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Organisation de Coopération Et de Développement Économiques (ocde)

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URANIUM

RESOURCES PRODUCTION AND DEMAND

AUGUST 1973



A JOINT REPORT BY THE
OECD NUCLEAR ENERGY AGENCY
AND THE
INTERNATIONAL ATOMIC ENERGY AGENCY



ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

URANIUM

RESOURCES PRODUCTION AND DEMAND

A JOINT REPORT BY THE
OECD NUCLEAR ENERGY AGENCY
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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The Organisation for Economic Co-operation and Development (OECD), which was set up under a Convention signed in Paris on 14th December, 1960, provides that the OECD shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;*
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development;*
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.*

The Members of OECD are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

The OECD Nuclear Energy Agency (NEA) was established on 20th April 1972, replacing OECD's European Nuclear Energy Agency (ENEA) on the admission of Japan as a full Member. NEA thus groups eighteen European Member countries of OECD and Japan, with Canada and the United States as Associated countries. The Commission of the European Communities takes part in the work of the Agency.

The objectives of NEA remain substantially those of ENEA, namely the orderly development of the uses of nuclear energy for peaceful purposes. This is achieved by:

- assessing the future role of nuclear energy as a contributor to economic progress, and encouraging co-operation between governments towards its optimum development;*
- encouraging harmonisation of governments' regulatory policies and practices in the nuclear field, with particular reference to health and safety, radioactive waste management and nuclear third party liability and insurance;*
- forecasts of uranium resources, production and demand;*
- operation of common services and encouragement of co-operation in the field of nuclear energy information;*
- sponsorship of research and development undertakings jointly organised and operated by OECD countries.*

In these tasks NEA works in close collaboration with the International Atomic Energy Agency, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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Part I

GENERAL

1. FOREWORD

In August 1965, a report entitled "World Uranium and Thorium Resources" was published by the European Nuclear Energy Agency, on the basis of an examination carried out by the ENEA Study Group on the Long-Term Role of Nuclear Energy in Western Europe.

It was foreseen at the time of publication that the results of this examination would need to be updated at intervals, and in December 1967 a second report, "Uranium Resources, Revised Estimates" was published. In order to enlarge the geographical coverage of the study, and to receive the advice of experts from uranium-producing countries outside the OECD area, this revision was made jointly with the International Atomic Energy Agency, Vienna.

During 1968 a joint ENEA/IAEA Working Party prepared a first report on "Uranium Production and Short Term Demand", in an attempt to relate information on uranium production supplied by the members of the Working Party, with a prediction of the probable demand over the next ten years. The report was published in January 1969.

In September 1970 a report on "Uranium Resources, Production and Demand" was published jointly by ENEA and the IAEA. This report contained an updating of the uranium resources position since 1967 which was again carried out by the joint ENEA/IAEA Working Party on Uranium Resources. In addition, the Secretariat had prepared estimates of uranium and separative work requirements which were annexed to the report.

The present report is essentially similar to the previous one, in that it contains updated information on uranium resources, production and demand. Part II on Uranium Resources and Production was

prepared in the framework of the joint NEA*/IAEA Working Party on Uranium Resources, as was the case in the three foregoing reports. The estimates of requirements for natural and enriched uranium, contained in Part III of the Report, have been prepared by a "Working Party on Uranium Demand", with an international membership set up for this purpose in spring 1972 by the NEA Study Group on the Long-Term Role of Nuclear Energy. As a result of this approach the estimates for uranium and separative work demand are based on corporately agreed input data, and the scope of the demand calculations has been extended considerably through access to relevant computer programs in several participating countries.

* NEA, the Nuclear Energy Agency of OECD, replaced ENEA as the Agency's official name following the admission of Japan as a full member in April 1972.

2. SUMMARY AND CONCLUSIONS

The present report is essentially similar in content to that published in September 1970. However, subsequent changes in the parity of the US dollar (the basis for classifying resources), and different assumptions for the demand calculations, render comparison with the earlier figures more complex.

Reasonably assured world uranium resources under \$10/lb U_3O_8 now amount to 866,000 tonnes uranium (1,126,000 short tons U_3O_8), an increase of about one-third over the past three years.

Annual production of U_3O_8 has remained fairly stable during this period, attaining a modest increase of about 10 per cent to a 1972 total of something over 19,000 tonnes uranium (25,000 short tons U_3O_8). Annual production capacity is planned to reach about 30,000 tonnes uranium (40,000 short tons U_3O_8) by 1975 and could attain about 50,000 tonnes uranium (65,000 short tons U_3O_8) by 1978.

Estimates of future demand have been based upon individual national forecasts of varying tendencies. As a result, it has been considered more appropriate to suggest a range of figures, rather than attempt a single authoritative forecast. The ranges have been so chosen (see Fig. 3) as to allow more latitude for a shortfall in capacity than an excess. The possibility that an accelerated nuclear programme might be instituted in many countries to overcome an energy shortage was not considered in this report.

Annual demand for uranium is expected to establish itself in the region of 60,000 tonnes uranium (about 80,000 short tons U_3O_8) by 1980 and almost double this figure by 1985. No shortages of uranium supply are to be expected in the 1970s. However, the rapid growth in demand in the coming decade cannot be satisfied on the basis of existing uranium exploration levels. Given the necessity of a lead time of about eight years between discovery and actual production,

it is therefore essential that steps be taken to increase the rate of exploration for uranium so that an adequate forward reserve may be maintained.

The assumed predominance of light water reactors in the growth of nuclear power over the next ten to fifteen years imposes an annual demand for separative work of the order of 30,000 to 40,000 tonnes SWU* by the early 1980s. Existing and currently planned separative work capacity is therefore almost certainly bound to be saturated within the next ten years. In theory, the lead time for construction of additional capacity is within that required for the nuclear power stations it will feed, but hesitations over the extension of separative work capacity could introduce significant delays. If new separative work capacity is not provided in a timely manner, operators may be led to favour plutonium or to the choice of reactor types which minimise separative work requirements.

Notwithstanding the uncertainties with regard to future availability of natural and enriched uranium supplies, it is clear from the work of the Study Group that the most significant variations in demand arise not from one or another strategy involving mainly enriched uranium reactors, but from variations in the growth of nuclear power as a whole. This finding underlines the continuing necessity of improving the quality of nuclear power forecasts in the light of past experience, and of updating these forecasts at frequent intervals, taking into account the latest developments in energy policy.

* Separative Work Units.

3. DEFINITIONS

The present report is principally concerned with uranium resources considered to be exploitable in the near future. Deposits from which, for various reasons, uranium is not readily recoverable, or which are unlikely to be exploited in the foreseeable future, are not included in the summary tables. As in the previous report, there is therefore no mention of resources in the price classification of \$15 to \$30/lb U_3O_8 , because it is unlikely that such material will be worked in the short term. For the same reason, by-product uranium is not in general included in the totals of available resources (an exception is uranium from gold production in South Africa).

The following price ranges have been applied to the different resource categories reported on:

- up to \$10/lb U_3O_8 (\approx \$26/kg U) [Abbreviated <math>\\$10 uranium]
- \$10 to \$15/lb U_3O_8 (\$26 to \$39/kg U) [Abbreviated \$10-15 uranium]

In this context it should be mentioned that current uranium prices are of the order of \$6/lb U_3O_8 . However, taking into account that actual prices may often be lower than full cost prices, reflecting an unfavourable market position, and that the general trend of uranium costs is likely to increase, the price limit of \$10/lb U_3O_8 has been maintained in this report. Due to parity changes of the US\$, the absolute value of this price limit (as of March 1973) is about 17 per cent lower than in the previous report. It should be noted, however, that the symbol \$ is employed throughout this report to represent the US dollar (at March 1973 values) whereas in the last report it represented the EMA u/a*. The March 1973 US dollar now

* EMA u/a: European Monetary Agreement units of account.

corresponds to 0.82895 EMA u/a (as against 1.00 EMA u/a in the last report). It would therefore be unwise strictly to compare the detail of the resource figures quoted in the two price ranges with corresponding figures in previous years, although in practice the overall impression given by such a comparison is probably reasonable.

In this report, as previously, uranium in each price range has been subdivided into two categories:

The term Reasonably Assured Resources as employed in the previous report, has been retained for the first category, and refers to uranium which occurs in known ore deposits of such grade, quantity and configuration that it can, within the given price range, be profitably recovered with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of ore-body habit. Reasonably assured resources in the price category below \$10/lb are equivalent to Reserves in the mining sense.

The term Estimated Additional Resources refers to uranium surmised to occur in unexplored extensions of known deposits or in undiscovered deposits in known uranium districts, and which is expected to be discoverable and economically exploitable in the given price range. The tonnage and grade of estimated additional resources are based primarily on knowledge of the characteristics of deposits within the same districts.

Consequently the Estimated Additional Resources usually do not represent material which is definitely known to be available and recoverable, but as defined above, may include, for example, postulated deposits in known uranium districts. These qualifications are given in the individual country reports. It should also be noted that a significant proportion of resources in the \$10-\$15 category is in the same deposits as the lower cost material. As mining continues at a cut-off grade appropriate for the lower costs, much of the higher cost material will be lost entirely or become even more costly for later recovery. On the other hand, the estimate of resources in the higher priced category is, overall, a very conservative one in that prospecting and exploration have been directed primarily toward the identification of lower-cost resources; thus reliability is higher for the price range below \$10 per pound and lower for the high-cost deposits.

