World uranium resources

by M.V. Hansen*

With the development of nuclear fission, a whole new industry has emerged complete with its problems of demand, resources, and supply. Spurred by special incentives in the early years, prospectors discovered over 20 000 occurrences of uranium in North America alone, and by 1959 total world production had reached 34 000 tonnes uranium from mines in South Africa, Canada, and the United States.

This rapid growth led to problems. As purchases for military purposes ended, so did government procurement contracts. The large reserves and production capability which had been developed as a result of government purchases, lacked a substantial, commercial market, resulting in an over-supply of uranium and a fall in its price to less than US $5 per pound in the late 1960s. Although forecasts made in the late 1960s 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. At about the same time, the price of coal also rose substantially.

The economics of nuclear power immediately improved and the price of uranium began to climb in 1974. But there were negative effects too . Uranium production costs rose dramatically, as did capital costs, and money for investment in new uranium ventures became scarcer and dearer. However, demand continued to grow and increased exploration resulted in substantial increases in uranium reserves and production capability, further spurred by prices approaching US $115/kg U (US $43/ pound U_3O_8) early in 1978.

The demand for uranium began to decrease in the middle of 1979 as a consequence of the activities of nuclear power opposition groups, reduced projections of growth in demand for electricity, and the incident at Three Mile Island. Prices for spot sales and new contracts fell rapidly to their present level of about US $70/kg U (US $27.50/pound U_3O8). The cost of producing uranium has to be much lower than this price, perhaps around US $50/kg U, if the industry is to remain economic. But costs are rising rapidly, resulting in drastically reduced uranium ore reserves, especially low-cost reserves, in the United States. Canada's low-grade reserves are likewise seriously affected, but higher grades could be available under current economic conditions. Less seriously affected are some large, relatively higher-grade reserves in Australia where unit production costs are low, and South Africa where uranium is recovered primarily as a by-product and its production is controlled more by the price and production of gold than by the price of uranium. The costs of operating mines in virtually all countries are affected by the current poor market demand and depressed prices for uranium. Opening new mines or re-opening old ones, especially in remote areas, would probably be uneconomic at present prices. In countries where production centres are forced to close or reduce operations drastically, there is yet another threat. If closures and reductions are sustained for a long period, the technical manpower is lost to other industries and the equipment becomes obsolete.

Curiously however, world uranium production reached new heights in 1979 and 1980 – 38 000 and 41 000 tonnes U, respectively – in spite of the current market situation. In the United States, production reached an all-time high of 21 850 tons U_3O_8 (16 800 tonnes U) in 1980, even though many companies had closed mines and mills, or reduced production during the year. Shutdowns were partially offset by new production centres coming on-line while many mills fulfilled contracts from existing stockpiles after mines had been shut down. There was also a marked increase in production from *in-situ* operations.

Known uranium resources

Since 1967, the IAEA has participated in a joint Working Party on Uranium Resources with the Nuclear Energy Agency (NEA) of the OECD to publish estimates of the world's uranium resources at intervals of about two years. The joint working party has in the past reported only Reasonably Assured Resources and Estimated Additional Resources, but the latest report, published in December 1979, includes for the first time some indications of the possible extent and location of Speculative Resources. A new report is now in preparation for publication late in 1981.

Table 1 lists among other things the Reasonably Assured and Estimated Additional Resources. New information up to 1 January 1980 was obtained for Australia, Canada and the United States. A recent discovery of 35 000 tonnes U reported in Bordeaux, France has, however, not been added to France's total. Actual or projected 1979 production was subtracted from the December 1979 figures as appropriate. Uranium reserves' data are not yet available for the 1981 report, so for this article 1 January 1980 has been chosen as the cutoff date.

