Trends in Uranium Supply

by Maurice Hansen

INTRODUCTION AND HISTORY

Prior to the development of nuclear power, uranium ores were used to a very limited extent as a ceramic colouring agent, as a source of radium and in some places as a source of vanadium. Perhaps before that, because of the bright orange and yellow colours of its secondary ores, it was probably used as ceremonial paint by primitive man. After the discovery of nuclear fission a whole new industry emerged, complete with its problems of demand, resources and supply. Spurred by special incentives in the early years of this new nuclear industry, prospectors discovered over 20 000 occurrences of uranium in North America alone, and by 1959 total world production reached a peak of 34 000 tonnes uranium from mines in South Africa, Canada and United States.

This rapid growth also led to new problems. As purchases for military purposes ended, government procurement contracts were not renewed, and the large reserves developed as a result of government purchase incentives, in combination with lack of substantial commercial market, resulted in an over-supply of uranium. Typically, an over-supply of uranium together with national stockpiling at low prices resulted in depression of prices to less than $5 per pound by 1971. Although forecasts made in the early 1970's increased confidence in the future of nuclear power, and consequently the demand for uranium, prices remained low until the end of 1973 when OPEC announced a very large increase in oil prices and quite naturally, prices for coal also rose substantially.

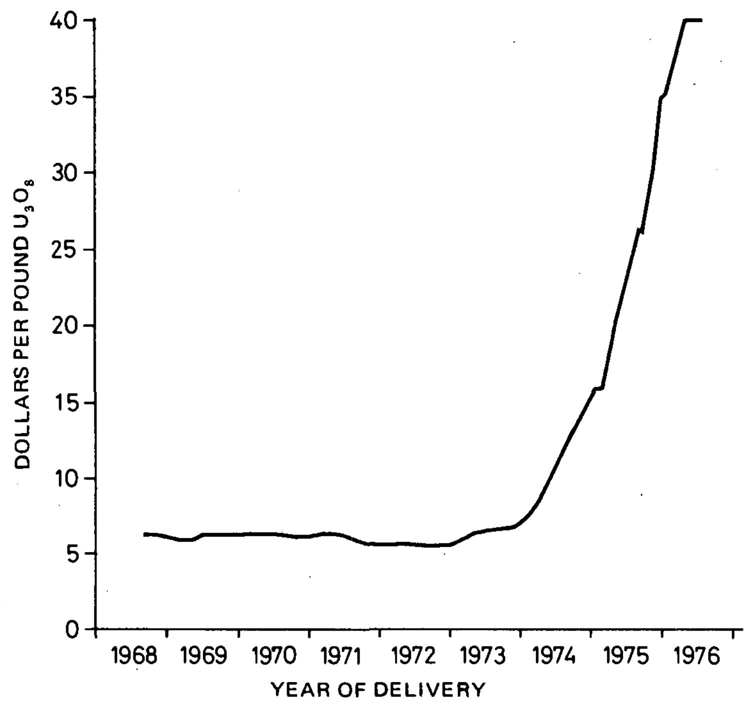
The economics of nuclear fuel immediately improved and prices for uranium began to climb in 1974. But the world-wide impact of the OPEC decision also produced negative effects on the uranium industry. Uranium production costs rose dramatically, as did capital costs, and money for investment in new uranium ventures became more scarce and more expensive. However, the uranium supply picture today offers hope of satisfactory development in spite of the many problems to be solved.

URANIUM RESOURCES

The future demand for uranium fuel is expected to reach a cumulative total of 2 to 3 million tonnes uranium by the year 2000. The supply of uranium fuel to meet this demand will be drawn from uranium resources and its assessment depends on estimates of production capability, market fluctuations, political factors and conversion of undiscovered resources into reserves. In fact, the recent skyrocketing price of uranium (Figure 1) makes the assessment of uranium resources more difficult because of vastly changed financial and operational parameters.

Mr. Hansen is a member of the Nuclear Materials and Fuel Cycle Section, Division of Nuclear Power and Reactors.

