GE-867

URANIUM, SUPPLY AND DEMAND

(Lecture Notes)

by

P.D. Toens

MARCH 1981

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1. INTRODUCTION

From the history of mans use of energy it is evident that no single source of energy has ever remained dominant. The rise and fall in importance of every form of energy source is some=thing entirely to be expected even though it may be impossible to forecast with much accuracy the time period in which this will come about. It is of interest to note that the advent of each new fuel source has been preceeded by a major event in the history of man on the planet earth.

For example, the industrial Revolution saw the dramatic rise of the use of coal. The First World War and the almost simultaneous advent of the automobile resulted in the steep rise in oil pro=duction. Likewise the Second World War and the splitting of the atom gave rise to the dramatic rise in the use of nuclear power (Fig. 1).

Gazing into our crystal ball we can possibly quite safely forecast that beyond the year 2000 similar patterns will emerge recounting the rise of nuclear power, solar power and thermonuclear fusion and ultimately the use of hydrogen in fusion.

It can probably also sadly be predicted that major changes in mans source of energy will also coincide with events of catestrophic proportions.

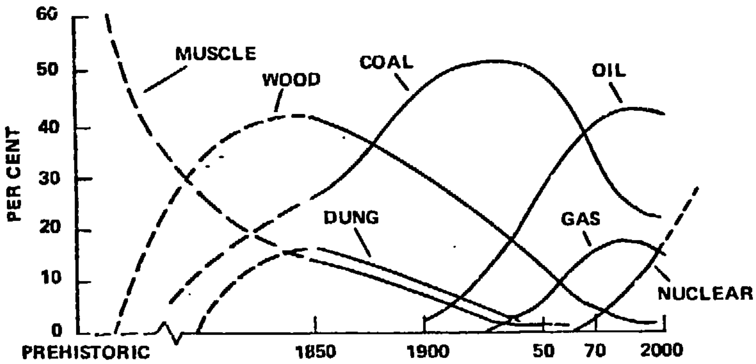


FIG. 1 : World energy sources - the historical pattern showing percent contribution to total supplies (*after Pallister, 1974*)

2. GEOLOGICAL SETTING OF URANIUM RESOURCES

Turning now to cyclicity of another nature it is of interest to note that the uranium provinces of the Globe are distinctly time-bound and occur in a series of five clearly defined mega-rhythms ranging from the late Proterozoic to the Recent. Although uranium is ubiquitous it needs a certain geological setting in order to accumulate and its migration and concentration of uranium depends primarily on its crystal chemistry and on that of other elements which build-up the earths crust.

It is of interest to note that a different type, or a combination of different types, of uranium mineralisation is found to be characteristic of each epoch and a study of these variations has in the recent past led to a better understanding of the behaviour of uranium under wide ranging conditions.

During the Archaean the anoxygenic conditions militated against the solution of uranium from the potential source areas and the oldest sedimentary deposits contain largely mechanically deposited thorium and uranium minerals with a low Th/U ratio.

As the atmosphere became slightly oxygenated around 2 600 Ma hexavalent uranium tended to go partly into solution to be re=precipitated in the four valent state thus explaining the presence of uraninite mechanically derived from the basement together with a second generation of uranium.

The above processes gave rise to the major quartz pebble conglo=merate deposits of South Africa, Canada and Brazil which range in age from 2 800 to 2 200 Ma. The end of this period, in all the four continents mentioned above, is followed by a succession of red coloured rocks which on a global scale host few important uranium deposits.

The hiatus noted above is followed by the next major peak which occurs in rocks of the 1 800 - 1 700 Ma age range and embraces the Lower and Middle Proterozoic. These deposits include the vein-like deposits of Canada, Australia and the sedimentary deposits of Gabon.

The hiatus which occurs between 1 500 and about 700 Ma is again worldwide and contains no uranium deposits of any importance. The third generation occupies a relatively short space of time between 700 and 500 Ma, when the vein-type and granitic deposits of Namibia and Katanga formed during the Pan African orogenesis. The next hiatus occurred in the period between the Cambrian and the Carboniferous when mainly red bed and marine deposits were formed.

