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URANIUM RESOURCES AND REQUIREMENTS

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J.M. SILVER

W.J. WRIGHT

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ABSTRACT

The amount of uranium available to support the world's nuclear power programs depends on the price which users are prepared to pay for its recovery. As the price is raised, it is attractive to recover uranium from lower grade deposits, thereby increasing the total quantity available.

About 3.5 million tonnes of uranium is estimated to be available to the Western World in deposits which could be recovered for present day costs of less than $A30 per kilogram. This amount is believed to be sufficient to meet the nuclear power program until the turn of the century. There are good prospects for the discovery of further deposits (particularly in Africa, Canada, South America and Australia) which could extend these resources.

If the Fast Breeder Reactor is introduced by about 1990, it could ultimately decrease the demand for uranium from about 2020 onwards. The total amount of uranium required to support the Light Water Reactor power program until this happens would be about 7 million tonnes. On present evidence, this could be available from high grade deposits, together with some low grade deposits and by-product sources at costs less

continued

than $A60 per kilogram.

If the Fast Breeder Reactor is not introduced as expected, the dema for uranium will continue to increase and it could be necessary to recov uranium from black shales or ultimately from sea water at costs ranging up to $A300 per kilogram.

Australia has about 19% of the reasonably assured resources of uran in the Western World recoverable at costs of less than $A20 per kilogram or about 9% of the resources (reasonably assured and estimated additiona recov rable at costs of less than $A30 per kilogram. Australia's potent for further discoveries of uranium is good. Nevertheless, if Australia did not export any of these resources it would probably have only a marginal effect on the development of nuclear power; other resources wou be exploited earlier and prices would rise, but not sufficiently to make the costs of nuclear power unattractive. On the other hand, this policy could deny to Australia real benefits in foreign currency earnings, employment and national development.

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AUSTRALIA; COST; FORECASTING; GEOLOGIC DEPOSITS; MARKET; URANIUM; URANIUM ORES

CONTENTS

INTRODUCTION

The growing demand for nuclear power requires the development of uranium resources and the establishment of production facilities at all stages of the nuclear fuel cycle. Critics of nuclear power have argued that sufficient uranium resources might not be available for this program, and within a few years a position could exist similar to that with oil, where dwindling reserves are controlled by a few nations demanding high prices. The opposing argument sometimes put forward by the mining industry is that the market for uranium might only be short-lived because of the impending introduction of the Fast Breeder Reactor or the development of alternative resources such as fusion or solar power; the commensurate policy would therefore demand the development and sale of resources as soon as possible.

As is often the case, both of these views must be qualified. The purpose of this paper is to examine the possible requirements for uranium in the future and to relate these to the available resources. Since the paper looks to the future, any examination of the problem must be based on assumptions which might be questioned; the validity of these assumptions is an important part of the arguments which follow.

URANIUM IS WHERE YOU FIND IT - AT A PRICE

The amount of uranium available depends on the price which users are prepared to pay for its recovery. As the price is increased, there is an incentive to recover uranium from lower grade or more difficult deposits.

The world is not short of uranium for any conceivable nuclear power program if all constraints of price and technology are removed. Uranium is not a particularly rare element in the Earth's crust and it occurs at concentrations of 2-4 parts per million in most rocks. The total inventory of uranium in the world is therefore about 10^{13}-10^{14} tonnes, although this is obviously only recoverable at infinite cost and at the expense of considerable disruption to present lifestyles.

As more realistic limits are placed on the permissible costs of recovery, the available resources decrease dramatically.

By convention, uranium resources are quoted in international references as being available within cost* categories of $A20 per kg uranium

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* These costs must not be confused with the market prices. The costs do not include previous development costs or profits; they are marginal production costs. Prices are determined by market forces; the costs of production are only one of many factors which operate to determine prices.

($US10/lb.$U_3O_8$) and $A30 per kg ($US15/lb.U_3O_8). Table 1 shows the distribution of these resources between the major countries. The data are shown for two levels of confidence in the geological estimates. The amounts shown in the column headed 'Reasonably Assured Resources' have been well defined by drilling of the deposits and there is confidence tha these amounts could be recovered for the costs shown. The 'Estimated Additional Resources' are surmised to occur in unexplored extensions of known deposits or in unproved deposits in known uranium districts.

Thus, if a cost limit of $A20 per kg U is placed on the resources, about one million tonnes of uranium is almost certainly available and a similar amount is probably available. At a cost limit of $A30 per kg U, a further 650 000 tonnes is available and 850 000 tonnes is probably available. If these categories are combined, about 3.5 million tonnes of uranium could be available at reasonable costs of recovery at today's money values.