Figure 1: Historical Exchange value for U_3O_8 for immediate delivery



From Nuclear Exchange Corporation

Uranium resources are divided into "reasonably assured resources", which for the purposes of this report can be equated with reserves, and "estimated additional resources". Each of these categories are further broken down by cost-of-production: less than $15 per pound U_3O_8, and $15 to $30 per pound U_3O_8. (These values refer to the purchasing power of the US $ as of 1 January 1975.) Prior to 1975, the categories were based on selling prices; since then the figures represent the cost of production. (Canadian resources are based on selling prices, but for the purpose of most reports, Canadian resources can be compared to other resources based on cost.)

REASONABLY ASSURED RESOURCES

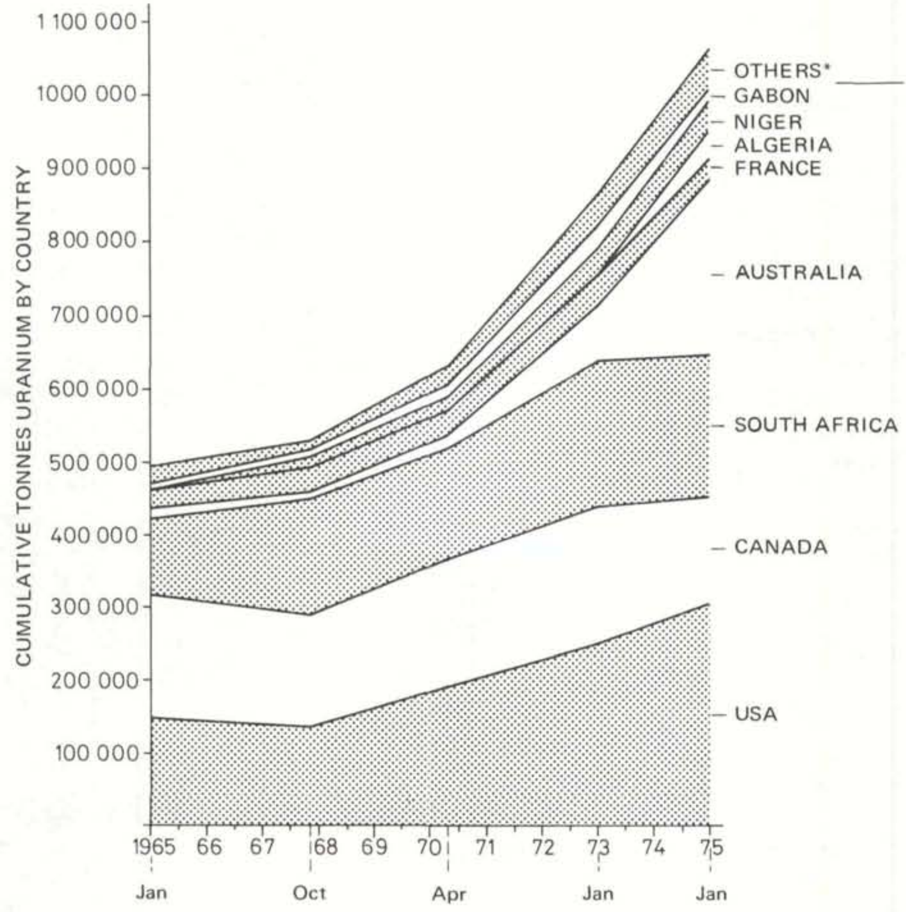
Table 1 shows reasonably assured resources reported by the joint NEA/IAEA Working Party since 1965. Reasonably assured resources are in known ore deposits of such grade, quantity and configuration, based on specific sample data and measurements and knowledge of ore body habit, that they could be recovered within a given production cost range with currently proven mining and processing technology.

Table 1: Reasonably Assured Resources of Uranium

Country	1965 Less than $10/lb	1967 Less than $10/lb	1970 Less than $10/lb	1973 Less than $10/lb	1975 Less than $15/lb
	TONNES U				
Algeria					28 000
Argentina	3 800	6 900	7 700	9 200	9 300
Australia	12 000	8 200	16 700	71 000	243 000
Brazil			800		9 700
Canada	162 000	154 000	178 000	185 000	144 000
Central African Republic			8 000	8 000	8 000
Congo	4 600	4 600			
Denmark (Greenland)				5 600	
Finland					
France	28 000	35 000	35 000	36 600	37 000
Gabon	3 800	3 100	10 400	20 000	20 000
Germany (Federal Republic)					500
India					3 400
Italy		1 200	1 200	1 200	1 100
Japan			2 100	2 800	
Korea					
Mexico			1 000	1 000	5 000
Morocco	4 600	4 600			
Niger		9 000	20 000	40 000	40 000
Portugal	5 400	7 000	7 400	6 400	6 900
South Africa	108 000	158 000	154 000	202 000	186 000
Spain	8 000	8 000	8 500	8 500	10 000
Sweden					
Turkey				2 200	2 600
United Kingdom					
United States	150 000	138 000	192 000	259 000	320 000
Yugoslavia				6 000	4 200
Zaire				1 800	1 800
Others*	3 800	3 800	2 800		
Totals	494 000	541 400	645 600	866 300	1 080 500