The fourth generation peaks around the Permian and gives rise to the major sandstone deposits of North America and Europe and the Gondwana deposits of South America, Africa and India. There is not a distinct break between the fourth and fifth generation as a number of occurrences are present in the Cretaceous building-up to a peak covering the Late Tertiary to the Recent which contain the major sandstone and calcrete deposits of North America, Australia and Namibia.

Years x 10^9		Type of strata	Type of uranium deposit
0.68 ±	O_2 in=creasing; $CaMg(CO_3)_2$ abundant	Oxidised cratonal sediments (Red beds)	No economic sedi=mentary deposits. Veins with pitchblende
1.9 ±	TRANSITIONAL ATMOSPHERE		
2.2 ±			
2.6 ±	Biological O_2 in hydro=sphere in balance with Fe^{++} $4FeO + O_2 \leftrightarrows 2Fe_2O_3$	Mostly un=oxidised cratonal sediments (Banded iron=stone)	Conglomerates with detrital uraninite and brannerite etc.
3.2	Chemical evolution → biogenesis. Juvenile gases. No free O_2	K-low granites greenstones graywackes	No economic deposits.
3.5 - 3.6	Oldest dated minerals, thermal event.	Records obscure	
4.6 ±	Meteoritic and oceanic Pb		

FIG. 2 : Evolution of the primitive Earth. Partly after Cloud, 1976

3. GLOBAL RESOURCES

The task of estimating the world's mineral resources is a fairly recent undertaking and as far as uranium is concerned, this is a task assuming ever increasing important and is constantly moni= tered by the IAEA and its Working Groups on an on-going basis.

Uranium resource estimates are divided into three separate categories reflecting different levels of confidence. The cate= gories are further separated into resources that can be produced at less than \$80 kg/U, between \$80 and \$130/kg U and above \$130/ kg U.

There are two basic categories of resources and are defined as follows:

- *Reasonably Assured Resources* refers to uranium that occurs in known mineral deposits of such size, grade and configu= ration that it could be recovered within the given pro= duction cost ranges, with currently proven mining and pro= cessing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably Assured Resources have a high assurance of existence and in the cost category below \$80/kg U are considered as *reserves*, for the purpose of this report.

- *Estimated Additional Resources* refers to uranium in addition to Reasonably Assured Resources, that is expected to occur, mostly on the basis of direct geological evidence, in:

  : extensions of well-explored deposits,
  : little-explored deposits, and
  : undiscovered deposits believed to exist along a well-defined geological trend with known deposits.

  Such deposits can be identified, delineated and the uranium subsequently recovered, all within the given cost ranges. Estimates of tonnage and grade are based primarily on knowledge of the deposit characteristics as determined in its best-known parts or in similar deposits. Less reliance can be placed on the estimate in this category than for Reasonably Assured Resources.

The resource level of Estimated Additional Resources should be considered as having a *potential* for later conversion to Reasonably Assured Resources as the possible result of further exploration effort.

Current estimates represent an incomplete appraisal, therefore efforts are currently under way to assess what further potential resources are likely to exist, and in what regions exploration should be concentrated to identify them. This assessment had led to the establishment of yet another resource category with a still lower degree of confidence than Estimated Additional Resources, as follows:

- *Speculative Resources* refers to uranium, in addition to Estimated Additional Resources, that is thought to exist mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The location of deposits envi= saged in this category could generally be specified only as being somewhere within a given region or geological trend. As the term implies, the existence and size of such resources are highly speculative.

As at 1 January 1979 the Reasonably Assured Resources of the Western World which could be recovered at less than $130/kg U amounted to 5 180 000 t U and the Estimated Additional resources amounted to 4 900 000 t U making the combined total 10 080 000 t U.

4. PRODUCTION OF URANIUM

In spite of the cutback in the nuclear industry world production has steadily increased and in 1979 production was about 38 000 t U as compared to 1976 when the production was 28 852 tons.

