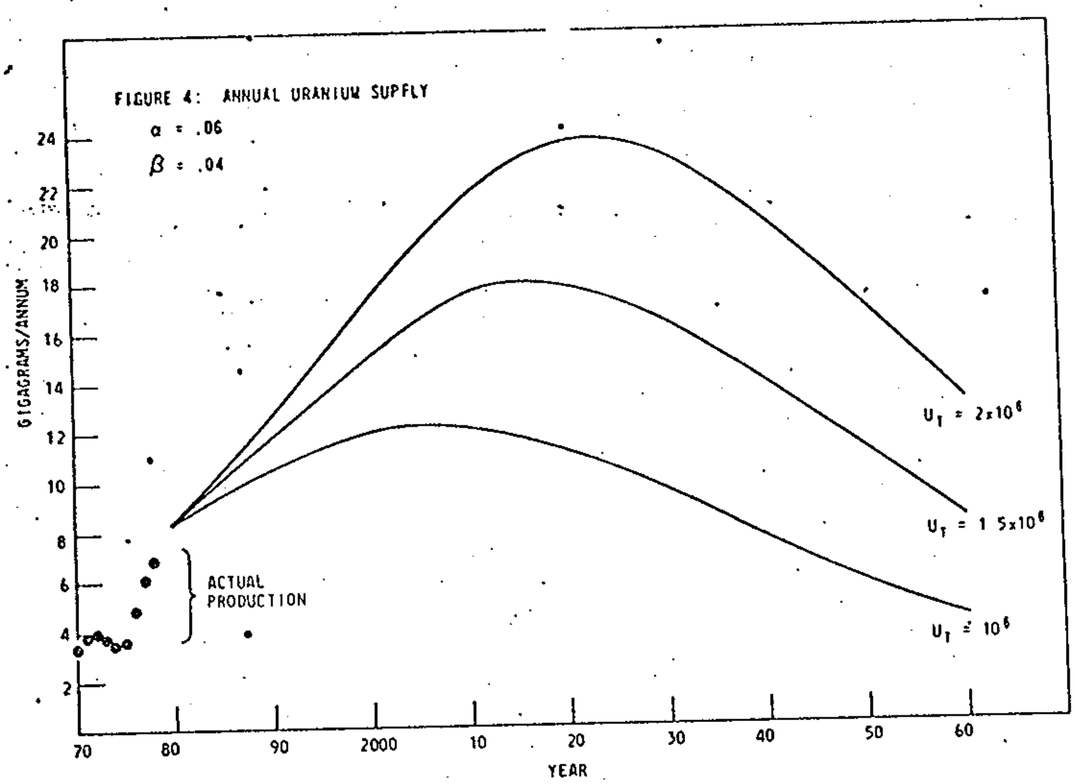


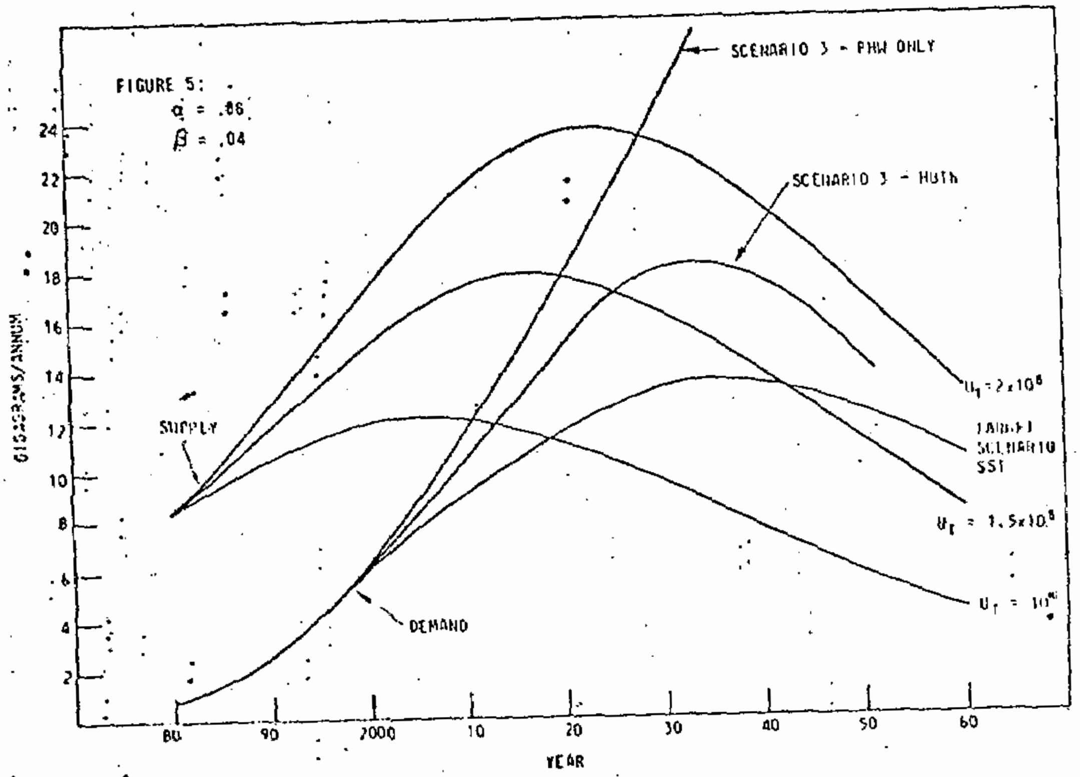
Cumulative production exceeds demand during the whole period, suggesting that an ultimately recoverable resource of about 1 million megagrams is quite sufficient to provide uranium for the domestic nuclear program envisaged in scenario 3 until about 2050.

Another way to make this comparison which has been used in the past is to compare recoverable uranium in the ground (equivalent to cumulative discoveries) with uranium commitments for operating reactors. This comparison is shown in Figure 3 and again the implication is that a resource of 1 million megagrams is adequate to satisfy the demands arising in scenario 3.



An important feature lacking in both these assessment methods is the timing of the uranium production. Figure 4 shows annual uranium production curves assuming a discovery rate of 6%, an exploitation rate of 4% for a range of ultimately recoverable resources varying from 1 to 2 million megagrams. The larger the ultimately recoverable uranium resource, the larger the annual production rate. Larger resources also lead to a more peaked production curve, with the peak occurring somewhat later in time. The production rate at the peak amounts to about 1.2% of the ultimately recoverable resource.





In Figure 5 some typical annual demand curves are superimposed on the supply curves of Figure 4. Initially, production exceeds domestic demand by a large margin and presumably this uranium could be exported. It would be uneconomic to stockpile the excess output for long periods of time. As the domestic nuclear program grows more uranium is required. The point at which the supply and demand curves cross represents the date at which Canada would need to begin importing uranium to supply the domestic nuclear program for the 3 scenarios shown. These dates are summarized in the table below