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Table 1. Exploration, production, resources and production capability

Country	First exploration	First production	Total production to 1980	US $80/kgU Reasonably Assured (1000 tonnes U)	US $130/kgU Reasonably Assured (1000 tonnes U)	US $80/kgU Estimated Additional (1000 tonnes U)	US $130/kgU Estimated Additional (1000 tonnes U)	Attainable maximum production capability	Year maximum production capability reached	Qualitative potential
Algeria	Before 1961	–	0	28	28	0	6			moderate/high
Argentina	1968	–	750	23	28	4	9	700	1983	high
Australia	1947	1954	9 600	292+	301	127+	53	20 000	1990	very high
Austria	–	–	0	2	2	0	0			moderate
Bolivia	Late 1960s	–	0	0	0	0	< 1			moderate
Botswana	Late 1960s	–	0	0		0	0			moderate/high
Brazil	1952	1979	100	74	74	90	90	1 000	1983	high/very high
Canada‡	1942	1938	131 500	230	259	381	770	15 500	1990	very high
Centr Afr Rep	1947	1982	0	18	18	0	0	1 000	1982	moderate
Chile	1950	–	0	0	0	5	5			low
Denmark (Greenland)	1955	–	0	0	27	0	16			moderate/high
Egypt	–	–		0		0	5			–
Finland	1959	1958	< 100	0	3	0	< 1			moderate
France	1945	1949	29 600	38	54	26	46	4 500	1986	moderate/high
Gabon	1948	1969	9 700	36	35	0	0	1 500	1982	moderate/high
Germany, Fed Rep	1953	1975	200	4	5	7	8	200	1984	low
India	1953	–		30	30	1	24	200	1979	high
Italy	1954	1981	0	0	1	0	2	< 100	1981	moderate
Japan	1954	1970	< 100	8	8	0	0	< 100	1979	low
Korea (Rep of)	–	–		0	4	0	0			low
Madagascar	1946	1955	4 000	0	0	0	2			moderate
Mexico	1957	–	< 100	6	6	2	2	90	1979	moderate/high
Namibia	1966	1977	9 400	113	122	30	53	5 000	1985	high
Niger	1954	1967	13 000	157	157	53	53	12 000	1986	high
Philippines	1953	–	0	< 1	< 1	0	0	< 100	1981	low
Portugal	1945	1945	2 200	7	8	3	3	300	1984	moderate
Somalia	1955	–	0	0	7	0	3			moderate
South Africa	Mid 1950s	1952	88 000	242	386	54	139	10 700	1986	high/very high
Spain	1952	1958	1 200	10	10	9	9	1 300	1985	high
Sweden	Mid 1950s	–	200	0	301	0	3	400	1983	moderate/high
Turkey	1956	–	0	2	4	0	0			moderate
United Kingdom*	1945	–	< 100	0	0	0	7			moderate
United States+	1945	1942	272 300	496	673	773	1 158	44 200	1990	very high
Yugoslavia	1965	–	0	5	7	5	20	400	1990	moderate
Zaire	1920s	1940s	25 600	2	2	2	2			high

Except where noted, data on resources are from *Uranium Resources, Production and Demand* (December 1979), adjusted for 1979 production and updated to 1 Jan 1980

* Total production from 1845 for glass and ceramic colouring and radium 200 tonnes

\+ Source US Department of Energy (US figures from DOE/GJO-100(80), January 1980)

‡ Uranium in Canada – 1979 assessment of supply and requirements – at a price of US $130/kg U and US $200/kg U

The Speculative Resources of each continent are shown in Table 2. When these figure were first published, they were accompanied by a warning that the estimate was highly subjective; that the totals were not meant to indicate ultimate resources of uranium, and that the tonnages of Speculative Resources presented should not under any circumstances be used for nuclear power programme planning purposes. Even if the Speculative Resources exist there is no guarantee that they will be discovered or, if discovered, that they can be made available – and it is likely that a major part of these resources may not be discovered and brought into production during the first quarter of the 21st century. For these reasons the IAEA/NEA report concluded, the figures should be looked upon as a guide for establishing priorities for future exploration and evaluation efforts.

Other resources

In addition to the estimates of resources costing up to US $130/kg U, there are additional higher-cost, generally lower-grade, resources. Some of these are extensions of the conventional deposits included in the US $130/kg U category, and there are others that because of great depth, or remote location, might also cost over US $130/kg. Also, very large amounts of uranium are known to be distributed at very low grade in several areas. In general, it is technically so difficult to recover uranium from these occurrences that they cannot be considered as resources; but a few types lend themselves to cheaper large-scale recovery techniques, and some are mined for other minerals and the uranium can be recovered at reasonable costs as by-product or co-product.