FIG. 3 : NEA/IAEA classification scheme for uranium resources

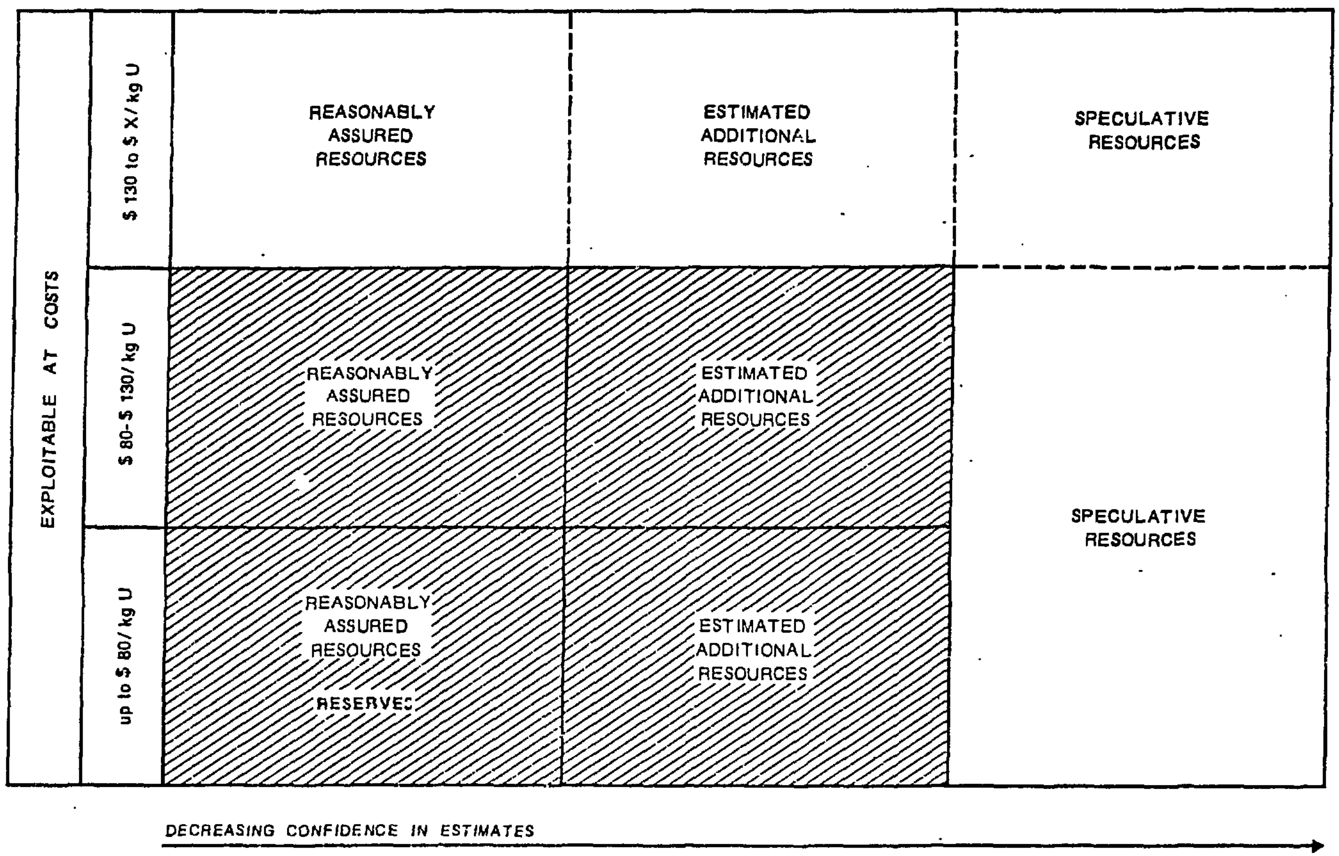


TABLE I : REASONABLY ASSURED RESOURCES (1 000 tons U)

(Data available 1 January 1979)