TABLE 1

DATE AT WHICH URANIUM IMPORTING BEGINS

Scenario (See Appendix)	Ultimately Recoverable Uranium 10^6 Mg	$1.5x10^6$ Mg	$2x10^6$ Mg
PHW only (Scenario 3)	2011	2020	2028
High Burnup Th (scenario 3)	2013	2025	Beyond 2050
Self Sufficient Th (Low Growth target scenario)	2018	2042	Beyond 2050

From Figure 5 it can be seen that introducing the thorium cycle in 2000 in scenario 3 will require an ultimately recoverable resource of more than 1.5 million megagrams. Since the supply and demand curves do not match, more uranium is required than one would have expected from Figures 2 and 3 - possibly almost a factor of 2 higher. The difference, of course, is due to exported uranium. Initially, large production excesses are exported, leading to the possible occurrence of later shortages. The benefit of the production model is that it gives some perspective to the timing of these possible future shortages. Of course, it is not expected that in real life the demand and supply will follow the smooth curves shown. However, these general trends are realistic. Initially uranium will be relatively easy to discover and produce. As more and more is used, commercially exploitable resources will become scarcer and the discovery rate will fall off. Production will peak and begin to decline. This trend can be countered to some extent by increasing expenditures on exploration and mine development. However, spending money will not create uranium deposits, the ultimately limiting parameter. A recent assessment of Canada's uranium supply and demand(6) suggests that speculative resources, which are additional to those classified in the measured, indicated, inferred and prognosticated category may amount to about 1 million megagrams. Thus the range shown in Figures 4 and 5 is probably realistic.