* F.R. Germany, Italy, Turkey, Yugoslavia. Primarily for years these countries were not reported separately.

Figure 2: Relative Growth of Reasonably Assured Uranium Resources
(NEA/IAEA Joint Working Party on Uranium Resources)



* Others: Argentina, Brazil, Central African Republic, Congo, F.R. Germany, Denmark (Greenland), Spain, India, Italy, Japan, Morocco, Mexico, Portugal, Yugoslavia, Zaire.

It should be pointed out that for the first four reporting periods (viz. 1965–1973), the reasonably assured resources are at a cost of US $10 or less per pound. Because of the rapid rate of inflation in recent years, the NEA/IAEA Working Party in their December 1975 report concluded that the resources at less than $15 per pound U_3O_8 are probably equivalent to those reported at $10 or less in previous reports.

Figure 2 shows graphically the information contained in Table 1. Several countries have shown minor increases in reasonably assured resources during the 11 year period, but the most dramatic increase has occured in Australia. Uranium resources in the USA have shown

Table 2: Estimated Additional Resources of Uranium

Country	1965 Less than $10/lb	1967 Less than $10/lb	1970 Less than $10/lb	1973 Less than $10/lb	1975 Less than $15/lb
	TONNES U				
Algeria					
Argentina	12 000	16 000	17 000	14 000	15 000
Australia		2 300	5 100	78 500	80 000
Brazil			800	2 500	8 800
Canada	223 000	223 000	177 000	190 000	324 000
Central African Republic			8 000	8 000	8 000
Congo					
Denmark (Greenland)				10 000	
Finland					
France	22 000	15 000	19 000	24 300	25 000
Gabon		2 700	5 000	5 000	5 000
Germany (Federal Republic)					1 000
India					800
Italy					
Japan					
Korea					
Mexico					
Morocco					
Niger		10 000	29 000	20 000	20 000
Portugal	2 300	5 000	6 000	5 900	
South Africa		16 000	11 500	8 000	6 000
Spain					8 800
Sweden					
Turkey					400
United Kingdom					
United States	250 000	250 000	390 000	538 000	500 000
Yugoslavia				10 000	
Zaire				1 700	1 700
Others*	15 000	15 000	8 500		
Total	524 300	555 000	676 900	915 900	1 004 500

* F.R. Germany, Italy, Turkey, Yugoslavia during those years when their resources were not listed separately.

a fairly steady increase, while those in Canada and South Africa have remained more or less even. It should be noted that Algeria was added to the list of countries with uranium resources in 1975.

ESTIMATED ADDITIONAL RESOURCES

Estimated additional resources are believed to occur in unexplored extensions of known deposits or in undiscovered deposits in known uranium districts. Such deposits can be reasonably expected to be discovered and mined in the given cost range. The quantities of estimated additional resources, however, are based primarily on knowledge of the characteristics of deposits within the same districts and are less accurate than estimates of reasonably assured resources.

Table 2 shows estimated additional resources reported during the same period as Table 1. Only about one million tonnes uranium are predicted to be found within these parameters.

RESOURCES AT HIGHER COSTS

Uranium resources were also reported to the NEA/IAEA Working Party at costs of $15 to $30. Within this increment, the reasonably assured resources totalling 730 000 tonnes uranium are primarily estimated from a relatively small amount of data developed while exploring for lower cost resources. Estimated additional resources in this cost increment total 680 000 tonnes uranium.

RESOURCES ESTIMATED FROM GEOLOGICAL INFORMATION

In addition, the USA and Canada have started programmes to determine the uranium potential of regions where the geological conditions may be favourable for uranium deposits. Because of the nature of the estimates, quantities estimated on the basis of the data available may be several orders of magnitude less accurate than either reasonably assured or estimated additional resources.