Included in these categories are some resources recovered as a by-product from gold and copper mining in South Africa. These resources would be in a higher cost category if they were not associated with the economic mining of the other minerals.

Beyond the cost limits of $A20-30 per kg U, some lower grade deposit which are already known, become economic to recover. These resources are of conventional uranium mineralisation (that is, with a similar composition and mineralisation to the resources discussed above) and are mostly adjacent to the minable ore bodies of higher grades. The USA is estimated to have 1.2 million tonnes of uranium available in these types deposits which could be recovered at a cost of $A30-60 per kg U; a simila amount (or more) is likely to be found in the rest of the world.

Obviously all the conventional deposits of uranium in the world have not been found, but how much more might be available in this class of dep is a matter for speculation. Of the major land masses, only the USA and Western Europe have been explored intensively and even there, new explora and new techniques of exploration and recovery, are expected to yield positive results. Africa, South America, Canada and Australia are still relatively unexplored and all are prospective for new discoveries of low cost ore. It seems evident, therefore, that given the incentive of reaso selling prices, new discoveries of conventional deposits will be made, at least equal to the amount presently defined.

At costs slightly above $A30 per kg U, uranium can be recovered from

TABLE 1

ESTIMATED WORLD RESOURCES OF URANIUM[1]

(tonnes uranium)

Country	Cost range to \$A20/kg U (\$US10/lb U_3O_8)		Cost range \$A20-30/kg U (\$US10-15/lb U_3O_8)	
	Reasonably assured resources	Estimated additional resources	Reasonably assured resources	Estimated additional resources
Australia[2]	184 000	32 000	60 000	46 000
Canada	185 000	190 000	122 000	219 000
France	37 000	24 000	20 000	25 000
Gabon	20 000	5 000		5 000
Niger	40 000	20 000	10 000	10 000
South Africa	202 000	8 000	62 000	26 000
Sweden			270 000	40 000
USA[3]	242 000	738 000	81 000	438 000
Other countries	53 000	52 000	26 000	47 000
TOTAL	963 000	1 069 000	651 000	856 000

(1) *Data for countries other than Australia and USA from 'Uranium - Resources, Production and Demand'. Joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency (Paris 1973). The NEA/IAEA report does not include estimates for the USSR, China and certain European countries.*

(2) *Data for Australia as at 30 June 1975. AAEC 23rd Annual Report (in press).*

(3) *Data for USA as at 31 December 1974.*

phosphate rocks as a by-product of soluble phosphoric acid production. The major deposits of uraniferous phosphates occur in the USA (Florida, Idaho and adjacent States), along the Mediterranean coast (Morocco), in Australia (Duchess, Lady Annie in Queensland), and in Brazil and the Central African Republic; typically these deposits contain 0.005-0.07% uranium. The total resource of uranium in phosphate rocks in the USA is at least 1 million tonnes and a similar amount (or more) could be available elsewhere in the world. Unfortunately, the uranium can only be recovered from that fraction of the rock which is treated to produce 'wet-process' phosphoric acid, rather than superphosphate, and this limits the rate of production which might be attained. On reasonable assumptions on the use of phosphoric acid as fertiliser, production of 2000-5000 tonnes of uranium per year appears feasible in the USA.

At costs ranging from $A100-300 per kg U, large reserves of uranium can be recovered from black shales which occur in the USA (Chattanooga shales), in Sweden and Greenland. These contain 0.01-0.03% uranium and constitute a total resource of at least 10 million tonnes.

In the same, or slightly higher, cost category, uranium may be recovered from sea water, which contains about 0.002 parts per million uranium or 2 milligrams per cubic metre; the total resource in this category is about 4000 million tonnes of uranium.

Table 2 summarises these resources in appropriate cost categories. Since the rates of production of uranium from by-product sources (copper, gold, phosphates) is limited, the main resource available in the event o further discoveries of conventional deposits would be the black shales, at a cost in excess of $A100 per kg U, followed by sea water at costs bel $A300 per kg U.

It is still arguable whether the recovery of uranium from such low grade resources as the black shales would be acceptable in terms of the other resources required for their recovery and the total environmental impact of mining these deposits. The 'energy content' of black shales (expressed as the amount of heat generated per tonne of shale if the contained uranium was used in thermal nuclear reactors) is comparable with that of coal, and enormous amounts of shale would need to be mined and treated each year to provide sufficient uranium for a nuclear power program. The strip mining of shales at this rate would therefore be subject to the same environmental constraints as in the mining of coal.