Tailings. Some 47 000 tonnes U contained in the tailings of gold mines in South Africa, are included in the estimates of Reasonably Assured and Estimated Additional Resources, recoverable at less than US $130/kg U. A further 28 000 tonnes in tailings are estimated as recoverable at higher costs. In the United States, uranium has been recovered from the tailings at several sites, but the quantities are not large.

Phosphate rock: Almost all marine phosphorites currently used to produce fertilizer are uraniferous. The

Table 2. Speculative resources by continent

Continent	Number of countries	Speculative resources (million t U)
Africa	51	1.3–4 0
America, North	3	2.1–3 6
America, South and Central	41	0 7–1 9
Asia and Far East[1]	41	0 2–1.0
Australia and Oceania	18	2 0–3.0
Western Europe	22	0 3–1.3
Total	176	6.6–14 8[2]
Eastern Europe, USSR, China	9	3 3–7.3

[1] Excluding China and the eastern part of USSR.
[2] A small portion of the potential represented by those Speculative Resources has likely been discovered during the period 1977 to 1979, although this would not appreciably alter the judgements contained in the table.

grades range from 0.001 per cent uranium to as much as 0.07 per cent with the average close to 0.01 per cent. Estimates of world reserves of phosphate rock are in the range 75 000 to 130 000 million tonnes of which 80 per cent is located in three countries: Morocco, the United States, and the USSR. The uranium content would be about 10 million tonnes, nearly all in very low concentrations . It could be recovered only as a by-product of phosphoric acid production.

Table 3 shows the distribution of uranium in marine phosphate deposits throught the world.

Seven plants are operating in the United States, recovering uranium from phosphoric acid produced in Florida and Louisiana. Two uranium recovery curcuits are planned in France and one is operating in western Canada. The US plants have capacities ranging between 75 and 500 tonnes U per year. Investigations on techniques of uranium recovery from phosphoric acid are also being conducted in Egypt, Israel, Jordan, and Japan.

Copper Leach: Porphyry copper deposits contain uranium which can be recovered on a small scale from copper-leach solutions. Several tens of thousands of tonnes might be recovered by this means by the year 2000. A production unit is in operation at the Bingham Canyon copper-mine in Utah, USA, and a second recently went on stream at Twin Buttes in Arizona. Other sites under consideration are in Montana and Nevada in the USA, and in Chile. In South Africa, uranium is being recovered with copper and other associated minerals from the Phalaborwe carbonatite deposit.

Marine black shales: Many marine black shales, which are rich in organic matter, contain uranium at grades of 0.001 to 0.008 per cent. Occasionally, as in southern Sweden, the grade can exceed 0.02 per cent and these Swedish shales are included as Reasonably Assured Resources recoverable between US $80 and US $130/kg U The marine shales which occur in large areas of the United States are of much lower grade. The Chattanooga Shale, which has received considerable attention, could be a potential long-term, very costly source of uranium.

Coals and lignites: Although most coals contain less than 0.001 per cent uranium, some low-rank and impure coals can contain as much as 1.0 per cent. Certain United States lignites – in parts of North and South Dakota and Montana – contain about 0.4 per cent uranium and were exploited for short periods for their uranium content.

Although the present market does not provide incentive for mining US lignites, the total contained uranium is quite substantial as shown in Table 4.

When uranium-bearing lignites are burned, most of the uranium is retained in the ash and therefore should be available as a by-product from lignites mined for fuel, however, most have a low heat value and are not useable for fuel.

A total of 111 000 tonnes uranium have been estimated in the East Ebro Valley, Spain, but feasibility studies have shown that recovery costs will be well above US $130/kg U. A uraniferous coal in the Northern Transvaal of South Africa is also regarded as potentially viable.