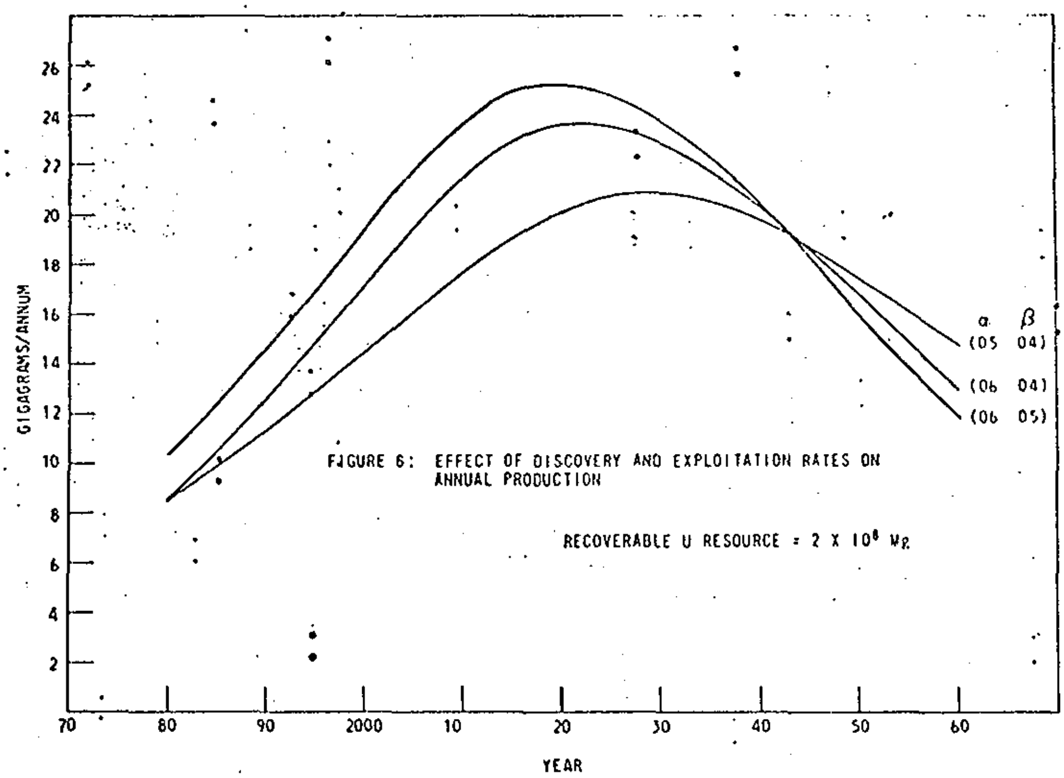


FIGURE 6: EFFECT OF DISCOVERY AND EXPLOITATION RATES ON ANNUAL PRODUCTION

Figure 6 shows the effects of varying the discovery and exploitation rates. Increasing the exploitation from 4% to 5% increases early production with a more rapid later decline. Increasing the discovery rate from 5% to 6% has the same effect. Figure 7 shows the effect of increasing the exploitation rate by 25% from 4% to 5% in 2030. In the period from 2030 to 2060, 44,000 megagrams more uranium is produced.