Finally, information from the USSR, Eastern Europe and China could not be included in the report because data have not been made available. Therefore, where the word "world" is used in this report, these countries are not included.

Important note

All resources are expressed in metric tons of uranium metal (tonnes U), and for convenience are also given in short tons U_3O_8 (1 short ton U_3O_8 = 0.7693 tonnes U). The latter value is given in brackets, e.g. 1,000 tonnes U (1,300).

A conversion table is given below:

Tonnes U	Short tons U_3O_8	Tonnes U	Short tons U_3O_8
1	1.3	6	7.8
2	2.6	7	9.1
3	3.9	8	10.4
4	5.2	9	11.7
5	6.5	10	13.0

Table 1
ESTIMATED WORLD RESOURCES OF URANIUM
(Data Available January 1973)

Type of Resources Country	Price Range <\$ ¹⁾ 10/lb U ₃ O ₈				Price Range \$10-15/lb U ₃ O ₈			
	Reasonably Assured Resources (Reserves)		Estimated Additional Resources		Reasonably Assured Resources		Estimated Additional Resources	
	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈
Argentina	9.2	12	14	18	7.7	10	23	30
Australia	71	92	78.5	102	29.5	38.3	29	38
Brazil	-	-	2.5 ²⁾	3.3	0.7	0.9	-	-
Canada	185	241	190	247	122	158	219	284
Central African Republic	8	10.5	8	10.5	-	-	-	-
Denmark (Greenland)	5.6	7.0	10	13	-	-	-	-
Finland	-	-	-	-	1.3	1.7	-	-
France	36.6	47.5	24.3	31.5	20	26	25	32.5
Gabon	20	26	5	6.5	-	-	5	6.5
India	-	-	-	-	2.3	3	0.8	1
Italy	1.2	1.6	-	-	-	-	-	-
Japan	2.8	3.6	-	-	4.2	5.4	-	-
Mexico	1.0	1.3	-	-	0.9	1.2	-	-
Niger	40	52	20	26	10	13	10	13
Portugal (Europe)	6.4	9.3	5.9	7.7	1	1.3	10	13
(Angola)	-	-	-	-	-	-	13	17
South Africa	202	263	8	10.4	62	80.6	26	33.8
Spain	8.5	11	-	-	7.7	10	-	-
Sweden	-	-	-	-	270	351	40	52
Turkey	2.2	2.8	-	-	0.5	0.6	-	-
USA	259	337	538 ³⁾	700	141	183	231	300
Yugoslavia	6	7.8	10	13	-	-	-	-
Zaire	1.8	2.3	1.7	2.2	-	-	-	-
TOTAL (rounded)	866	1126	916	1191	680	884	632	821

1) \$ Value of March 1973: 1\$ = 0.829 EMA u/a = 0.829 SDR (Special Drawing Rights). This \$ value corresponds to \$42.22 per fine ounce of gold.

2) Plus 70,000 tonnes U by-product from phosphates.

3) Plus 70,000 tonnes U by-product from phosphate and copper production.

4. THE URANIUM RESOURCES POSITION IN RELATION TO DEMAND

One of the main objectives of uranium reports of this kind is to illustrate the development of the uranium resources position compared with forecasts of uranium requirements. As a first step in such an exercise, the new resource figures are compared with those from the previous report. It is not believed that the factual changes in the uranium price brackets employed to characterise the resources figures and which are explained in the foregoing chapter have as yet considerably affected the total of the resource estimates, although they may well in the future. Therefore, the working party believes the comparison is a reasonably accurate portrayal of the change in resources that has occurred.

The <\$10 reasonably assured resources (reserves) - as of January 1973 were as follows: 865,000 tonnes U (1,125,000). This compares with the estimate for the corresponding category as of 1st January, 1970 which was as follows: 645,000 tonnes U (840,000). Thus the net increase in reserves for the period 1970 to 1973 is 220,000 tonnes U.

Table 1 shows the figures from the individual countries: it also gives corresponding figures of \$10 estimated additional resources and resources in the \$10 - 15 category.

Table 2 gives annual uranium production figures on a country-by-country basis for the years 1969 to 1972. It can be seen that the annual production was relatively stable during these years and only increased from some 18,000 tonnes uranium in 1969 to about 20,000 tonnes U in 1972.

Table 3 lists annual production capacities existing in 1973 as well as planned capacities for 1975 and capacities attainable by 1978, together with the corresponding low-cost reserves supporting these production capacities.

Table 2
WORLD URANIUM PRODUCTION

Countries	1969		1970		1971		1972	
	tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈
Argentina	42	55	45	60	45	60	26	33
Australia	254	330	254	330			-	-
Canada	3,430	4,450	3,530	4,580	3,830	4,980	4,000	5,200
France	1,180	1,530	1,250	1,630	1,250	1,630	1,380	1,800
Gabon	500	650	400	520	540	700	210	270
Japan	-	-	-	-	-	-	15	20
Mexico	30	40						
Niger	-	-	-	-	430	560	870	1,130
Portugal	94	122			81	105	81	105
South Africa	3,080	4,000	3,167	4,117	3,220	4,186	3,076	4,000
Spain	55	72	51	66	60	78	60	78
Sweden	29	38	14	18	8	10	7	9
USA	8,900	11,600	9,900	12,900	9,470	12,300	9,900	12,900
TOTAL	17,600	22,880	18,610	24,200	18,930	24,610	19,660	25,550

Note: No production figures were available for India; the processing capacity of the Jaduguda mill is 1,000 tonnes of ore per day, which indicates production of a few hundred tonnes U per year.

Table 3

WORLD URANIUM PRODUCTION CAPACITIES

Countries	Reasonably Assured Resources \$10/lb U ₃ O ₈ (Reserves)				Annual Production Capacities					
	1973		Net changes since 1970		1973		Planned for 1975		Attainable 1978 ¹⁾	
	10 ³ tonnes U	10 ³ short tons U ₃ O ₈	10 ³ tonnes U	10 ³ short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈
Argentina	9.2	12	+ 1.5	+ 2	46	60	165	210	520	670
Australia	71	92	+ 54	+ 70	-	-	770	1,000	4,600	6,000
Canada	185	241	+ 7	+ 9	4,600	6,000	6,500	8,500	10,800	14,000
France	36.6	47.5	+ 2.6	+ 2.1	1,800	2,300	1,800	2,300	2,000	2,600
Gabon	20	26	+ 9.6	+ 12.5	600	780	600	780	1,200	1,560
Italy	1.2	1.6	0	0	-	-	92	120	92	120
Japan	2.8	3.6	+ 0.7	+ 0.9	30	40	30	40	-	-
Mexico	1	1.3	0	0	30	40	225	300	340	450
Niger	40	52	+ 20	+ 26	750	975	1,500	1,950	1,500	1,950
Portugal	7.4	9.6	0	0	114	148	114	148	170	220
South Africa	202	263	+ 48	+ 63	4,130	5,370	3,800	5,000		
Spain	8.5	11	0	0	115	150	132	171		
Sweden ²⁾	-	-	0	0	120	155	120	155	120	155
USA	259	337	+ 67	+ 87	14,600	19,000	14,600	19,000	26,000 ³⁾	34,000
Yugoslavia	6	7.8	+ 6	+ 7.8	-	-	-	-	230 ⁵⁾	300
TOTAL (rounded)	850	1,105	+215	+ 280	27,000	35,000	30,500	40,000	48,000 ⁴⁾	62,000 ⁴⁾

1) Given favourable market situation and adequate lead time.

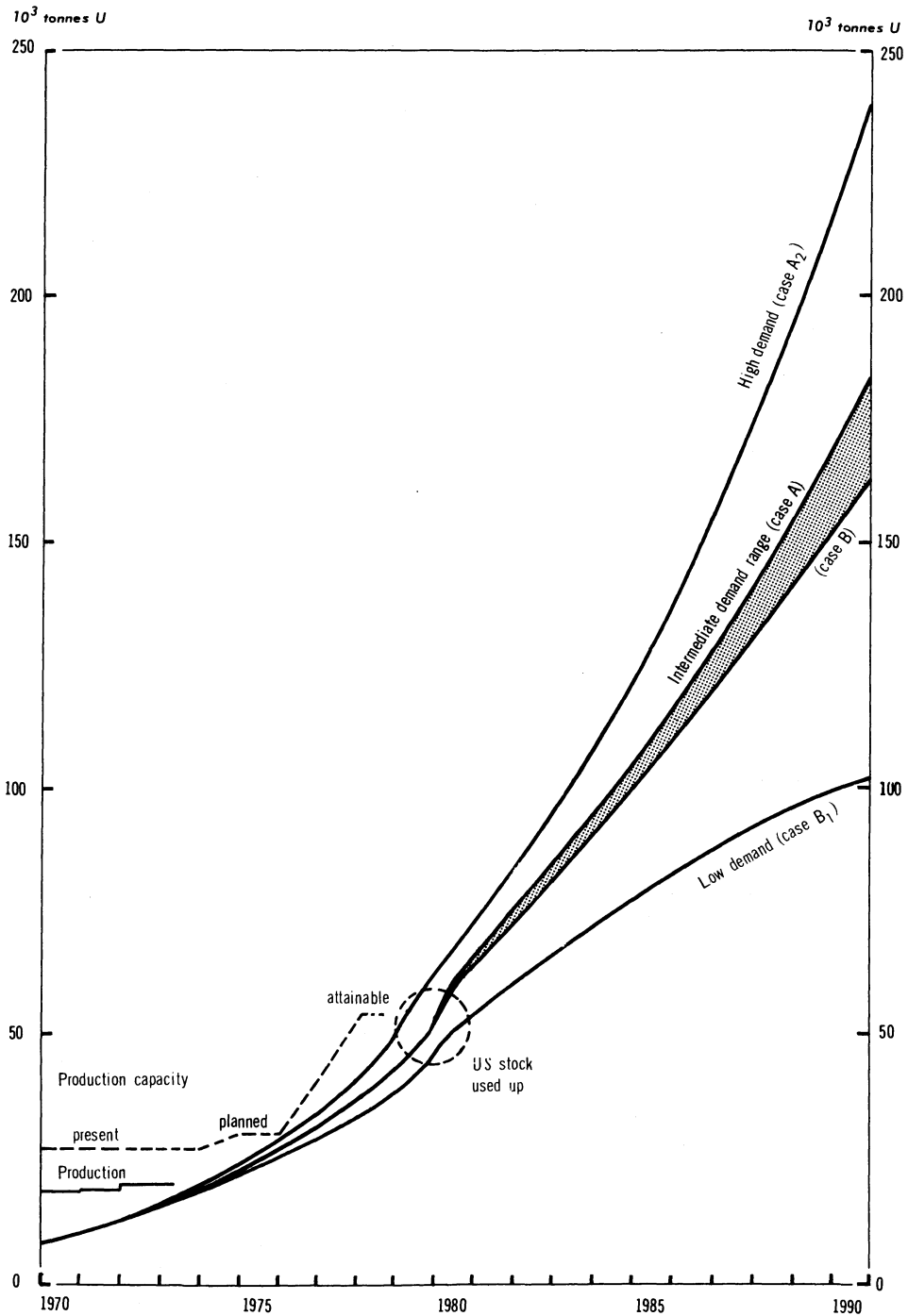
2) Production based on resources available at \$10 to 15/lb U₃O₈.