Table 3. Distribution of uranium in marine phosphate deposits

Area	Million tonnes U
Africa	8 5
USA	3.0
Near East and Asia	1.6
Australia	0 8
Latin America	0.8
Pacific Islands	0 015
Total *(rounded)*	15 0

Table 4. Western US lignites containing low-grade uranium

Area	Lignite (t)	Contained U %	Contained U tU
South Dakota	43 000 000	0 007	2 900
South Dakota	45 000 000	0.004	1 900
North Dakota	25 000 000	0 011	2 700
Montana	15 000 000	0 004	750
Wyoming	640 000 000	0 0025	16 000
Total			24 250

Monazite: Uranium is a minor constituent in the mineral monazite which is mined for its thorium and rare earth content. The uranium resources from this source in India are estimated at 7700 tonnes U Reasonably Assured and 5000 tonnes U Estimated Additional Resources, recoverable at more than US $130/kg U. Less important monazite deposits are located in Brazil, Egypt, Republic of Korea, Sri Lanka, and the United States.

Igneous rocks: Although most igneous rocks contain uranium in amounts representative of the crustal abundance (2 to 4 ppm), some formations are considerably richer and have been considered as possible sources of uranium. Some intrusive bodies, carbonatites and alkaline intrusives have such high grades that they are recoverable at less than US $130/kg U: e.g. reserves in carbonatites in South Africa, and resources recoverable at US $80–130/kg U in intrusives in Greenland.

The largest quantities however are in very extensive low-grade granite such as the Conway Granite in the United States. The immense size of an operation to extract significant quantities of uranium from this source would be comparable to the largest stripping operations known today, and would undoubtedly affect the environment so much that large-scale production from such sources is doubtful.

Sea-water. The world's oceans are estimated to contain 4000 million tonnes of uranium. Recent figures indicate that recovering uranium from sea-water would cost US $5000 to US $7000 per kg U. The schemes require treatment of huge volumes of water (354 000 tonnes of water to produce one kilogram of uranium) which would present many engineering problems.

Other occurrences: Some occurrences of uranium have not been investigated in depth because of obvious obstacles to recovery. Among these is the Black Sea organic mud which may contain a sizeable quantity of uranium but whose recovery would depend on the removal and processing of enormous quantities of material. The concomitant technological and environmental problems are beyond solution within the foreseeable future.

Production capability

Estimates of the quantities in various deposits in the world say very little about the rate at which uranium could be produced to satisfy demand. The physical nature of an ore-body can be one limiting factor. Resources are distributed in a great variety of types of deposits, each with its own characteristics, and the annual level of production which can be attained will depend on the physical and economic contraints of each ore-deposit. Shallow high-grade deposits which can be quarried will be easier and more profitable to develop than deeper underground deposits.

A resource may not be developed if producers lack confidence that the demand for their product will continue. A lot of money has to be invested before production can begin, and producers will need to negotiate sales contracts at a reasonable rate of return to justify development of an ore-body.

In addition to physical and economic constraints of the type outlined above, the policies of both producer and consumer governments may act directly or indirectly to inhibit the development of resources, or limit the availability of production: export and import policies; national energy policies, and environmental licensing and safety requirements. For example, Canadian guidelines to maintain adequate supplies of uranium for domestic consumption might limit availability of production for export. The import policies and certain other domestic policies of consumer States have in the past acted to limit access to markets. In many countries, the resolution of important environmental and social issues has led to delays in developing resources or lowered the demand necessary to support such development. Additionally, arrangements to satisfy the non-proliferation concerns of States are an essential feature of all aspects of nuclear trade. Political circumstances can change markedly and swiftly, which can have significant effects on availability of production.

All these considerations are relevant in estimating uranium supply and world demand. However, to compare supply and demand projections, possible political problems are left aside and the projected attainable uranium production capabilities are determined largely on the basis of known low-cost resources.

Estimates of the projected attainable capacities for uranium production throughout the world are shown in Table 5. The conditions necessary to reach 110 000 tonnes production per year by 1990 must be emphasized. Clearly, the growth of nuclear power must become more predictable in order to provide the incentive and lead-time to establish the necessary mining and milling facilities. Evidence of continued growth of the nuclear industry would stimulate the exploration needed to increase resources so that such production rates can be sustained, as well as provide the confidence needed to obtain the necessary financing.