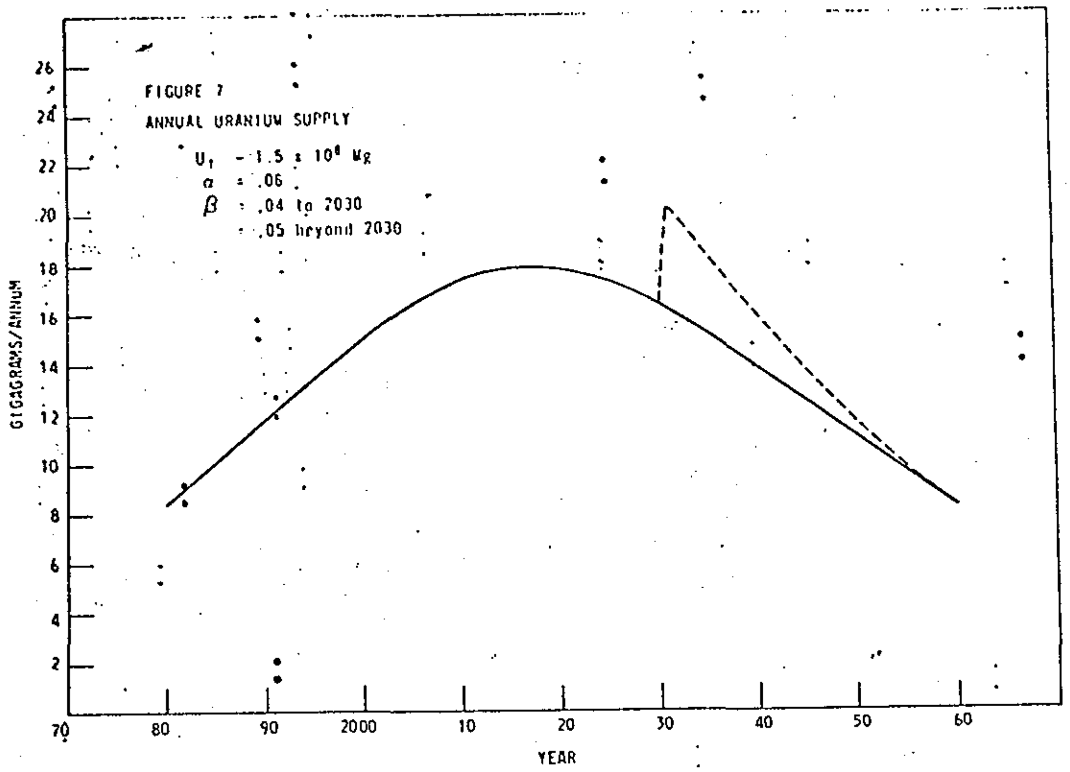


FIGURE 7
ANNUAL URANIUM SUPPLY

ECONOMIC CONSIDERATIONS

Nothing has been mentioned in the production model concerning economics. The price of uranium will depend on supply and demand. However, demand on Canadian resources will be international and therefore will depend on nuclear programs in foreign countries as well as in Canada. While it is difficult to predict the actual level of demand which will arise in the first part of the next century, it is unlikely that it will be affected significantly by commercialization of the fast breeder reactor, partly because of inertia in the electrical generating system. Converters will provide the bulk of the world's nuclear power well into the next century. Uranium demand at present and higher prices is therefore likely to continue.

Future costs of producing uranium are likely to increase gradually in real terms as a result of increased regulatory requirements, increased exploration expenditures, etc. Costs will also depend on ore grades and other technical aspects of ore bodies such as size, accessibility, etc. If the distribution of these characteristic is smooth one could expect a smooth escalation of costs. If, however, the distribution is irregular (which is the situation with gas and oil fields) one may be faced with sudden large jumps in exploitation costs.

Increases in prices due to scarcity are even more difficult to predict. Figure 5 suggests that scarcities may become apparent early in the next century. Because the cost of nuclear electrical energy is insensitive to the price of uranium, there may be a tendency for this price to increase rapidly early in the next century, even though the exploitation costs increase only gradually. We have already seen rapid increases in the petroleum price due to expected future scarcity.