COST RANGE	<$80/kg U RESERVES	$80-130/kg U	TOTAL AT < $130/kg U
Algeria	28	0	28
Argentina	23	5.1	28.1
Australia	290	9	299
Austria[2]	1.8	0	1.8
Bolivia	-	0	0
Botswana	0	0.4	0.4
Brazil	74.2	0	74.2
Canada[1]	215	20	235
Central African Republic	18	0	18
Chile	0	0	0
Denmark	0	27	27
Egypt	0	0	0
Finland	0	2.7	2.7
France	39.6	15.7	55.3
Gabon[2]	37	0	37
Germany, Federal Republic of	4	0.5	4.5
India	29.8	0	29.8
Italy	0	1 2	1.2
Japan	7.7	0	7.7
Korea, Republic of[4]	0	4.4	4.4
Madagascar[2]	0	0	0
Mexico[3]	6	0	6
Namibia	117	16	133
Niger[2]	160	0	160
Philippines[2]	0.3	0	0.3
Portugal	6.7	1.5	8.2
Somalia[3]	0	6.6	6.6
South Africa	247	144	391
Spain	9.8	0	9.8
Sweden[5]	0	301	301
Turkey	2.4	1.5	3.9
United Kingdom	0	0	0
United States of America	531	177	708
Yugoslavia	4.5	2	6.5
Zaïre[2]	1.8	0	1.8
Total (rounded)	1,850	740	2,590

\- Less than 100 tonnes U.

1. The material reported as reserves is mineable at prices up to $ CAN 125/kg U and other Reasonable Assured Resources are mineable at prices between $ CAN 125 and $ CAN 175/kg U.
2. Source of data: Uranium Resources, Production and Demand, Paris, 1977.
3. Data refer to resources "in-situ", rather than recoverable.
4. Reported as 13,000,000 tonnes of ore with an average grade of 0.04% U_3O_8.
5. No uranium production allowed in a deposit of 300,000 tonnes U due to a veto by the local authorities for environmental reasons.

TABLE II : ESTIMATED ADDITIONAL RESOURCES
(1 000 tons U)
(Data available 1 January 1979)

COST RANGE	< $80/kg U	$80-130/kg U	TOTAL AT < $130/kg U
Algeria	0	5.5	5.5
Argentina	3.8	5.3	9.1
Australia	47	6	53
Austria [2]	0	0	0
Bolivia [2]	0	0.5	0.5
Botswana	0	0	0
Brazil	90.1	0	90.1
Canada [1]	370	358	728
Central African Republic	0	0	0
Chile	5.1	0	5.1
Denmark	0	16	16
Egypt	0	5	5
Finland	0	0.5	0.5
France	26.2	20	46.2
Gabon [2]	0	0	0
Germany, Federal Republic of	7	0.5	7.5
India	0.9	22.8	23.7
Italy	0	2	2
Japan	0	0	0
Korea, Republic of	0	0	0
Madagascar [2]	0	2	2
Mexico [3]	2.4	0	2.4
Namibia	30	23	53
Niger [2]	53	0	53
Philippines [2]	0	0	0
Portugal	2.5	0	2.5
Somalia [3]	0	3.4	3.4
South Africa	54	85	139
Spain	8.5	0	8.5
Sweden	0	3	3
Turkey	0	0	0
United Kingdom	0	7.4	7.4
United States of America	773	385	1,158
Yugoslavia	5	15.5	20.5
Zaïre [2]	1.7	0	1.7
Total (rounded)	1,480	970	2,450

1), 2), 3) - As in footnotes to Table 1.

NB: A number of occurrences of uranium are not well enough defined to be included in Tables 1 and 2 but are described in Part III, the country reports.

The projections of uranium production capability are based on known resources recoverable at less than $80/kg U and estimates as to the attainable production capability are shown in Fig. 4 from which it can be observed that there is a projected uranium production capability of 119 000 tons per year by 1990. For this, however, to become a reality the growth of nuclear power must become more predictable in order to provide the incentive and sufficient lead time for the establishment of the necessary mining and milling facilities.

In the short to medium term uranium marketing patterns will be influenced by the number of orders for new reactors and this coupled with the fact that because several major projects will start production in the 1980's, there is concern that a short term over-supply situation may develop and that prices may level off or fall in terms of real money. Stability in the uranium market is therefore of a primary concern to the major producers and consumers alike.

5. FUTURE URANIUM REQUIREMENTS

Figs. 5 and 6 compare the projected uranium requirements for a series of mixed strategies for high and low nuclear growth pro= jections. With the projection of maximum production capability from known resources including phosphates.