The economic impact on the reactor program of using these higher co

TABLE 2

ESTIMATED LOW COST AND OTHER URANIUM RESOURCES

Conventional Resources	Cost of recovery ($A/kg U)	Typical uranium concentration %	Resources available (millions of tonnes U)
Probable (explored areas)	<20	>0.10	2
	20-30	>0.05	1.5
	30-60	>0.03	2
Possible (future exploration)	<30	>0.05	2-3
	30-60	>0.03	2-3
Other Resources			
By-products (Copper, Gold)	<30	~0.03	0.3*
Phosphate rocks	30-50	>0.005	2*
Shales	100-300	>0.01	10
Sea water	<300	~0.02 ppm	4000

* *Production rate limited by main process stream.*

uranium resources is probably not sufficient to delay the program or to influence power utilities to use alternative energy resources as presently defined. An increase of $A1/kg U in uranium price might be reflected in an increase of 0.002 cents per kilowatt-hour in the cost of power from a nuclear station. An increase to $A100-300/kg U from present-day prices of about $A50/kg U would be unwelcome, but probably not totally unacceptable.

Nevertheless, the incentive remains for both environmental and economic reasons to continue to explore for higher grade deposits of uranium and these are likely to be the main resource to be utilised for the next 20-30 years at least.

ARE THESE RESOURCES SUFFICIENT?

Uranium has almost a single end-use, that is, as a fuel in nuclear reactors and this fact makes it relatively easy to calculate the future demand for uranium if the nuclear power program (and some technical features of the reactors involved) are known. These programs are usually established by power utilities some 5-8 years ahead of the requirement for uranium supplies, but predictive methods - with all their inherent errors -

must be relied upon in projecting these programs beyond this period.

The predictions given here are based on the following assumptions:

(i) Electrical energy consumption will continue to grow, allowing for increases in population, living standards, and a preference for the use of electricity over other forms of energy.

(ii) Beyond 1985, all new base load generating stations in the USA, Europe and Japan will be nuclear. At present, more nuclear than fossil-fired plant is being ordered in these areas because of their lower generating costs; by the year 2000, nuclear plant will represent about 60% of world electrici generating capacity.

(iii) The Light Water Reactor (LWR) will continue as the main type of nuclear power station to be installed for at least 20 years.

(iv) The Fast Breeder Reactor (FBR) will be generally introduced from 1990. The subsequent rate of installation will be such that 50% of the new capacity in the year 2000 will be met by FBRs.

On these assumptions, the estimated requirements for uranium in the Western World are as shown in Table 3. The 'standard' estimate relates to present national plans for future nuclear growth, while the 'low' estimate assumes that the developed countries experience a steady decreas in the rate of growth of electricity demand from the 7-9% for 1960-70 to 3.5% for 1990-2000.

TABLE 3

URANIUM REQUIREMENTS

(thousands of tonnes U)

	1975	1980	1985	1990	1995	2000
'Standard Estimate'						
Annual	20	57	115	175	245	280
Cumulative	20	216	670	1390	2455	3750
'Low Estimate'						
Annual	20	54	100	140	195	210
Cumulative	20	205	610	1210	2065	3080

Thus, to the year 2000, the Western World might expect to need 3.1-3.8 million tonnes of uranium.

If these numbers are compared with the resource estimates given in Table 2, it could be reasonably argued that sufficient conventional resources are already known to be available to satisfy requirements to the end of the century, which is a lead time of about 25 years. When the prospects for discoveries of new conventional deposits are considered, plus the contribution from by-product sources and the availability of low grade resources such as shales and sea water, the reserves situation appears to be adequate for the proposed program until well into the next century.

The situation is summarised in Figure 1, which shows the cumulative demand and supply position, and the dates at which each resource level would be exhausted if used exclusively and without allowing for further resource additions.