3) 1,000 tonnes by-product included.

4) Estimates for South Africa not included.

5) Construction of mine and concentration plant to be completed in 1976.

Figure 1
ANNUAL WORLD URANIUM REQUIREMENTS



Assuming recycling of plutonium in LWRs; the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing notional use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services; and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

For details see Part III, 2 and Table 7.

The Working Party on Uranium Demand, consisting of experts in reactor characteristics who are also familiar with the problems of achieving nuclear power station construction targets have estimated the most likely nuclear power station installation rates up to 1990. They have considered possible variations in these power programmes, the effects of introducing various reactor types and other assumptions on uranium demand. The results of this work are given in Part III of this report. The results in terms of annual and cumulative uranium demand respectively are summarised in Figures 1 and 2.

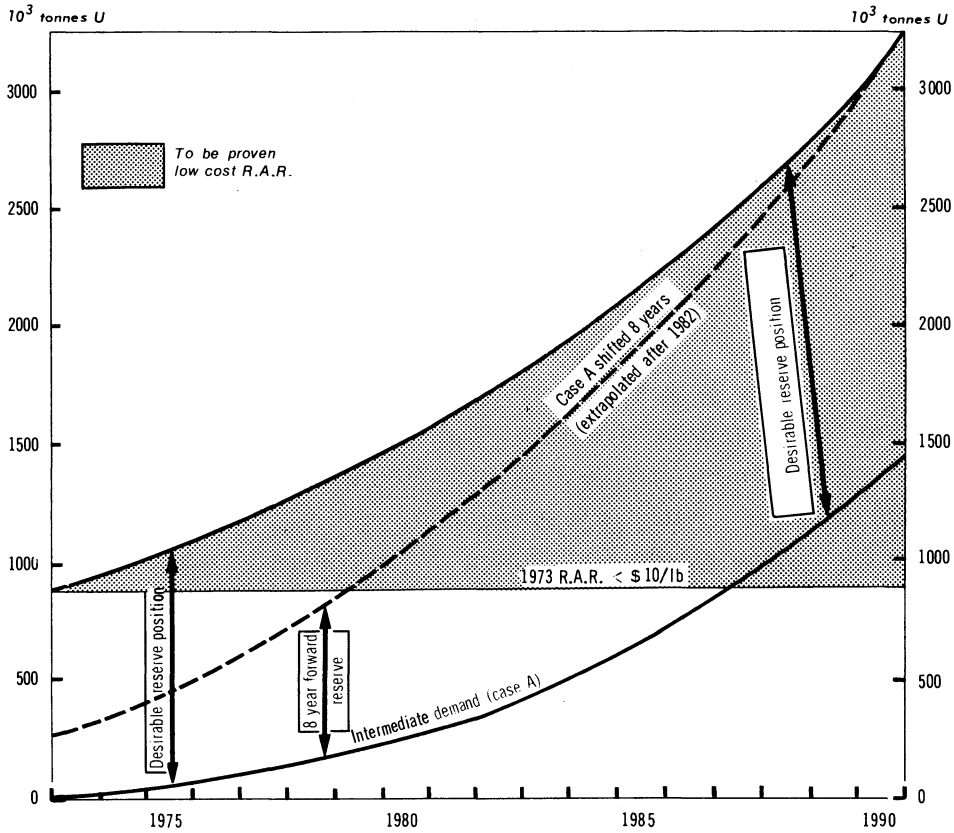
Figure 1 shows that a demand of 50,000 tonnes U per annum is likely to be reached sometime between 1979 and 1981. It is necessary to consider whether a matching production of 50,000 tonnes U per annum can be achieved by then and more particularly, whether this production rate can be sustained by the reserves available.

Figure 1 also shows an estimate of the annual production capacity attainable by 1978, given a favourable market situation and an adequate lead time. This production capacity is estimated at about 54,000 tonnes per annum, so it is unlikely that there will be any difficulty in meeting demand during the 1970s, provided, of course, that the necessary additions to capacity are made. Nevertheless, it is the opinion of the Uranium Resources Working Party that this 1978 annual production capacity is close to the ultimate or maximum production capacity which could be attained from presently known reserves and resources. Figure 1, however, shows that the annual demand is predicted to increase steadily above 50,000 tonnes per annum, so that the likely demand doubles between 1980 and 1985. The presently known reserves would not support a production rate of anything like 100,000 tonnes U per annum.

Figure 2a indicates that the present \$10 reserves, if they could all be used up, would just be sufficient to provide the fuel up to the period 1987 for the case of medium power growth and high LWR installation rates (called Case A later in the report). However, the mining industry must maintain a forward reserve of the order of eight years, production to assure uranium supply at the projected rate. This concept of an eight-year forward reserve can be conveniently illustrated by displacing the demand curve so that it lies eight years earlier, as is indicated by the curve "Case A shifted eight years" on Figure 2a. The intersection of this curve with the line indicating <\$10 uranium reserves shows that in 1979 the presently

Figure 2 a

RELATIONSHIP BETWEEN URANIUM RESERVES AND CUMULATIVE REQUIREMENTS¹

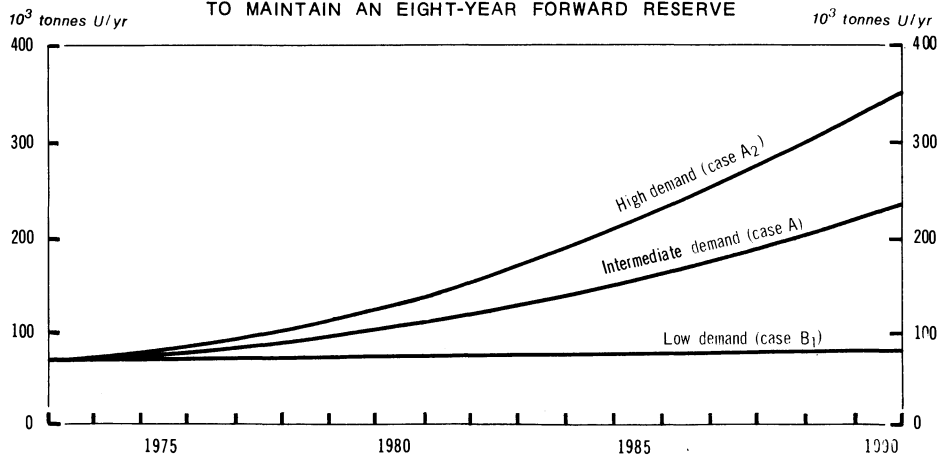


* For more details see Figure 4 and Part III, 2.