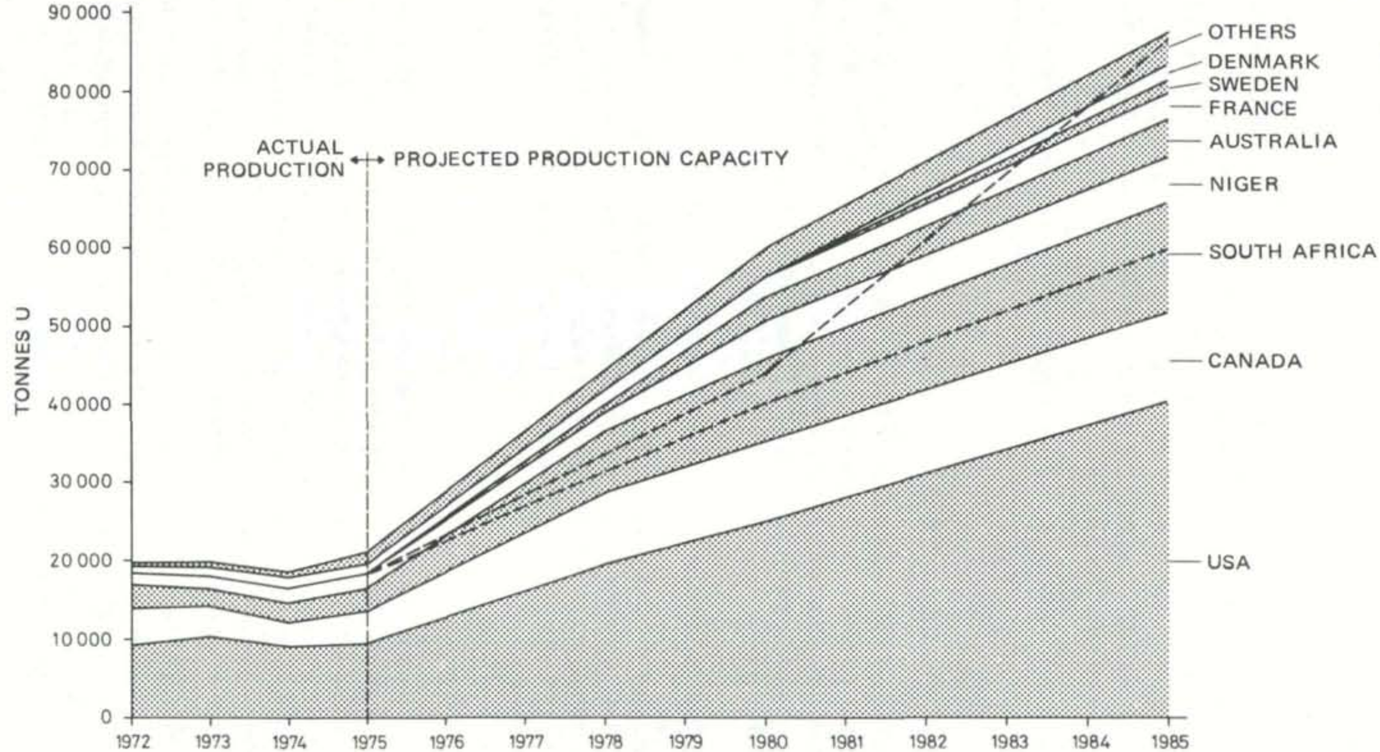
SUPPLY TRENDS

"Trends" is not really a very good word to use because it implies a history from which projections can be made. This is hardly true for uranium. In its early years, uranium was produced to fulfill primarily military needs in a market environment which was virtually artificial. In the USA in addition to a base price, production and grade bonuses were paid, an allowance was paid for mine development, haulage was paid for distances up to 100 miles and even further on special contracts, and special allowances were made for construction of ore processing plants. Under such conditions, naturally there was an available supply.

But those conditions do not exist any more. The market is virtually entirely commercial. Prices are set not by government needs but by the buyer and seller in the market place, and as has already been pointed out for spot sales in Figure 1, this environment appears to be somewhat poorly defined, especially when one considers prices paid for long-term contract delivery of yellowcake in 1976 ranged from a low of $7.10 to $32 per pound.