These comments are not meant to serve as projections; they merely indicate that the fuel cycle costs of a given fuel cycle are far from being the only criterion on which to judge its economic desirability. Another way of saying this is that one should not expect progressive implementation of nuclear fuel cycles according to the fuel cycle costs. Probably of more importance is the length of time a fuel cycle can be expected to remain viable. Figure 5 suggests that fuel cycles giving the greatest reduction in uranium demand will be of most interest. Other factors affecting the choice of fuel cycle will be the cost of disposing of nuclear wastes and the effect of mining on the environment. For example, it may be cheaper to deal with low volume, highly concentrated wastes than with low concentrations of highly dispersed wastes.

DISCUSSION

The range of uranium resources, 1-2 million megagrams, used to calculate the curves in Figure 5 represent the best estimates it is possible to make at this time. However even the lower limit is far from assured, and the upper limit is estimated on the basis of very indirect information. It would not be prudent to base a power program on the high estimates.

Figure 5 suggests that system expansion based on Candu-PHW reactors using the natural uranium cycle will likely require importation of uranium early in the next century, possibly as early as 2010. Fuel supplies for reactors commissioned in the early 1980's could thus be affected. Under these circumstances it is impossible to predict the price of uranium and it would be highly desirable to have some alternative system which could provide a ceiling to this price. Ideally such a system should be available now since the full benefits of an alternative fuel cycle are not significant until the new system supplies a substantial part of the market. In Figure 5 important reductions in uranium consumption occur some 35 years after introduction of the new system.

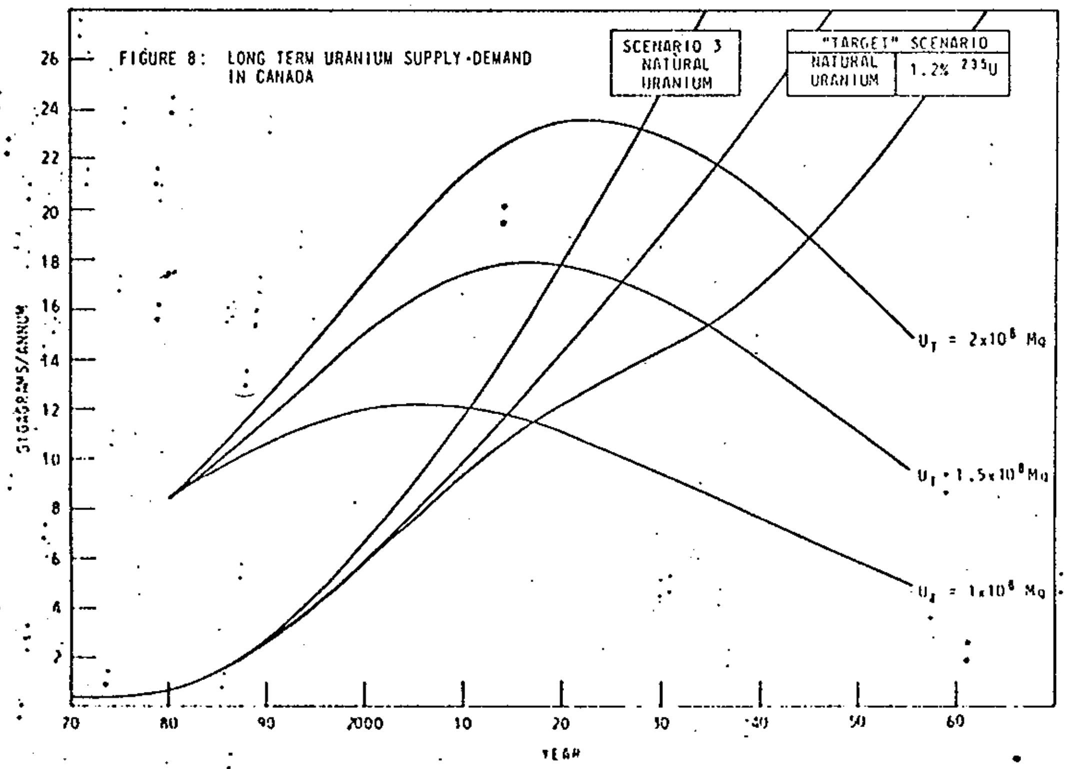


Figure 8 shows the effect of introducing a slightly enriched uranium (1.2% U235) cycle in 1995. For the low growth "target" scenario the effect of this introduction is most pronounced during the years 2015 to 2035. The postponement of the date at which uranium importation is required varies from about 2 years to 10 years, depending on the magnitude of the ultimate uranium resource. The effectiveness of this cycle would not be as large for a more rapid growth scenario.