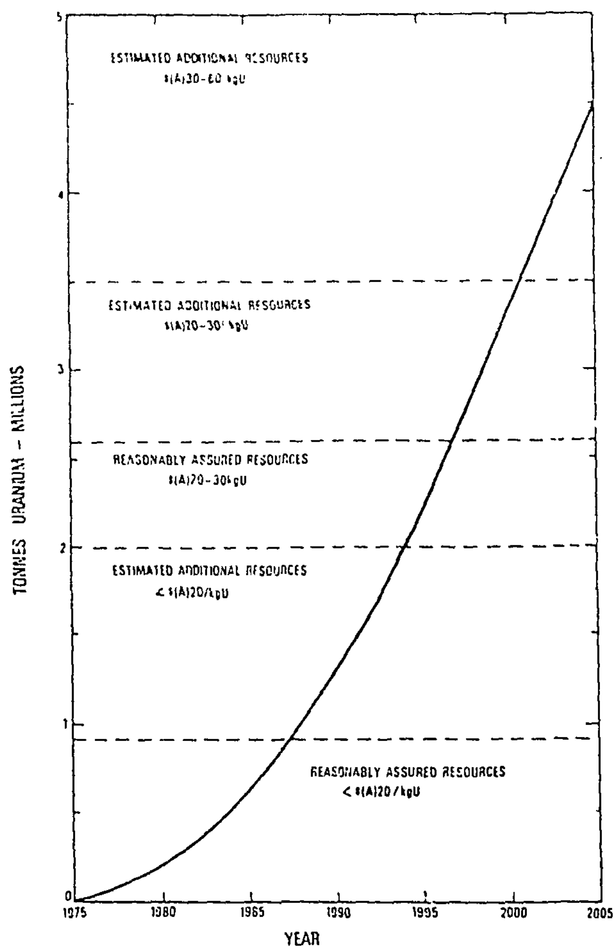

FIGURE 1. CUMULATIVE WORLD URANIUM REQUIREMENTS AND RESOURCES

Obviously, various countries will expect to exhaust their resources at different times according to their pattern of supply and demand. The USA in particular, which accounts for nearly half of the Western World's consumption, is likely to run out of low cost resources during the 1980s and will therefore need to turn to higher cost resources or imports to satisfy demand.

THE ELUSIVE MARKET

What then of the opposing argument, that Australia should hasten the development of its resources before the market fades?

The argument usually hinges on the fact that the introduction of the Fast Breeder Reactor could quickly end the demand for uranium. In principle, FBRs do not need any new uranium feed, since they could operate on the plutonium produced in first generation Light Water Reactor (LWRs) such as the Pressurised Water Reactor (PWR) and Boiling Water Reactor (BWR). The FBR could also produce more plutonium than it consume by 'breeding' plutonium from depleted uranium which is the 'tails product from uranium enrichment.

On the assumptions for reactor programs given previously, including the introduction of FBRs, the demand for uranium will continue to increas at least until 2010-2020. A decrease in the rate of growth of the market could be apparent soon after the year 2000 and there could be a decrease in absolute terms beyond 2020.

Assuming the introduction of the FBR in this manner, the total amoun of uranium required to supply the LWR program to 2000, including the amou required to support these reactors over their operating lifetime of 25-30 years (i.e. up to 2030 in some cases), would be about 7 million ton and Table 2 shows that this quantity could be available from conventional resources.

If the FBR or other alternative forms of energy conversion fail to become economic over the next 50 years, then uranium consumption would continue to increase. In this case the low cost resources could become exhausted beyond 2020 and it might be necessary to exploit the shales anc sea water. These very low grade resources contain sufficient uranium to service thermal nuclear power for several hundred years.

HOW IMPORTANT ARE AUSTRALIA'S RESOURCES OF URANIUM?

Australia possesses about 19% of the reasonably assured low cost resources of uranium available in the Western World (Table 2) or about 9% of the total conventional resources below a cost of $A30 per kg U.

It might be expected that these resources could be increased significantly through exploration programs planned for the next few years.

Nevertheless, if Australia did not export any of these resources, this would probably have only a marginal influence on the overall resource picture. If these resources are excluded from Figure 1 for example, the date of exhaustion of the Western World's resources is brought forward, but not sufficiently to upset the conclusions reached earlier on the availability of uranium to support the nuclear power program. In the short term, the withholding of Australia's resources from the market would probably increase selling prices (not costs) because it would increase competition for the available materials and it would provide opportunities for some producers to expand their share of the market. The net gain (in financial terms) of such a move would be felt overseas through the increased prices and a larger market for suppliers other than Australia.

The alternative strategy of allowing the export of uranium could provide benefits to Australia in foreign currency earnings, employment and national development. To quantify these benefits, estimates must be made of the possible market which could be achieved and of the costs, revenues and employment which might be involved.