In consideration of the early artificiality of the government-controlled uranium market and the apparent instability of its recent commercial past, it would be erroneous to refer to a uranium supply "trend" in a future context. Only a generality about the past can be

Figure 3: Recent Uranium Production Rates and Projected Capacities



——— Production Capacity

- - - - - Uranium Requirements (Highest estimate without Pu or U recycling, lowest estimate with Pu and U recycling in 1981)

Others: Argentina, Gabon, Federal Rep. of Germany, Italy, Japan, Mexico, Portugal, Spain, Yugoslavia expressed — when a market existed, a supply existed. Therefore, in a further context, the projected demand and possibilities of fulfilling that demand are practically the only tools available to define supply trends. The future supply of uranium depends not only on the availability of uranium reserves, but also upon the rate at which resources can be brought into production.

Table 3 lists the rates at which various countries reporting to the NEA/IAEA Working Party have estimated expansion of their uranium production capacities up to 1985. Figure 3 is an expression of these data in graphic form in order to show the estimated expansion by country relative to each other and to the total. Also shown in Figure 3 are the high and low requirements estimates. The upper requirements line is the high estimate without uranium or plutonium recycle while the lower line represent the low estimate with uranium and plutonium recycle beginning in 1981.

Cumulative requirements through 1985 range from 513 000 to 594 000 tonnes uranium. Thus it may be concluded that reasonably assured resources will be sufficient until at least 1985 and that in all likelihood planned expansion of production capacity of uranium-ore-processing plants will assure an adequate supply. The increase from 26 000 tonnes annual capacity in 1976 to 87 000 tonnes in 1985 is an increase of slightly over 300% — a challenging but not impossible task. But what about the period after 1985? What problems will have to be solved? What will be the restrictive factors on the supply of uranium?

First, the availability of resources should be questioned. At first glance (Table 1), it would appear that reasonably assured resources at less than $15 per pound U_3O_8 will be adequate until the late 1980's and the addition of the resources in the $15 to $30 cost increment would stretch supply to the mid 1990's. But this is not necessarily the case. Even though there appears to be an adequate quantity of uranium in ore reserves, the physical limitations of size, shape and depth of an ore body impose restraints on the optimal mining rates. For instance, although the conglomerate deposits in Canada are very large, they will not be mined out until well into the next century because of physical limitations to increasing the scale of operation. Therefore, these ore reserves will not contribute to a rapid increase in uranium supply. The production of uranium from gold ores in South Africa is absolutely limited by the rate at which the gold is mined. (This would also be a limiting factor in uranium as a by-product from phosphate or copper).

These restraints clearly indicate that more resources must be discovered and brought into production if the requirements beyond the late 1980's are to be fulfilled. This takes time — usually about 10 years — between beginning of the search for uranium and production of concentrate. This lead time is by no means fixed. It consists of various activities of varying lengths as shown in Figure 4. The various phases of geologic studies, exploration drilling, development drilling, mine development and plant construction must be carried out before uranium supplies become available from a new discovery. This of course assumes that a new discovery is made. Normally, unless a geologist possesses supernatural powers — and I don't know any who do — each search for uranium covers many thousands of square kilometres even before the possibility of a discovery can be determined. The search process, of course, involves a lot of land. It has been estimated that about 15% of the land surface of the earch has been explored for uranium. It might be safe to guess that an additional 20% is probably geologically uninteresting at present, about 10% would present serious logistical problems with presently known surface exploration and mining methods, perhaps 15% more is urban or agricultural land which would present special problems in exploration

Table 3: Uranium Production Capacities

Countries	Existing 1974	Planned 1975	Planned 1978	Projected* 1980	Attainable* 1985	
	TONNES U/YEAR					
Argentina	46	60	120	600	720	
Australia	–	–	760	3 260	5 000**	
Canada	4 600	6 500	8 500	10 000	11 500	
Denmark	–	–	–	–	1 000–1 500	
France	1 800	1.800	2 200	3 000	3 000–3 500	
Gabon	800	800	1 200	1 200	1 200	
Germany (Fed. Rep.)	250	250	250	250	250	
Italy	–	–	–	120	120	
Japan	30	30	30	30	30	
Mexico	–	–	210	320	1 000	
Niger	1 200	1 200	2 200	4 000	6 000	
Portugal	90	115	130	130	300	
South Africa	2 700	2 700	9 200	11 250	13 800	
Spain	60	144	340	680	680	
Sweden	–	–	–	–	1 300	
United States	13 500	12 000	19 000	25 000	40 000	
Yugoslavia	–	–	–	120	180	
						Total Requirements 2000***
Total (rounded)	25 100	25 600	44 100	60 000	87,000	200 000 300 000

* Market conditions permitting.