Assuming recycling of plutonium in LWRs: the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing notional use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services; and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

Figure 2 b

DESIRABLE DISCOVERY RATE FOR LOW COST R.A.R.
TO MAINTAIN AN EIGHT-YEAR FORWARD RESERVE



ERRATA

Page 51 - 2ème paragraphe

Lire les 4ème et 5ème lignes comme suit :

"Saskatchewan, la Gulf Minerals Canada Limited en collaboration avec Uranerz Canada Limited, prépare son projet d'exploitation du gisement d'uranium"

Page 52 - 3ème paragraphe

Lire la 7ème ligne comme suit:

"Lake par la Gulf Minerals Canada Limited et Uranerz Canada Limited illustre parfaitement à la"

Page 53 - Tableau

Supprimer les chiffres de la dernière ligne: "1.800 2.000"

ERRATA

Page 40 - 4th paragraph, 4th line

Should read: "Gulf Minerals Canada Limited, in partnership with Uranerz Canada Limited, is"

Page 40 - 4th paragraph, 6th line

Should read: "rate of 1730 tonnes uranium (2,250) per year beginning in 1975, based"

Page 41 - 4th paragraph, 5th and 6th lines

Should read: "regard, the recent development of the Rabbit Lake deposit by Gulf Minerals and Uranerz is an excellent illustration of both the lead-time and"

Page 42 - Table, Penultimate line

Should read: "Limited, in partnership with"

Therefore delete once: "Rabbit Lake, Sask. 1,800 2,000"

Page 110 - Table 12, Caption, Line 6

Replace: "national" by "notional"

known reserves would just correspond to this eight-year reserve. Since a substantial portion of the world reserves are in countries (e.g. South Africa) where the reserves could not be produced in that time-frame, but rather over a period of 20 years or more, the eight-year reserve position worldwide is likely to be inadequate to provide needed production levels. Furthermore, if no new exploration efforts were undertaken until 1979, the annual discovery rates for new reserves would then have to be rather high, of the order of 150,000 tonnes U. Such discontinuity in exploration activities should certainly be avoided and Figure 2a indicates a desirable reserve position resulting from a smooth increase of the mean discovery rate in the past eight years, of some 65,000 tonnes U per year, to a rate of 230,000 tonnes U per year in 1990. If discoveries would follow such a curve, an eight-year forward reserve would still be maintained in 1990. In Figure 2b such desirable discovered rates are also given for the minimum and maximum demand curves which are shown in Figure 1 and which, for the sake of clarity, were not included in Figure 2a.

The question is how to achieve such an increase in the rate of discovery of uranium as the most likely case requires. The exploration effort throughout the world is not increasing sufficiently to attain this objective. This situation is directly related to the present oversupply of uranium and the consequently depressed state of the market. Not only is there unused production capacity, but the uranium output in recent years has exceeded demand, causing a build-up of stockpiles and inventories.

Although this situation of over-supply is periodically encountered in the mineral industries, it is hard to draw a parallel with the uranium case when confronted with an exceptionally high growth in which a doubling of annual uranium requirements in five years is forecast. The magnitude of this challenge is brought more clearly into focus when viewed in the context of the lead times necessary for exploration and subsequent preparation of new production facilities.

Considering the development of uranium demand, it should also be borne in mind that even if no more reactors were ordered from now onwards, those presently operating or contracted for (some 200 GWe), would require a total of some 600,000 tonnes during their lifetime and the annual demand would be not less than 25,000 tonnes U per year by 1980. However, according to the assumptions made in this

report, the annual demand will achieve the range of values indicated in Figure 1, i.e. of the order of 50,000 tonnes per annum by 1980 and 100,000 tonnes per annum by 1985.

The important inference from this report is that it is essential that urgent steps be taken to increase the rate of exploration for uranium so that an adequate forward reserve may be achieved. The necessary incentives for exploration will vary according to the circumstances of individual countries. Current uranium prices are generally not adequate to induce the necessary exploration, or the increased expansion of production capability needed. Some means should therefore be found to ensure that the production levels required are achieved so as to avoid shortage and an unstable market in the 1980s. It is important that this matter be fully appreciated by governments, utilities and mining companies.

Part II

URANIUM: RESOURCES AND PRODUCTION

1. NATIONAL REPORTS ON URANIUM PROSPECTING, RESOURCES AND PRODUCTION

ARGENTINA

Recent Developments

In connection with the data appearing in the ENEA/IAEA report of September 1970, special reference is made to the points listed below relating to the development of uranium resources in the Argentine Republic.

The regular aerial prospecting programmes have been continued and a new uranium-bearing district (Sierra de Pichinán) has been discovered in the Chubut Province. This district is situated 30 km to the west-north-west of the district known as "Los Adobes" and is considered to be of moderate interest.

Various uranium-bearing bodies have been found in sub-horizontal sedimentary rocks (sandstone and conglomerate) from the Cretaceous period.

Physical exploration by means of drilling was started in 1971 and is continuing.

Exploration work has been resumed in the district of Sierra de Conechingones (San Luis Province), after it had been suspended nearly ten years ago. This time new geological and structural concepts are being applied. The importance of this zone, which originally seemed very slight, has increased since evidence has been found of the continuity of certain uranium-bearing bodies, i.e. those affected by tectonics. These deposits are located in disturbed areas within Palaeozoic granites.

Physical exploration by means of drill holes was resumed in 1971 and was continued in 1972 in sectors of the district which are already known. Prospecting will be extended in the direction of those

granite-bearing areas in which the structural conditions are similar to those containing uranium-bearing bodies.

Major exploration efforts were made in the Sierra Pintada district of Mendoza Province, where a drilling plan which had been interrupted some years ago for budgetary reasons is now being continued.

So far the figure for reasonably assured resources is estimated at 5,000 tonnes uranium (6,500) and it is believed that the potential of the district is of the order of 9,000 tonnes uranium (12,000), with an average content of 0.13 per cent uranium (0.15 per cent U_3O_8). The thickness of the mineralized bodies sometimes exceeds 20 m.

Apart from the Sierra Pintada district, where the main development of uranium-bearing resources has taken place, there have been no noteworthy changes as far as the rest of the country is concerned.

Resources

At present, for costs of less than \$10/lb U_3O_8 , the figure for Argentina's reasonably assured resources is 9,200 tonnes uranium (12,000) and 14,000 tonnes uranium (18,000) for estimated additional resources.

For the cost category between \$10 and 15/lb U_3O_8 , the estimate for reasonably assured resources is 7,700 tonnes uranium (10,000) and for estimated additional resources 23,000 tonnes uranium (30,000).

Virtually all of Argentina's uranium resources of major interest are contained in sedimentary rock of the continental or transitional type (Tertiary, Cretaceous and Permian).

The distribution of resources according to different price categories was calculated on the basis of the cost of ore exploration and hydrometallurgical tests of ore concentration in each uranium-bearing district.

Production

The production of uranium concentrates in Argentina is still being carried out in small plants or pilot installations, whose total output is between 35 and 45 tonnes uranium (45 and 60) per annum. This output is intended for the 320 MWe reactor at Atucha (Buenos Aires Province) which is to go into operation in 1973. Obviously the cost of producing this yellowcake is higher than it would be in plants operating on an industrial scale.

The Malargüe plant (Mendoza Province), with a production capacity of 35-40 tonnes uranium (45-50) per annum, is producing concentrates at the rate of 27 tonnes uranium (35) per annum, processing ores from the same district and recovering cement copper as a special product. It is working with amine solvents and obtaining yellowcake with a content of more than 70 per cent uranium (80 per cent).

In the "Don Otto" district (Salta Province), the secondary ores are still being treated by heap leaching, but since the end of 1970 the production of preconcentrates by direct calcium precipitation has been discontinued because a pilot plant using ion exchange resins came into operation and is producing yellowcake of grades higher than 60 per cent (70 per cent).

Work has now started on the Los Adobes (Chubut Province) project with a view to providing it with heap leaching facilities and an amine solvent plant which will give it the capacity to produce up to 35 tonnes uranium (45) per annum of yellowcake in 1974.

A major portion of the hydrometallurgical studies on the ore resources of the Sierra Pintada district (Mendoza Province) has now been completed and it is assumed that it will be possible to produce yellowcake from it at a cost of approximately \$10/lb uranium with a plant operating on an industrial scale.

It is planned that this plant should have an initial production capacity of 350 tonnes uranium (450) per annum in 1977 and that this should be increased annually until it reaches 700 tonnes uranium (900) in 1981. The ore from the district will have to be processed by alkaline methods.

The pilot plant at Córdoba for the refining of preconcentrates was destroyed by fire. It will be replaced by new installations which are now under construction and which will make it possible to obtain products of nuclear purity (uranyl nitrate or UTC). Production capacity will be 90 tonnes uranium (115) per annum. These installations came into operation in the second half of 1972.

AUSTRALIA

Recent Developments

The search for uranium in Australia has increased significantly in recent years and has resulted in a substantial increase in resources. Although uranium mineralization has been discovered at a number of localities throughout Australia in host rocks of various ages, the major economic discoveries to date are confined to rather narrow zones of the Precambrian Shield principally in the Northern Territory, Queensland and South Australia and in Tertiary sediments derived from the Precambrian rocks.

During the past two years, drilling programmes have outlined substantial new reserves in deposits workable by open-pit mining in the Northern Territory, Queensland, South Australia and, more recently, in Western Australia.

Reasonably Assured Resources

Uranium resources developed to date in Australia have all occurred in small-to-medium-sized hydrothermal fissure vein-type deposits. These were all in rocks of Precambrian age and ranged in grade from 0.065 to 0.85 per cent (1.5 to 20 lb U_3O_8 per short ton).

In three areas in particular, substantial new reserves have been proven. These are the Alligator Rivers Uranium Field in the Northern Territory, the Westmoreland area in Queensland and the Mt. Painter/Lake Frome Basin area in South Australia. In the case of the first area, formations exhibiting anomalous radioactivity were known previously and the southernmost of the new discoveries is only 45 km from the South Alligator Field where a number of relatively small, but rich, uranium deposits have been mined. The occurrence of uranium in the other two areas was also known previously, but their potential was not recognised.

The renewed exploration effort has increased the reasonably assured resources in conventional deposits recoverable at up to \$10 per lb U_3O_8 by 54,100 tonnes uranium (70,300) and in the \$10-15 per lb U_3O_8 category by 22,800 tonnes uranium (29,600).