From these graphs it is abundantly clear that large increases in the production capability will be required by the turn of the century if the world is not to face a major energy crisis. Obviously this increase in production capability will have to go hand in glove with an increased discovery rate.

6. CONCLUSIONS

In the long term nuclear energy remains the only viable alter= native and the current hold-up of nuclear power programs evident in a number of countries today is at its worst no more than a temporarily lull to give mankind a breathing space to adjust to

FIG. 4 : Projection of maximum attainable production capability from known resources 1980 - 2025

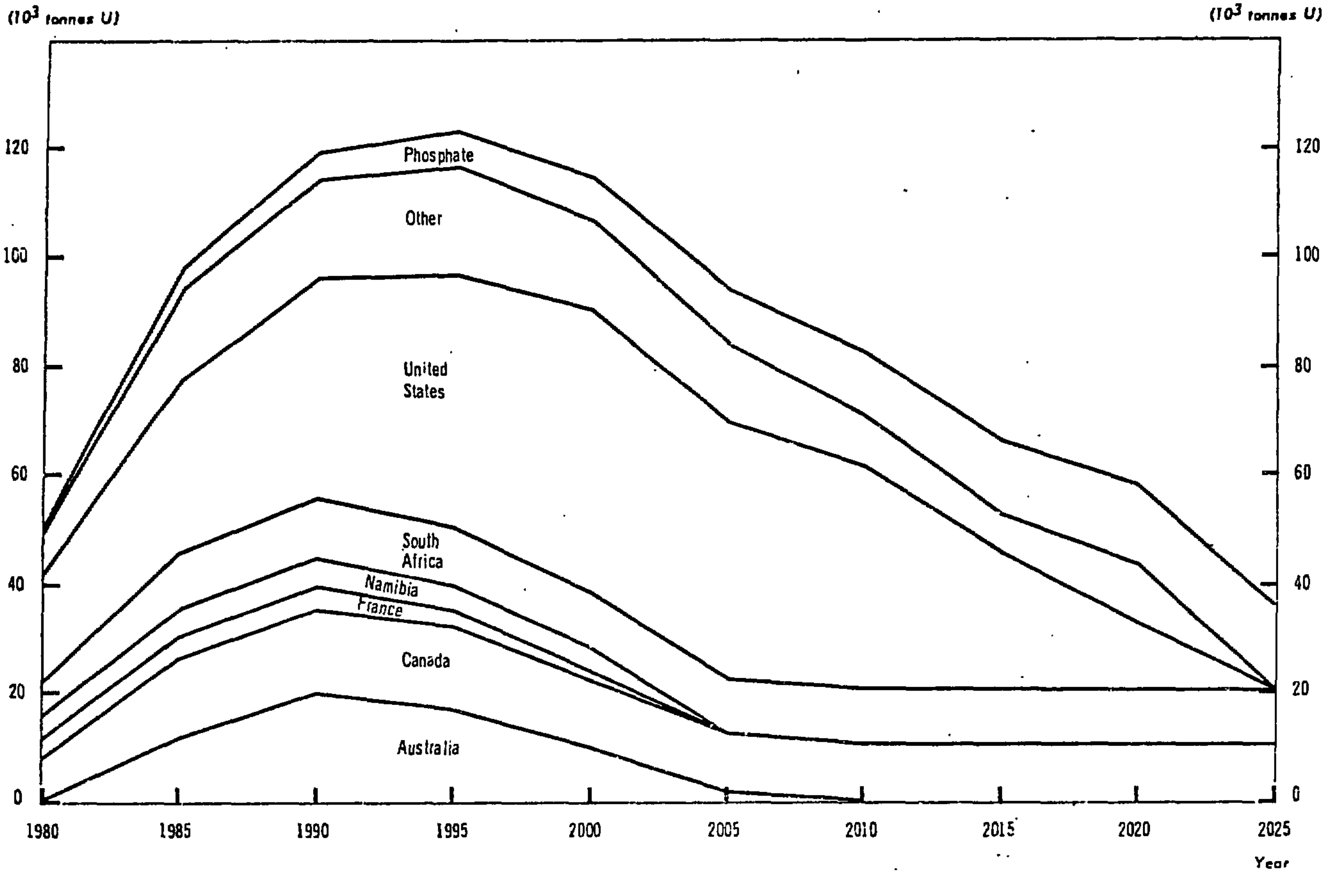
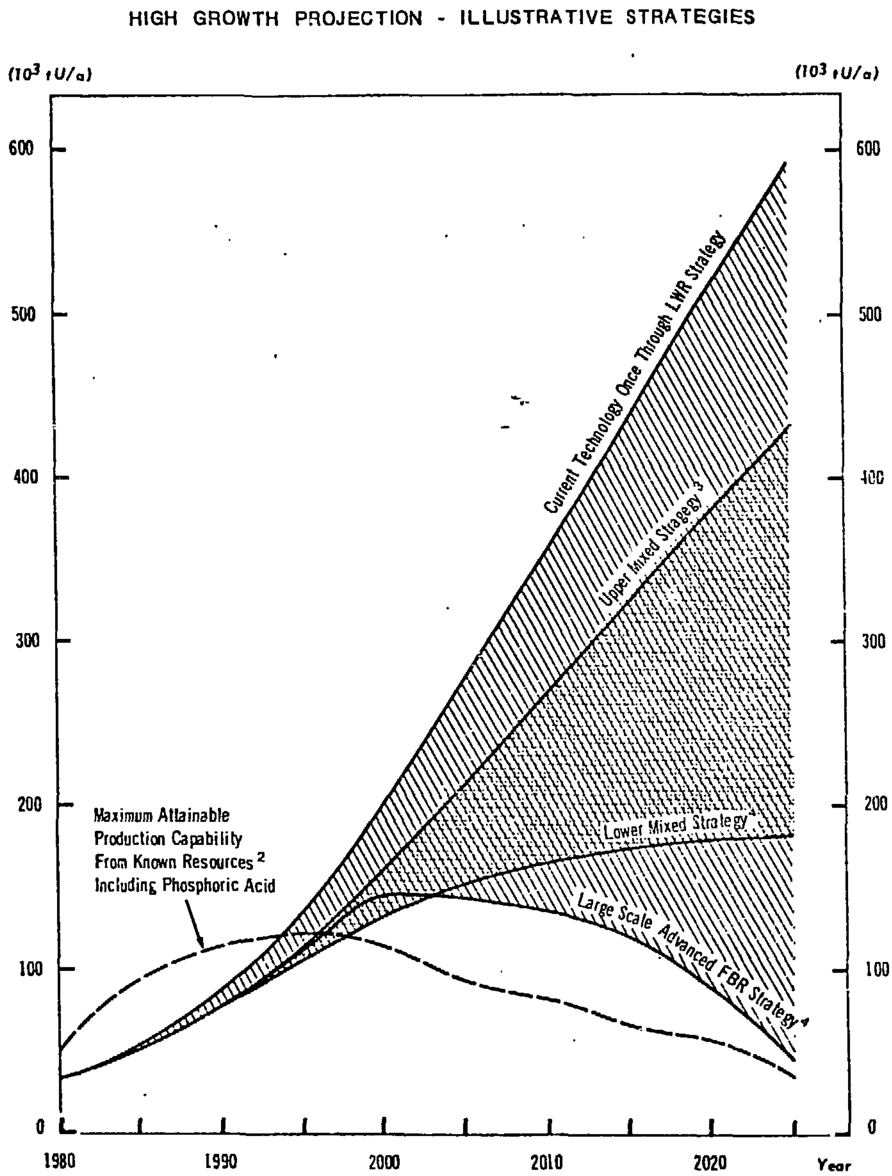