The estimates of markets, which have been examined in detail by the Australian Atomic Energy Commission, are confidential at this stage since their publication could prejudice future commercial negotiations. However, if a broad view is taken of the world market for uranium by 1985, and related to the resources and capacity to expand production in other countries, the Australian share of the market by that date could be sufficient to require commitment of yellowcake plants on all major deposits of uranium as presently defined. In addition, it could be possible (and desirable) to install plants for the conversion of yellowcake into natural uranium hexafluoride and for its subsequent enrichment, so that by the mid-1980s, Australia has a proportion of sales being effected as upgraded products, with increased benefits.

If the Australian uranium industry were to be developed in this manner to satisfy 15-20% of the world market (which is commensurate with the state of the presently defined resources), then by 1985:

(i) The uranium industry could be earning about $3000 million per year at *projected prices* or about $1000 million per year in current (1975) money values. These values should be compared with the current earnings from wool exports of about $800 million, or mineral exports of about $2500 million.

(ii) The uranium industry could be employing about 2300 people *directly* and probably supporting a similar number of people in the provision of consumables and operating services.

(iii) A labour force of 3000-3500 would be engaged in construction projects in the industry for the decade 1980-90. The indirect labour required in other industries to support these construction projects would be at least 3000 people.

(iv) The construction of these plants would require about $1750 million (in 1975 money values) to be spent by 1985; most of this money would be spent in Australia and would therefore provide employment and growth.

(v) The wages bill in the industry could be about $100 million per year, equivalent to about $35-40 million in 1975 money values.

The uranium industry has the potential to contribute to the Australian economy on a scale which probably exceeds that of any other single development. By the mid-late 1980s it could be one of our most important mineral exports in terms of overseas earnings and could be earning considerably more than the wool (or wheat) industries at that time. Further, the industry could provide employment for 8000-10 000 people in total by 1985 which, although much smaller than the number employed in the wool industry, would provide a significant increase in labour productivity.

CONCLUSIONS

1. Between 1975 and 2000, the Western World might require 3.1-3.8 million tonnes of uranium and this amount is estimated to be available in conventional ore bodies and recoverable at present-day costs of less than $A30 per kg U.

2. The general introduction of the Fast Breeder Reactor from about 1990 onwards should reduce the annual demand for uranium at some time after 2020. Allowing for the operation of Light Water Reactors and Fast Breeder Reactors from 1975 to about 2025, the cumulative demand for uranium might be about 7 million tonnes, and this amount is estimated to be available from conventional (including low grade) deposits at present day costs of less than $A60 per kg U.

3. If the Fast Breeder Reactor is not introduced as expected, and alternative sources of power such as fusion or solar energy are not developed, the demand for uranium would continue to increase during the

next century. This would exhaust low cost conventional resources and require the recovery of uranium from shales and/or sea water at costs of $A100-300 per kg U.

4. It follows therefore that adequate resources are available to the Western World on which to base the projected nuclear power program, although at progressively higher cost.

5. The market for uranium will continue to grow at least for the next 20-30 years; there is no substantial argument to suggest that the market will diminish until well beyond 2000.

6. Australia's influence on the market, as measured by its resources, is small. The withholding of Australia's resources from development would not greatly influence the resource projections for the Western World, but it could deny Australia real benefits in foreign currency earnings, employment and national development.

GLOSSARY

The following definitions are provided for the reader not familiar with some nuclear and other terms used in this paper. The explanations are drawn from standard glossaries.*

breeder	A reactor which produces more *fissile* material than it consumes. *Fertile* material included in the core is transformed into *fissile* material by *neutron capture*.
depleted (material)	Reduced in concentration of one or more specified isotopes in a material or in one of its constituents; *depleted uranium* is uranium whose uranium 235 concentration has been reduced.
fast reactor	A reactor in which *fission* is induced predominantly by *fast neutrons*, that is, neutrons moving at high speeds; whence *fast breeder reactor*.
enrich	To increase the abundance of a particular *isotope* in a mixture of the *isotopes* of an element; whence *enrichment*, *isotope enrichment*.
fusion	The process of building up more complex nuclei by the combination, or fusion, of simpler ones. This is usually accompanied by release of energy.
hexafluoride	The gaseous compound uranium hexafluoride (UF_6), used in diffusion and centrifugal uranium enrichment plants. (Abbreviated 'hex'.)
tailings, tails	The rejected portion of an ore in mineral processing; waste; the tails product from uranium enrichment is *depleted uranium*.
thermal neutron	A neutron in thermal equilibrium with its surroundings. At room temperature it has low energy and slow velocity; whence *thermal fission* (caused by thermal or slow neutrons), *thermal nuclear power*.
yellowcake	The uranium oxide concentrate produced by a uranium treatment plant.

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