The deposits in the Northern Territory include both typical vein-type and large disseminated-type of ore-bodies. The ore mineral is usually pitchblende. Although the ore-bodies include some

exceptionally high-grade ore - up to 78 per cent in places - the average grade of exploitable ore outlined to date is of the order of 0.4 per cent uranium (0.5 per cent). Thus the Alligator Rivers Uranium Field, which contains almost 80 per cent of reasonably assured resources in the less than \$10 per lb category, must be regarded as of major world importance.

Numerous uranium deposits have been found in volcanics and sediments of Carpentarian age (1800-1400 million years) in a narrow zone extending from Calvert Hills, near the Northern Territory/Queensland border, to Mary Kathleen near Mt. Isa - a distance of more than 500 km. The Westmoreland deposits, situated near the border, consist of pitchblende in a shear-zone adjacent to a trachyandesite dyke which follows a joint-plane in a conglomerate, and within the sandstones and conglomerates adjacent to the dyke. Secondary mineralization has also been encountered which in places extends laterally up to 1700 m from the original source. Although a number of small uranium deposits have been discovered in the general Mt. Isa belt, only a few have been proven to be of economic interest because of the refractory nature of the mineralization and the presence of acid-consuming gangue. Finally, the Mary Kathleen deposit contains significant reserves capable of exploitation by open-pit mining.

In the Mt. Painter area of South Australia, substantial resources have been discovered in Archaean granite and gneissic rocks, as well as in hematitic breccia masses, as a result of an intensive drilling programme. In addition, an extensive drilling programme for sedimentary uranium deposits has been carried out in the Lake Frome Basin and three deposits have been discovered to date near Lake Frome.

Estimated Additional Resources

Significant uranium mineralization has been discovered recently in a number of areas in addition to those described above. However, it is too early to predict the total resources which will be outlined in these additional areas as exploration and evaluation proceeds. Hence no allowance has been made for their potential in the estimated additional resources category. The figures given for the two price ranges are thus very conservative and may be regarded as an estimate of further reserves likely to be discovered in the known uranium fields by the use of conventional exploration and processing techniques.

From the data available, with continued exploration the prospects for discovery of further resources in the Alligator Rivers Uranium Field are most promising, and it would be reasonable to expect that, over and above the presently established reasonably assured resources recoverable at less than \$10 per lb, an additional 77,000 tonnes uranium (100,000) will be discovered in the next five years at the present rate of exploration.

A number of occurrences of significant uranium mineralization have been reported recently as a result of drilling programmes in Tertiary sediments in both South Australia and Western Australia, and further discoveries of uranium deposits seem likely as exploration continues.

A drilling programme is in progress to test the discovery of significant uranium mineralization over an extensive area near Yeelirrie, about 600 km north-east of Perth. From the limited information available, it would appear that there is an extensive, mainly flat-lying shallow deposit of sedimentary uranium infilling old drainage channels which would be amenable to open-pit mining. The ore mineral appears to be predominantly carnotite and the uranium appears to have been leached from the nearby granite. Although there has not been sufficient detailed work completed so far to enable valid predictions to be made on tonnage, grades or economically exploitable ore reserves, average grades of about 0.11 per cent uranium (2.7 lb U_3O_8 per short ton) have been indicated by drilling to date. There are, of course, areas of higher grade material but further detailed evaluation work will be necessary before ore reserve estimates can be made.

No significant economically exploitable uraniferous conglomerates have been discovered to date but preliminary shallow drilling in the Kimberley and Pilbara areas of Western Australia has confirmed the presence of radioactive minerals, and recent exploration results indicate that it is possible that large low-grade resources of Witwatersrand/Blind River-Type deposits may be present in these areas.

Although a number of uranium discoveries have been made recently in the West Australian Shield area, very little is known about them at this stage. Nevertheless, the geological potential is excellent for a substantial increase in resources beyond those shown in the Table as exploration proceeds.

Uranium has been found to occur at levels averaging less than 0.01 per cent uranium in major reserves of phosphate rock in north-west Queensland. However, whilst this represents a significant resource, at this stage it is not possible to indicate the extent of the reserves or possible cost of recovery. By the same token no allowance has been made in the resource estimates for uranium recovered by heap leaching, or as a by-product of treatment of other mineral deposits such as fluorite, vanadium and/or copper in Queensland and Western Australia, even though these represent a significant resource.

Estimated Resources of Uranium

Price Ranges	Reasonably Assured		Estimated Additional	
	Tonnes U	Short tons U ₃ O ₈	Tonnes U	Short tons U ₃ O ₈
\$10/lb U ₃ O ₈	70,800	92,000	78,500	102,000
\$10-15/lb U ₃ O ₈	29,500	38,300	29,200	38,000

Production

The Rum Jungle treatment plant was closed in April 1971 and dismantled. At present there is no production of uranium ore concentrate in Australia. The plant at Mary Kathleen has been kept on a care-and-maintenance basis since 1964. After modification it is planned to resume production in this plant by early 1975 with an annual capacity of about 800 tonnes uranium (1,000).

Three of the companies which have discoveries in the Alligator Rivers Uranium Field, Northern Territory, are engaged in studies of mining and milling operations. The timing for commencing these developments and their respective annual production of yellowcake has not yet been finalised. However, it is reasonably certain that by the latter part of the 1970s plants with a combined capacity of about 3,800 tonnes uranium (5,000) per annum will have been constructed. The actual yearly production until about 1980 will depend, among other factors, on developments in the world supply and demand position. When the market position improves in the early 1980s it can be expected that expansion of production would occur in the Alligator Rivers Uranium Field.

At present one can only speculate on the timing of operations and level of production of yellowcake which may occur at uranium deposits elsewhere in Australia. It would be reasonable, however, to expect a minimum total annual production of about 9,000 tonnes uranium (12,000) equivalent by perhaps 1982.

BRAZIL

Recent Developments

A great number of promising occurrences have been discovered in Brazil, but only in 1970 were sufficient funds allocated to intensify exploratory drilling activities and underground work.

The uranium exploration budget for 1970 was increased more than five times as compared to the 1969 budget and since then at a rate of about 40 per cent a year. In 1973, 42 geologists are exclusively engaged in planning, co-ordinating, supervising and controlling 37 projects, contracted with different organisations. This year, the expenditure, with uranium exploration, will reach the sum of 8.5 million dollars. For next year it is estimated that the budget will rise to around 11 million dollars.

Since 1970 until the present time, ten of the most promising uranium occurrences in Brazil are being evaluated by intensive drilling. The more favourable provinces geologically are being surveyed by different exploration methods, namely by airborne radiometry and airborne gamma spectrometry, geochemistry, carborne radiometry, emanometry and others. As a consequence, two small size deposits have been evaluated in the Poços de Caldas plateau and some promising occurrences in the Cambui-Figueira district, State of Parana and in the Iron Quadrangle, south of Belo Horizonte, State of Minas Gerais, could lead to the definition of medium-to-large deposits in a few years, depending on the results of the drilling programmes which are now being intensified.

Resources

The uranium-bearing deposits of Poços de Caldas, State of Minas Gerais, occur in an intrusive pipe of alkaline rocks covering

RESOURCES

Price Range up to \$10/lb U ₃ O ₈				Price Range \$10-15/lb U ₃ O ₈			
Reasonably Assured Resources		Estimated Additional Resources		Reasonably Assured Resources		Estimated Additional Resources	
10 ³ tonnes U	10 ³ short tons U ₃ O ₈	10 ³ tonnes U	10 ³ short tons U ₃ O ₈	10 ³ tonnes U	10 ³ short tons U ₃ O ₈	10 ³ tonnes U	10 ³ short tons U ₃ O ₈
2.4	3.1	2.5	3.3	0.9	1.2	1.8	2.3

900 square kilometres. They are vein-type deposits, although the one known as "C-09", has a rather low dip with lenticular shape. The uraniferous mineralization is associated with fluorite, pyrite, zircon, molybdenum minerals and others. The country rock is a nepheline-syenite and is altered by hydrothermalism.

The C-09 deposit contains 2,400 tonnes U (3,120) as reasonably assured resources, evaluated by drilling. The estimated additional resources amount to 2,540 tonnes U (3,300). Feasibility studies showed that uranium could be produced at a cost around \$10/lb U_3O_8 .

The Agostinho deposit is a vein containing 940 tonnes U (1,220) as reasonably assured resources and 1,770 tonnes U (2,300) as estimated additional resources, evaluated by drilling, shafts and galleries. The material is rather refractory to treatment because part of the uranium is in the crystalline lattice of zirconium minerals. Feasibility studies to recover uranium showed that it could be produced at a cost between \$10-15/lb U_3O_8 , taking into account the production of MoO_3 .

Production

Small amounts of uranium concentrate and a large quantity of thorium are recovered as by-products in the process of rare-earths extraction from monazite, which occurs in sand beach deposits, along the Brazilian Atlantic coast.

The recently created Brazilian Nuclear Technology Company (CBTN - Companhia Brasileira de Tecnologia Nuclear), a subsidiary of the Brazilian Nuclear Energy Commission, is planning the exploitation of the C-09 deposit, by an already developed process with 75 per cent extraction of the uranium content. The estimated production capacity of the milling plant is 190 tonnes/year of uranium (250).

CANADA

Recent Developments

In reviewing the status of Canada's uranium resources, reference is made to the 1970 ENEA/IAEA Report entitled Uranium Resources, Production and Demand and the study initiated in mid-1969 by Canada's

Department of Energy, Mines and Resources to re-evaluate Canada's uranium resources. This study has continued and, while efforts have been directed primarily toward a refinement of geological criteria for assessing areas with favourable uranium potential, both new and revised data have been obtained from selected companies where appropriate. The results of this continuing study are summarised for the purpose of this report.