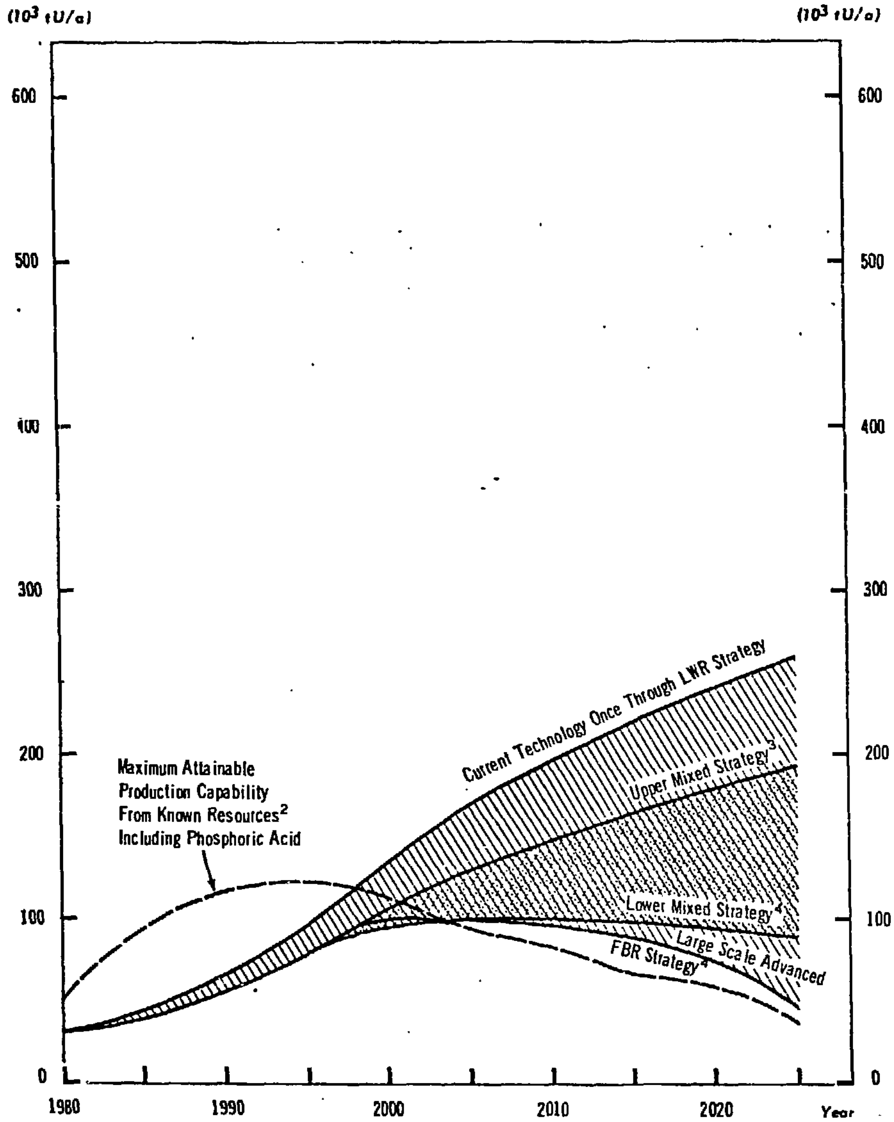
FIG. 5 : Comparison of annual world[1] uranium supply and demand to 2025 (modified INFCE diagram)



1. Data were not supplied nor included for USSR, Eastern Europe nor China.
2. Reasonably Assured and Estimated Additional Resources.
3. With Oxide-fuelled FBRs.
4. With Carbide-fuelled FBRs.

FIG. 6 : Comparison of annual world[1] uranium supply and demand to 2025 (modified INFCE diagram)

LOW GROWTH PROJECTION - ILLUSTRATIVE STRATEGIES



1. Data were not supplied nor included for USSR, Eastern Europe nor China.
2. Reasonably Assured and Estimated Additional Resources.
3. With Oxide-fuelled FBRs.
4. With Carbide-fuelled FBRs.

this new energy source. It is most important to realise that the use of uranium as a fuel will enable the oil and natural gas to be reserved for more important purposes than just burning, namely for transport, as a chemical feedstock and as a raw material for the production of food.

It therefore behoves us to plan ahead and bearing the future energy needs of the world in mind, devote special attention to the location and production of the magic element uranium.

7. ACKNOWLEDGEMENTS

In compiling these lecture notes the author has drawn heavily on the publication "Uranium - Resources, Production and Demand" - a joint report by the NEA/IAEA, the OECD Nuclear Energy Agency and the International Atomic Energy Board dated December 1979.