Future prospects

The increase* in known uranium resources since they were first reported in 1965 has reflected the increase in demand for uranium for nuclear power plants. Although increases in price play a part in the availability of uranium, assurance of future demand ultimately sparks the exploration effort to find new deposits. Present demand is low, and so is the price – around US $27.50/lb U_3O_8

*When the next IAEA/NEA joint report on Uranium Resources is published later this year, it is likely to show an increase in the world's reserves compared to this article and to the December 1979 report as more data will have become available in the interim.

Table 5. Attainable production capabilities (tonnes U)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Argentina	135	200	280	380	680	680	680	680	680	680	680	680
Australia	600	600	2 300	3 800	5 000	6 500	12 000	13 600*	15 200*	16 800*	18 400*	20 000
Brazil[1]	103	510	510	810	970	970	970	970	970	970*	970*	970*
Canada	6 900	7 200	9 000	9 900	11 000	13 500	14 400	14 500	14 500	14 700	15 400	15 500
Central African Republic	0	0	0	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
France	2 950	3 450	3 650	3 870	4 020	4 020	4 020	4 520	4 520	4 520	4 520	4 520
Gabon	1 000	1 000	1 000	1 500	1 500	1 500	1 500	1 500	1 500	1 500	1 500	1 500
Germany, Fed Rep	100	100	150	150	150	200	200	200	200	200	200	200
India[2]	200	200	200	200*	200*	200*	200*	200*	200*	200*	200*	200*
Italy	0	0	120	120	120	120	120	120	120	120	120	120
Japan	30	30	30	30	30	30	30	30	30	30	30	30
Mexico[2]	90	170	550	550*	550*	550*	550*	550*	550*	550*	550*	550*
Namibia	3 700	4 100	4 400	4 550	5 000	5 000	5 000	5 000	5 000	5 000	5 000	5 000
Niger	3 350	4 300	4 500	4 500	5 800	8 000	10 500	12 000	12 000	12 000	12 000	12 000
Philippines[2]	38	38	76	76	76	38	0	0	0	0	0	0
Portugal	85	95	100	100	100	270	270	270	270	270	270	270
South Africa	5 240	6 500	7 300	8 600	9 900	10 400	10 600	10 700	10 700	10 600	10 600	10 400
Spain	339	678	678	678	678	678	1 272	1 272	1 272	1 272	1 272	1 272
Sweden	0	0	0	0	400	400	400	400	400	400	400	400
USA	19 000	20 900	24 300	27 100	30 900	33 600	34 100	35 000	38 400	40 800	42 600	44 200
Yugoslavia	0	0	120	120	120	180	180	180*	245*	310*	375*	440
Total (rounded)	43 900	50 100	59 300	68 000	78 200	87 800	98 000	102 700	107 800	111 900	116 100	119 300

[1] Planned production capacity
[2] Source Uranium Resources, Production and Demand (December 1977)
* Estimate of the NEA/IAEA Working Pary on Uranium Resources

(US $70/kg U). Production costs today are approximately the same as the spot price; however much of the production goes to fulfill existing contracts at prices substantially higher than the spot price, so producers are able to continue to operate. New contracts at present prices would probably be uneconomic unless they were fulfilled from very high-grade deposits.

It is very likely that only 20 per cent or less of the US $30/lb U_3O_8 (US $80/kg U) reserves reported in this article could actually be produced economically at present market prices, and the quantity could be as low as 10 per cent. If producers are forced to fulfill contracts at costs that cause high grading of operating mines, even more of the known reserves will be lost because they will become uneconomic at any reasonable market price.

It would be unrealistic to end this article on such a pessimistic note. Even if no nuclear power plants are ordered, uranium production will increase to meet the demands of those now being built and to maintain inventories of fuel at operating plants. Although experts and observers do not agree on the time required for a turn-around in demand, they do agree that preparation for that time must be made now and that the present market prices do not provide adequate incentive for producers to make those preparation.