Basically, the following procedure was used in developing the resource figures presented below. The Department first solicited the assistance of all present and prospective uranium producers in Canada. Individual companies submitted data, divided into given classifications of reliability and within given price ranges, based on their total costs and their acceptable margins of profit. These data were then assessed in the light of previous reserve and production figures and recent additions to geological knowledge of the respective areas. Finally, aggregated national totals were developed within the framework of the current NEA/IAEA definitions, as revised in the 1970 ENEA/IAEA Report.

For the latter purpose, the reasonably assured resources category was equated to the summation of measured and indicated reserves, as defined by the United States Bureau of Mines. Inferred reserves were included in the estimated additional resources category together with estimates for resources surmised to occur in unexplored extensions of known deposits, or in undiscovered deposits in known uranium districts.

It should be appreciated that, inherent in the aggregation procedure, there is an element of judgement involved, together with a degree of reliance on the data submitted by the companies. The latter is particularly true with respect to the classification of resources by price. In the aggregate, however, it is believed that the totals produced illustrate with reasonable accuracy the known resources available in Canada. Indeed, the total produced in the category of reasonably assured resources, exploitable at up to \$10/lb U_3O_8 , is judged to be within 10 per cent.

Reasonably Assured Resources

Reasonably assured resources of uranium exploitable at up to \$10/lb U_3O_8 are estimated at 185,000 tonnes of uranium (241,000), a net increase (after production) over the figures published in 1970. In arriving at these tonnages, allowance has been made both for the

amount of ore that can be recovered by mining, particularly in the case of the Elliot Lake area where recovery is about 80 per cent of ore in place, and for extraction in ore treatment, which averages about 95 per cent of mill feed. The increase over the 1970 reserve figures is primarily a reflection of results of exploration programmes begun in the late 1960s.

About 80 per cent of these resources are contained in quartz-pebble conglomerates in the Elliot Lake and Agnew Lake areas of Ontario. They occur at or near the base of the Huronian succession, and occupy local basins that are unconformably overlain by younger Huronian strata. The average grade of the resources in this category is about 0.09 per cent uranium (about 2 lb U_3O_8 /short ton). Most of Canada's remaining reasonably assured resources in the \$10 category are in pitchblende-bearing veins or related deposits which occur primarily in Saskatchewan and Newfoundland (Labrador). All of these deposits are tectonically controlled and are adjacent to major faults or fault zones that in the Canadian Shield usually trend north-easterly; some lie at the intersection of faults. Most are of relatively simple mineralogy and grades are generally in the range of 0.17 to 0.34 per cent uranium (4 to 8 lb U_3O_8 /short ton). Reasonably assured resources occurring in pegmatites within the \$10 price category are relatively small and limited at present to the Bancroft area of Ontario. These are unzoned red pegmatites with average grades between 0.09 and 0.17 per cent uranium (2 and 4 lb U_3O_8 /short ton).

Reasonably assured resources of uranium exploitable at between \$10 and \$15/lb U_3O_8 are estimated at 122,000 tonnes of uranium (158,000), an increase of some 20 per cent above previously published figures. Almost 90 per cent of these resources occur as conglomeratic deposits in the Elliot Lake and Agnew Lake areas, where extensive lower grade horizons have been intersected during exploratory drilling directed toward higher grade ores. Because of the tabular nature of these bodies, it is possible to calculate with reasonable accuracy their extent, thickness and grade, which generally ranges from 0.05 to 0.07 per cent uranium (1.2 to 1.6 lb U_3O_8 /short ton). A portion of the resources assigned to this category is uranium that can be recovered from Elliot Lake pillars using present bacterial leaching technology.

The remaining reasonably assured resources in the \$10 to \$15 category are about equally distributed between vein and pegmatitic deposits; the former occur in Saskatchewan, Labrador and British Columbia, whereas the pegmatites occur in the Bancroft area. Data on such resources are relatively limited since producers and prospective producers alike have been concentrating their efforts on further developing reserves in the lower priced category and often have not formally assessed their lower grade (higher priced) resources.

Estimated Additional Resources

Estimated additional resources of uranium exploitable at up to \$10/lb U_3O_8 are estimated at 190,000 tonnes of uranium (247,000), an increase over the figures published in 1970. Almost one-third of this total is attributable to inferred reserves, while the remainder comprises resources that are surmised to occur in unexplored extensions of known deposits, or in undiscovered deposits in metallogenic provinces in which uranium of ore grade is known to occur (i.e. known uranium districts). While there has been some reassessment of potential in all known districts, the increase is due largely to developments over the past three years in northern Saskatchewan and the consequent improvement in uranium potential for this province.

Estimated additional resources of uranium exploitable at between \$10 and \$15/lb U_3O_8 are estimated at 219,000 tonnes of uranium (284,000), also an increase over previously published figures. Because exploration efforts have primarily been directed toward lower priced resources, only some 10 per cent of this total is attributable to inferred reserves. The increase over previously published figures is primarily a result of an extension of geological knowledge in all 'known uranium districts'.

About 65 per cent of the estimated additional resources in both price categories occurs as uraniferous quartz-pebble conglomerates in the Elliot Lake-Agnew Lake areas of Ontario. Most of the remainder, again in both price categories, occurs as pitchblende-bearing vein or related deposits in Saskatchewan, Labrador, British Columbia and the Northwest Territories. In the context of 'known uranium districts', pegmatites account for only a small portion of estimated additional resources and consequently are limited to the Bancroft area of Ontario.

Other Potential Resources

There are numerous regions of Canada that are geologically favourable for uranium, in many of which uranium has been detected but not yet discovered in sufficient quantity and grade to constitute ore, and thus cannot be included, by ENEA/IAEA definition, in a statement of estimated additional resources. From a geological viewpoint, however, it is expedient to discuss the uranium potential of all favourable areas together, keeping in mind that only the potential resources in 'known uranium districts' are included in the 'estimated additional resources' described above.

The most immediate and recognisable uranium potential in Canada is associated with the uraniferous quartz-pebble conglomerates of the Early Proterozoic Huronian succession in the Elliot Lake and Agnew Lake areas of Ontario. Because of their stratiform nature such deposits offer a most reliable and accurate estimate of potential. Much exploration money has been expended in this region, as well as in parts of Quebec and the Northwest Territories where radioactive quartz-pebble conglomerates of equivalent age are known to exist. However, no deposits of economic significance have yet been reported in these latter areas.

Uranium deposits of the vein and replacement type offer, next to quartz-pebble conglomerate deposits, the greatest potential at the present time. The most favourable areas, in the light of present knowledge, are the Port Radium-Marian River, Baker Lake-Amer Lake, and Great Slave Lake-Nonacho Lake areas in the Northwest Territories, the Uranium City area, the Carswell Dome and the Wollaston Lake Belt in northern Saskatchewan, and the Makkovik-Seal Lake area in Labrador. Vein and replacement deposits also occur in British Columbia, and the geological environment of certain parts of the Cordillera is favourable for the occurrence of larger deposits than have yet been discovered.

No roll or peneconcordant uranium deposits in sandstones have yet been identified in Canada, perhaps because there has been comparatively little exploration for them. However, several areas in Canada are geologically favourable and, of these, the Carboniferous basin of the Maritime Provinces has the greatest potential because some uranium occurrences are known and many anomalies in the uranium content of stream sediments have been found there. Somewhat similar conditions exist in Cretaceous and Tertiary continental

sediments of the Cordilleran foreland, and in Tertiary basins within the Cordillera where, in two places, interesting values have been found in conglomerate channels.

Lignitic uranium deposits are known and have been explored in the early Tertiary beds of the Cypress Hills, southern Saskatchewan, but initial exploration was not sufficiently encouraging and drilling was abandoned in 1969. Uraniferous lignites have never been an important source of uranium and, with the growing emphasis on preservation of the environment, even if they were of ore grade, their exploitation would likely be limited.

Significant production has been obtained, prior to 1964, from pegmatitic uranium deposits in the Bancroft area of Ontario. Since 1968, additional reserves and potential resources have been identified in the area but these are not profitable at current prices. Although there has been much exploration activity on pegmatitic deposits elsewhere in the Grenville Province of Ontario and Quebec, and in eastern Ontario, northern Saskatchewan and adjacent parts of Alberta, Manitoba and the Northwest Territories, no deposits have been reported of size and grade to be currently economic. The importance of pegmatites as resources likely lies in the \$10 to \$15 price category.

Although there is some possibility in Canada that uranium may be obtained as a by-product of niobium production or from phosphate rock treated in the fertilizer industry, these sources have not yet been considered in the evaluation of Canada's uranium resources, since such production is not likely in the near future.

Production

Canadian uranium production in 1972 totalled 4,003 tonnes of uranium (5,204) of which some 3,768 tonnes (4,898) were shipped; over 85 per cent of this total came from Denison Mines Limited and Rio Algom Mines Limited which produce from quartz-pebble conglomerates in the Elliot Lake area of Ontario. The remainder came from Eldorado Nuclear Limited, a Crown-owned company, which produces from pitchblende-vein deposits in the Uranium City area of northern Saskatchewan. All are underground operations; total capacity of the three milling plants presently in operation is estimated at about 4,600 tonnes of uranium per year (6,000).