** Production could be further expanded depending on the future growth of the uranium market

*** Lowest estimate includes uranium and plutonium recycling beginning 1981. Highest estimate is without either uranium or plutonium recycling.

and mining, and perhaps around 15% is politically uninteresting. The remaining 25% is probably geologically interesting, politically and environmentally available, and logistically accessible. The remainder, including the areas already explored, may eventually be the target of further exploration effort and new discoveries.

Second, the exploration and development of uranium during the rest of the century will require an estimated 10 to nearly 20 thousand million dollars. Investment in uranium exploration must be as commercially attractive as investment in any other mineral commodity, therefore, in order for the necessary capital investment to be made, there must be some assurance that a demand for uranium will exist. In addition, there must be some idea of what the annual demand will be, and that there is a reasonable chance that new uranium deposits will be discovered. Thus, it becomes increasingly urgent that world uranium potential resources be assessed as soon as possible.

The problem of the amount of money needed, though great, is within the capability of the industry to solve. For instance, there have been in recent years several arrangements by which the consumer has assisted the producer through long term contracts for future deliveries. Such an arrangement assures a market and long term financing, by direct participation, through joint ventures, in exploration projects and by prepayment for uranium before it is produced.

Third, we cannot ignore a growing tendency of uranium producing nations to control the extent of foreign investment in uranium, as in Australia and Canada, nor can we ignore the possibility that others may limit or prohibit accesss to explore for or develop uranium resources within their borders. Uranium resources have always been regulated by governments to some extent, and the willingness or unwillingness of sovereign nations to allow development of their uranium industries can make very large differences in the world supply of uranium. There is not really much the industry can do to protect itself from adverse decision by governments, beyond constant market analyses which include likely or possible changes in government restrictions.

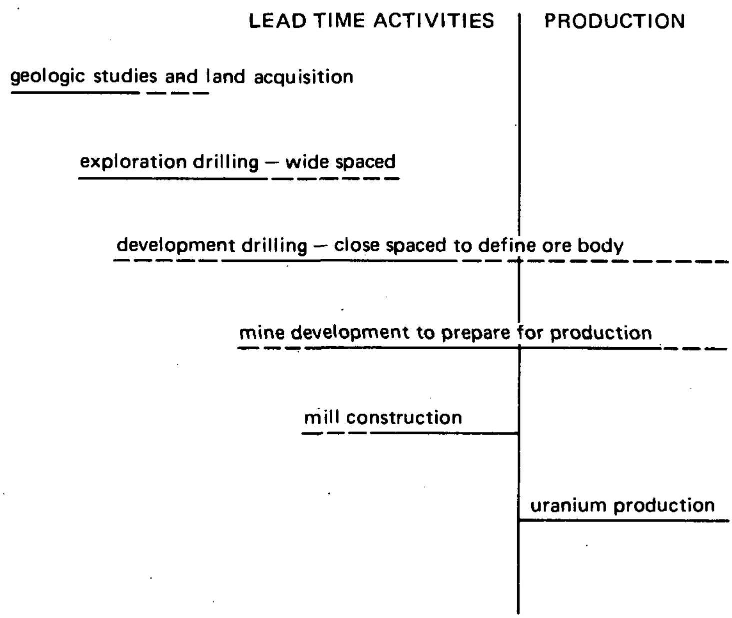
OTHER FACTORS AFFECTING SUPPLY

Assuming costs do not increase proportionately, a dramatic rise in the price of uranium concentrate should result in a much larger reserve of uranium, which is, in fact, exactly what happens. But this does not mean there will automatically be an improvement in the supply situation when there is a rise in price. In fact, there could be a temporary decrease in supply because over the short term low-grade ores are mined and processed at the same rate as high-grade ores, and, while the producers' cash flow may remain nearly the same, actual production of concentrate could be less because of the lower content of uranium in the ore. Larger volumes of uranium ore production, which require new mines and construction or expansion of ore processing plants, will overcome this temporary decrease in supply.