SUMMARY AND CONCLUSION

This report has taken a preliminary look at the long term uranium supply-demand picture in Canada. These preliminary results suggest a wide range of dates at which demand will exceed supply, varying from 2010 to 2045. The later dates correspond, in my opinion, to an unrealistically low energy demand picture and an unrealistically high faith in the amounts of uranium to be discovered. Some alternative to the natural uranium fuel cycle is required if fission energy is to make a significant contribution to Canada's future energy supply. The decision to commercialize another fuel cycle must be taken many years before the date at which supply and demand are equal, possibly by as much as 40 years if the change is to be fully effective. Before any decision concerning commercialization can be taken, the fuel cycle technology must be in place. This is far from the case in Canada at the moment. Even though a much more thorough analysis is required, I believe this report demonstrates an extremely urgent need for development of advanced fuel cycle technology.

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6) Department of Energy, Mines and Resources: Report EP79-3: "1978 Assessment of Canada's Uranium Supply and Demand" (June 1979)

APPENDIX

Two total energy growth scenarios have been considered in this report. Both are conservative by historical standards. Scenario 3, with an average annual growth rate of 2.7% is well below the long term growth of energy use in Canada of about 3.8% per annum. The scenario referred to as the "Target Scenario" has a total energy growth rate of 2.7% until the year 2000 and 2% thereafter. It is called the "Target Scenario" to emphasize the fact that stated government policy is to limit growth to 2% per annum. This has not yet been achieved.

Figure A-1 shows the total nuclear installed power corresponding to these two growth scenarios. This is derived as follows.[1] The relative growth rates of electrical energy has been about 3% higher than the growth rate of total energy for many years. This penetration is continued with the asymptotic limit of 60%. That is, the fraction of primary energy sources devoted to electricity production will tend towards 0.6 in the future. At present the fraction is 0.3. Nuclear electricity penetrates the total electrical market with a penetration rate of 11% which fits the planned expansion to 1990 very well. Nuclear power is most suited to base load operations; it is assumed arbitrarily that nuclear electricity will tend asymptotically to provide 60% of the total electricity.

At present the commercial nuclear system in Canada consists of CANDU PHW reactors operating on natural uranium. In the future, it may be necessary to use more advanced fuel cycles. Several examples have been used in this report. Aside from the uranium consumption figures for a given advanced cycle, the two parameters of most concern are the date of commercial introduction and the penetration rate.

The scenarios in Figure 5 are labelled:

(1) Scenario 3 - PHW only. This is a continuation of present practice. No advanced fuel cycles are introduced and the installed nuclear power shown in Figure A-1 refers only to CANDU-PHW's operating on natural uranium. This scenario is the least demanding from a reactor design point of view, but the most demanding from the uranium supply point of view.

(2) Scenario 3 - H.B. Thorium. In this scenario the nuclear power in Figure A-1 is supplied by both natural uranium CANDU's and by CANDU's operating on the thorium cycle using plutonium to initiate and sustain the thorium cycles. The burnup is about 30 MW.d/kg H.E. The advanced cycle is introduced in the year 2000 with a penetration rate of 9%, reflecting the probability that commercialization of a system containing fuel processing and active fuel fabrication in addition to significant changes in reactor design will be more difficult technically than the present reactor system. In fact, the figure of 9% was chosen rather arbitrarily to limit uranium consumption to about 1 million megagrams by 2050 and is probably quite optimistic considering that there are institutional difficulties to overcome as well as technical ones.