Since late 1966, Canadian producers have negotiated contracts totalling over 56,000 tonnes of uranium (73,000) for deliveries into the early 1980s. Of the 56,000 tonne (73,000) total, some 7,300 tonnes

of uranium (9,500) had been delivered to the end of 1972. Early in 1972, Canadian deliveries to Britain under the old "master" contract (1962 UKAEA option) were completed.

The Federal Government's five-year uranium stockpiling programme came to an end on 30th June, 1970. This was the second such programme designed to assist the industry after the collapse of markets in the late 1950s and early 1960s. The first was a one-year programme in 1963-64. Under these two programmes the Federal Government accumulated some 7,400 tonnes of uranium (9,600) at a total cost of some \$101 million. Subsequently, in view of the continuing poor short-term market situation, the Government indicated its willingness to consider further assistance to the industry, as a means of indirectly supporting established uranium communities. In late 1970, it was announced that Denison and the Federal Government had entered into a joint-venture stockpiling agreement whereby Denison would deliver up to 2,488 tonnes of uranium (3,234) into a joint stockpile over the period 1971 to 1974. The latter material, together with some of the Government's general stockpile (noted above), has now been committed to a group of Spanish utilities under a sale announced in early 1972.

As noted above, Canada's uranium industry is not currently operating at its full in-service capacity. Moreover, the industry has a capability to increase its capacity significantly beyond this level based on presently known reserves. All three producers have made plans to expand and/or reactivate their existing facilities as markets require. In this respect, in late 1972, Denison announced plans for a mill expansion to be completed by 1975. In addition, certain past producers still have a capability and may reactivate their facilities subsequent to obtaining suitable base-load contracts.

As a result of a renewed exploration effort in Canada, which began in 1966, two new prospective producing operations have been developed. First, in the Wollaston Lake area of northern Saskatchewan, Gulf Minerals Canada Limited, a subsidiary of German companies, are preparing their Rabbit Lake uranium project for production at the rate of 1730 tonnes (2,250) of ore per year beginning in 1975, based on a contract with German interests. The deposit, which is a pitch-blende replacement deposit, will be mined by open-pit methods; the project will cost an estimated \$50 million. Second, in the Agnew Lake area, about 40 miles east of Elliot Lake, Ontario, a new

operation has been developed by Agnew Lake Mines Limited. Although the project had reached an advanced stage of underground development, the company has been unsuccessful in negotiating a sales contract. Consequently, construction of the planned \$15 to \$20 million, 2,700-tonnes-a-day (3,000) mill has not yet begun, and development operations were suspended in early 1971; some \$15.4 million had been spent on the project to the end of 1971.

To summarise these various capabilities, it is expected that Canada's uranium production capacity will increase, following the completion of the Gulf-Uranerz project and the Denison mill expansion, to about 6,500 tonnes of uranium (8,500) per year by 1975. Although there are no firm plans beyond this, the industry could expand its productive capacity, based on presently known reserves to about 10,800 tonnes of uranium (14,000) a year. This expansion would necessitate additional sales and would take up to five years to complete.

Expansion beyond a level of about 10,800 tonnes of uranium (14,000) a year will depend largely on the development of additional reserves. Although there are a number of promising uranium exploration programmes underway in Canada, activity in general has declined to a very low level since 1969. While the decline is largely attributable to the poor short-term market outlook, an additional contributing element appears to be related to the unknown factors which might attend Federal Government legislation, yet to be enacted, limiting the degree of non-Canadian ownership in the Canadian uranium industry. Hopefully a resurgence in Canadian uranium exploration will occur as the market outlook improves and the ownership legislation is promulgated.

As noted above, the potential for additional uranium discoveries in Canada is considered excellent and, given adequate economic incentive and sufficient lead-time, reserves will undoubtedly be developed upon which new productive capacity can be based. In the latter regard, the recent development of Gulf Minerals' and Uranerz' Rabbit Lake deposit is an excellent illustration of both the lead-time and the effort required to bring a new operation to production. Discovered in late 1968, as a result of an exploration programme begun two to three years earlier, the deposit will not reach production until 1975, the seventh year after discovery; cost of the development, exclusive of most of the initial exploratory effort,

Uranium Milling Plants in Canada

Company	Location	Nominal Capacity	
		Tonnes /day	Short Tons/day
A) <u>Active</u>			
Denison Mines Limited	Elliot Lake, Ont.	5,400	6,000 ^{a)}
Eldorado Nuclear Limited	Eldorado, Sask.	1,600	1,800
Rio Algom Mines Limited - Quirke Mill	Elliot Lake, Ont.	4,100	4,500
B) <u>Inactive</u>^{b)}			
Can-Fed Resources Limited	Bancroft, Ont.	1,400	1,500
Preston Mines Limited	Elliot Lake, Ont.	2,700	3,000
Rio Algom Mines Limited - Nordic Mill	Elliot Lake, Ont.	3,400	3,700
- Panel Mill	Elliot Lake, Ont.	2,700	3,000
Stanrock Uranium Mines Limited*	Elliot Lake, Ont.	2,700	3,000 ^{c)}
C) <u>Under Construction</u>			
Gulf Minerals Canada Limited	Rabbit Lake, Sask.	1,800	2,000
Uranerz Canada Limited	Rabbit Lake, Sask.	1,800	2,000

- a) Present leaching capacity limited to about 4,000 tonnes (4,400) per day. Mill expansion to 6,400 tonnes (7,100) per day scheduled for 1975.
- b) Capacities listed refer to capacities at time of closure; other past producing mills have been dismantled.
- c) Partly dismantled; recovery of uranium from mine water only, 1964 to 1970.

* Amalgamated with Denison Mines Limited effective 12th February, 1973.

will be an estimated \$28,900 per annual tonne of uranium (\$22,200 per annual short ton U_3O_8)*. Indeed, had the deposit been an underground rather than an open-pit proposition, both the lead-time and the cost would most likely have been greater.

* Historically, capital costs in Canada's uranium industry (to 1959) averaged between \$34,800 and \$36,800 per annual tonne uranium (\$26,800 and \$28,300 per annual short ton U_3O_8), exclusive of townsites and municipal services; all but one of 23 mines were underground mines.

CENTRAL AFRICAN REPUBLIC

Resources

Prospecting continued in the Central African Republic until mid-1971 without further deposits being discovered. The country's uranium resources therefore remain unchanged. It may be recalled that they include, solely in the category of resources that can be worked at less than \$10/lb U_3O_8 , 8,000 tonnes uranium (10,500) of reasonably assured resources and the same quantity of estimated additional resources. These are in phosphatic Eocene deposits.

Production

The cost of processing this very special phosphatic ore, using a new process, is such that the Compagnie des Mines de Bakouma, set up in 1969, has had to postpone exploitation of the deposits and construction of a processing plant while current market conditions prevail.

DENMARK

Resources

In the South-West part of Greenland (Ilimaussaq) there are hyper-alkaline rocks, lujavrites, which contain 100-1,000 ppm (0.01 - 0.1 per cent) of uranium. The lujavrites cover several square kilometres, and the potential resources amount to approximately 250,000 tonnes of uranium (325,000).

In a smaller area in the northern part of the intrusion there are indications of at least 15,000 tonnes of uranium (18,000) in ore containing more than about 300 ppm U (0.03 per cent). 5,600 tonnes of this quantity can be classified as reasonably assured, the remainder fall in the category "Estimated additional". It has been calculated that the uranium can be extracted at costs of about \$10/lb U_3O_8 including interest and amortization. The price without interest and amortization is about \$5.40.

The cheap mining, the short haulage distance and the possibility of obtaining valuable by-products makes it probable that a considerable part of the deposits, containing about 250,000 tonnes uranium (325,000) at a grade of about 200 ppm (0.02 per cent) can be recovered at prices which are much lower than normal for ores of such low grade.

Production

None.

FINLAND

A private company, Atomienergia Oy, carried out some uranium mining and ore dressing experiments on a pilot plant scale near Joensuu, North Carelia, from 1958 until 1961. Since then no mills have been in operation, but exploration for uranium was continued and this work is being intensified. The work is being carried out by various companies and by the Geological Survey and is supported by the Finnish Atomic Energy Commission.

The most interesting deposits were discovered by Outokumpu Oy in the Precambrian sedimentary formations of Kolari, North of Finland, and of Paltamo in the East of Finland. The reasonably assured resources of these two deposits are estimated to amount to 1,300 tonnes uranium (1,700) between \$10 and \$15/lb U_3O_8 . These deposits are to be considered as domestic reserves and no decision has been taken with regard to mining. In addition to these deposits, uranium and thorium contents have been found in northern Finland on several locations in a large carbonatite deposit, which is explored by Rautaruukki Oy. For the time being, however, there are no exact results or estimates available on their values.

FRANCE

Recent Developments

An active prospecting effort has continued in France during these last years, mainly sustained by the Commissariat à l'Energie Atomique.

Work has been done in each of the three districts (Forez, Limousin, Vendée) which continue to be the source of almost all French production. It is oriented towards reconnaissance and evaluation of extensions of deposits being worked, as well as towards exploration for any additional mineralizations which, even if they are of lesser importance, may be worked and processed under satisfactory economic conditions where they are conveniently located in relation to processing plants.

Work has also continued on geological studies and on the exploration of sedimentary formations, primarily those of the Permian period. In this respect the good results in the Permian Basin of the Hérault area should be recorded (South of Massif Central).