Imbalances between supply and demand for uranium occur because of different judgements about the future demand for uranium. However, the interdependence between producers who have only one market and consumers who have only one source of supply should tend to minimize through co-operative efforts the risk of a supply-demand imbalance.

Mining of low-cost resources during periods of low prices has caused the loss of large quantities of marginal-grade material because it was left behind when the high-grade material

Figure 4: Approximate Relationship of Lead Time Activities and Uranium Production



was mined out. Depending on the nature of the deposit, this may be either because the cost of its removal by itself is far higher than its value or because it has been made physically inaccessible due to caving, backfilling, dilution, etc. In any case, without the higher grade ores, the lower grade material becomes totally uneconomic. The only way to solve this problem is by careful economic and operational optimization of the ore body before mining begins.

VERY LOW-GRADE SUPPLY

Exploration for very low-grade ore bodies (100 to 500 ppm) has not been carried out in the past. In fact, in a uranium market of $6 to $8 per pound, the appearance of a low-grade sample on the edge of an ore body was often justification to stop development drilling in that direction. As a result, our knowledge of very low-grade (and consequently high-cost) uranium ores is restricted to the small amounts of data generated while in search of high-grade deposits.

Recently the trend has changed. This is shown by the development of the Rossing deposit in South West Africa, the Swedish shales, and the interest in the Greenland low-grade deposit, all of which contain 250–400 parts per million uranium. The possibility that large low-grade deposits exist is being studied in the USA and Canada.

UNCONVENTIONAL SOURCES OF SUPPLY

A discussion of supply of uranium would not be complete without some mention of unconventional sources of uranium. There is no question of the existence of such sources. The major problem of their utilization lies in the extremes we would have to go to recover the uranium. Recovery of only 5 000 tonnes uranium per year (about 5% the demand in 1986 and only 2% in 1998) from phosphates would require 100% extraction of all uranium from all phosphates produced in the world; recovery of the same amount of uranium from granite would require an open pit 10 times the size of the largest strip mine operation today, plus an investment of over a thousand million dollars; recovery from the highest grade and thickest shale beds would require stripping 15 square kilometres each year creating unprecedented environmental and engineering problems; recovery from sea water, theoretically an almost endless supply assuming as much as a third of the uranium could be recovered — and this is probably optimistic, — would require processing 5 000 cubic kilometres of water. The best presently known agent for collecting uranium from sea water would have to be chemically processed at a rate of one million cubic metres *daily*. And because it must remain in sea water for two to four days, provision for storage for an additional 3 000 000 cubic metres would require a dike 6 metres wide, 5 metres high and 100 kilometres long.

Therefore, one may safely conclude that none of these unconventional resources of uranium can be considered an important supply source for a long time to come.

CONCLUSIONS

The supply of low-cost uranium until the mid-1980's will be sufficient. Beyond that, a very considerable effort will be necessary to supply the predicted rapidly increasing demand. A slowing of the rate of increase in energy consumption will reduce the demand to some extent, and more efficient use of energy will reduce it a little more. But the lead time (normally about 10 years) necessary to bring a uranium deposit into production is the major problem. The exploration effort to find uranium which will be used after the mid-1980's should be mounted now. The indications are that the exploration effort around the world is growing, that there is a definite awareness of the problems of supply, but the scale of effort that is needed is simply not being made.

It would not be fair to end this article on such a note of pessimism. Uranium is a fairly abundant element, and with about 25% of the earth's favourable land surface unexplored for uranium and another 15% that can be re-explored, there is a good possibility for new discoveries.

The availability of manpower may present local temporary problems for some uranium mining companies, but adequate benefits can overcome the manpower problem. If the financial resources can be found, there is little reason to believe that supplies will ultimately fall seriously behind demand except in a few isolated cases. But the job facing the producer of uranium is probably one of the greatest challanges any segment of the mining industry has ever faced. In the next quarter century the industry must grow at an unprecedented rate of 12—15% per year from a relatively high base, spend an estimated 10 to 20 thousand million dollars and supply an energy hungry world with a cumulative total of two to four million tonnes of uranium. Although there is the danger of wildly fluctuating prices and periods of serious supply-demand imbalances, it is likely that the demand for uranium can be met if producers and consumers co-operate in all phases of uranium production.