(3) Target Scenario - SST. This is the most optimistic of the scenarios. A low energy growth has been selected and a more advanced thorium cycle has been introduced in the year 2000 with a penetration rate of 9%. The thorium cycle is introduced using plutonium. After initial start-up no further plutonium is required. This calls for a very high level of technical achievement which is unlikely to take place on the time scale shown but is included to provide a lower limit to the uranium demand.

Because of current interest, the low enriched uranium once through cycle has been chosen for special attention in Figure 8. The uranium enrichment is 1.2% giving a fuel burnup of about 20,000 MW.d/t and a reduction in mined uranium requirements of about 30%.

The three demand curves are labelled

(1) Scenario 3 - Natural Uranium - This is the same as the first curve described for Figure 5.

(2) Target Scenario - Natural Uranium - This curve compared to the first curve in Figure 8 shows the effect of reducing the total energy growth rate from 2.7% to 2% after the year 2000.

(3) Target Scenario - 1.2% U^{235} - This curve shows the effect introducing in 1995 the LEU cycle with a very high penetration rate - 25%. This high penetration rate was chosen to provide the greatest possible impact on uranium consumption. If there are few technical problems in reactor design and operation arising from this change in concept an early introduction and high penetration rate may be possible, since no processing is involved, and enriched fuel is commercially available.

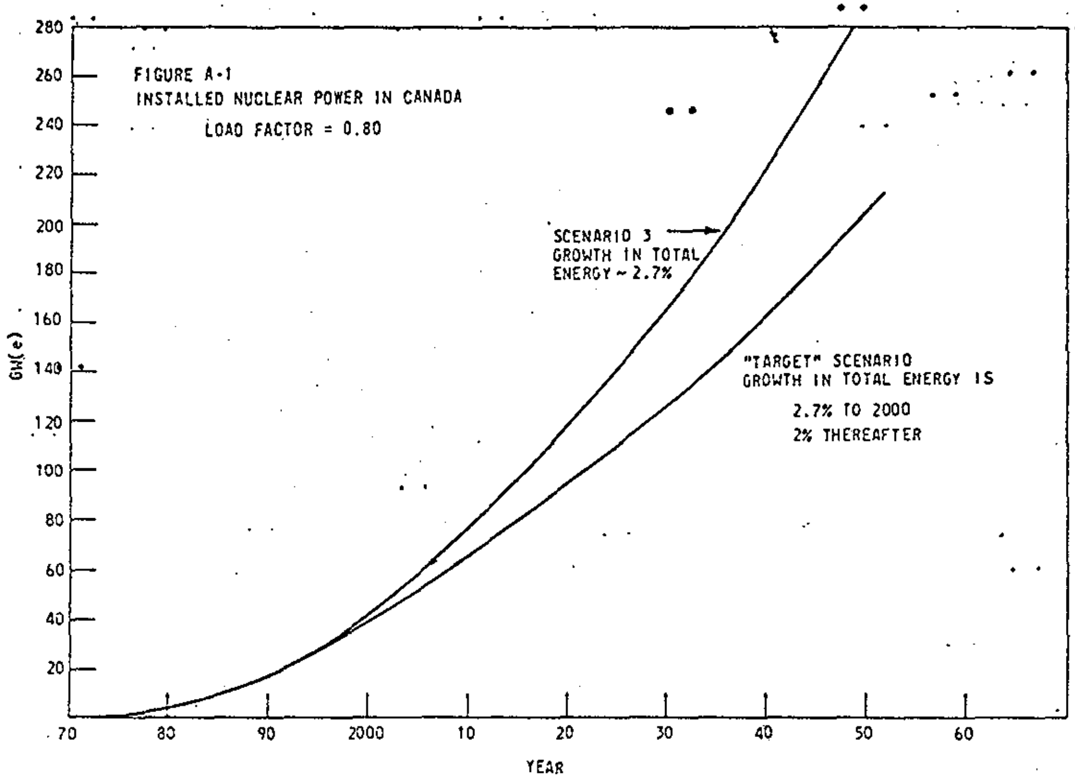

FIGURE A-1
INSTALLED NUCLEAR POWER IN CANADA
LOAD FACTOR = 0.80