Reasonably Assured Resources Workable at Less than \$10/lb U₃O₈

The following are classified in this category:

- first, resources which have been investigated in terms of exploitability under existing economic conditions on the uranium market, i.e. on the basis of production costs substantially lower than \$10/lb U₃O₈. These resources are therefore undervalued in relation to any estimate based strictly on \$10;
- secondly, resources for exploiting for which no plans have as yet been made and regarding which no specific economic studies have been carried out, but for which according to all available evidence, production costs would remain under \$10. Such is the case for the Hérault deposits (Permian, south of the Massif Central).

The new discoveries have not only resulted in compensating for uranium ore mined during these last years as well as for the losses due to the rise in the cut-off grades in the operating mines; they have also allowed a net increase of the reasonably assured resources, which amounted to 36,600 tonnes uranium (47,500) by January 1973.

Estimated Additional Resources Workable at Less than \$10/lb U₃O₈

These estimates are based on:

- the possible extension, both laterally and in depth, of known deposits; this implies a good knowledge of the regional geology and of uranium mineralization in the regions in question; or
- the existence of various occurrences found on the surface and/or by drillings which are too few in number for the reserves to be defined. The geological context is known, at least in broad outline, and so is the type of deposit.

It should be pointed out that these criteria are restrictive and take account only of mineralizations which are specifically known to exist, whereas the ore tonnages, grade and certain other characteristics determining exploitability remain open to conjecture and can only be assessed by comparison with other known cases.

Defined accordingly, the estimated additional resources have increased up to 24,300 tonnes uranium (31,500) by 1st January, 1973.

Geological Distributions

Seventy-five per cent of the reasonably assured resources are found in vein-type deposits in granites or, to a lesser extent, in their surrounding metamorphic rocks (Massif Central, Brittany). The largest deposits consist of groups of ore-bodies which seem at this stage to be controlled by structural factors, particularly by faults. Stockworks may be found at the intersection of several faults or in certain distinct petrographic units ("episyenites").

Twenty-five per cent of these resources are in sedimentary formations (organic silts) of the Permian period which are continental lacustrine deposits, as is the case for the Hérault deposits.

The estimated additional resources are also in one or the other of these two types of deposit with 60 per cent in veins and 40 per cent in Permian sediments.

Resources Workable at \$10 to \$15/lb U₃O₈

The assessment of resources in this price range takes into account low-grade ores already known to exist in deposits which are extensions of zones workable at less than \$10, together with a number of deposits not being worked at present owing to their characteristics (low grade and/or small size of reserves).

The reasonably assured resources in this price range total 20,000 tonnes uranium (26,000) and the estimated additional resources amount to 25,000 tonnes uranium (32,500).

Production

Production capacity in France has remained unchanged in recent years. Concentrates are produced from ores at three plants: l'Ecarpière (Vendée), Bessines (Limousin) and Saint-Priest (Forez), which can handle a total of one million tonnes of ore a year. In terms of uranium, their production capacity for concentrates is 1,800 tonnes (2,300).

However, this capacity has not been fully utilised in the last three years as indicated by the following output figures:

1970: 1,250 tonnes uranium (1,630)
1971: 1,250 tonnes uranium (1,630)
1972: 1,380 tonnes uranium (1,800)

The expected output for 1973 is 1,500 tonnes uranium (1,900). These figures include quantities of uranium recovered by leaching in situ in abandoned mines or workings, or even by heap leaching of low-grade ores that it would not be economically feasible to process normally in plants. In particular, the Compagnie Française des Minerais d'Uranium produces in this way, by heap leaching, a few dozen tonnes of uranium from its Langogne (Lozère) deposit.

A fourth plant (Gueugnon, Saône and Loire) is processing pre-concentrates purchased from the Compagnie des Mines d'Uranium de Franceville (Republic of Gabon).

Although the Forez mine is expected to be worked-out by 1978 or 1979, this capacity of 1,800 tonnes uranium (2,300) per year can be maintained and even raised to 2,000 tonnes (2,600) a year for at least ten to fifteen years in return for a relatively low investment, in the mines of Limousin and Vendée. This rate of production might subsequently be maintained by starting to work the Hérault deposits and the deposits of private producers.

Additional future capacity beyond these 2,000 tonnes uranium (2,600) a year would be considered only in the event of new large discoveries.

The full utilisation of existing capacity and its possible expansion would depend on market developments.

In the light of future demand, French supplies will also be supplemented by purchases abroad, primarily from mining operations in which French interests are now, or will be, participating (for example, in Gabon, Niger, etc.).

GABON

Resources Workable at Less than \$10/lb U₃O₈

Work over the last three years has primarily been concentrated on evaluation of the Oklo deposit, located about 2 km from the Mounana deposit.

Thus, known resources in Gabon, workable at less than \$10/lb U₃O₈, rose to 20,000 tonnes uranium (26,000) at the beginning of 1972, whereas total output for 1969, 1970 and 1971 was 1,440 tonnes uranium (1,870).

Prospecting in the same region has led to the discovery of some new indications of workable deposits which can for the moment be included in the category of estimated additional resources of some 5,000 tonnes uranium (6,500).

Resources Workable at \$10 to \$15/lb U₃O₈

Prospecting so far carried out beyond the area covering the above-mentioned deposits has revealed mineralization which, in view of their distance from the Mounana processing plant, the general characteristics of the deposits, the grade of the ore and also the fact that they are still being explored, can only be placed in this price range and in the estimated additional resources category. No further data warrants a change in the estimate given previously, i.e. 5,000 tonnes uranium (6,500).

Geologically, all these mineralizations lie in detrital sediments which have been deposited in fluvio-deltaic environment: they are sandstones occurring at the bottom of the Franceville series (Precambrian, i.e. 1,740 million years old). The uranium has been subsequently redistributed in these sediments either as a result of the erosion of the surrounding crystalline rocks, or the leaching of acidic volcanic materials which was contemporaneous with the sedimentation. The uranium was subsequently redistributed by the movements of paleo-water tables. The location of the mineralization is controlled by both structural and sedimentological factors.

Production

Production is in the hands of the Compagnie des Mines d'Uranium de Franceville (COMUF) whose plant has a capacity of 135,000 tonnes (150,000) of ore a year, corresponding to a potential output of

600 tonnes uranium (780) a year from preconcentrates which are sent to France (Gueugnon) for further treatment.

It is intended to increase, or even double, this capacity when market conditions allow.

The recent discovery of anomalies in the isotopic composition of natural uranium in one of these deposits in Gabon (OKLO) has no significant effect on the evaluation of reserves or on production capacities. Only the production schedule for 1972 has been held up somewhat, primarily because of the resultant substantial programme of scientific research to be carried out.

INDIA

Recent Developments

Singhbhum District in Bihar continues to be the main source of uranium although a few smaller higher grade deposits in the Himalayan terrain and low grade ores in Rajasthan have been located.

The Rajasthan deposits are at Umra and Udaisagar in the Udaipur district. A newly discovered occurrence of uranium in an amphibole schist exposed on the hanging wall side of copper mineralization, in one level of the Kolihan Copper Mine in Jhunjhunu district, is currently being drilled to explore for its extension along strike and dip.

A uraniferous syenite in Sarguja district, Madhya Pradesh, in which coffinite has been reported, is also being drilled.

Some mammalian fossils in the Siwalik formations (Tertiary) in the Himalayan foot-hills have been found to contain uranium and are being used as a guide in the search for uranium in these rocks.

Reasonably Assured Resources

India's estimates of uranium resources are as follows and fall within the cost range of \$10 to \$30 per lb U_3O_8 ; depending upon the nature, grade and location of the deposit.

Reasonably Assured Resources: 26,400 tonnes U (34,300)

Estimated Additional Resources: 23,500 tonnes U (30,565).

To these figures may be added the reasonably assured U_3O_8 reserves of 7,700 tonnes uranium (10,000) and estimated additional resources of 5,000 tonnes uranium (6,500) available in the monazite deposits.

In the absence of a detailed breakdown of these resources according to price categories used in the present report, the Indian Authorities have suggested retaining the resources figures given in the 1970 report for the purpose of Table 1.

Most deposits in the Precambrian rocks of Peninsular India are endogenous; those in the Himalayas are in rocks believed to be of Precambrian to early Palaeozoic age. A phosphorite deposit of Jurassic age in the Himalayas contains 0.017 to 0.034 per cent uranium, 100-1600 ppm Mo, and 300-5000 ppm nickel. The latter deposit is low in P_2O_5 , 12-14 per cent, from which recovery of uranium, molybdenum and nickel, would become contingent upon the development of a cheap process to eliminate its high carbonate content (reaching 22 per cent) and concentrate the phosphate. This is the only instance in India so far of sedimentary type deposit of uranium, although several minor sporadic occurrences of low-grade material in certain parts of the Permo-carboniferous (Gondwana) rocks have been located.

Production

The well-known deposit of Jaduguda in the Singhbhum district has been a producing mine for several years (capacity: 1,000 tonnes of ore per day). Underground development of Narwapahar and Bhatin deposits is continuing for eventual mining. A new deposit, that of Turamdih, in the same district is currently being drilled to explore for extension of ore and for estimation of the reserves. Drilling in Bagjata is now in its concluding stages and a survey is in progress to find mineralization between it and the Kanyaluka deposit (situated 4 to 5 km from each other) as both appear to be separated by a drag fold.

Some recoveries are expected from the copper tailings of the Roam-Rakha and Surda copper mines of M/S Hindustan Copper Ltd.

ITALY

Recent Developments

In 1970 and 1971, the uranium prospecting activities were continued over the national territory, especially in the Central Alps (Mine of Novazza, Province of Bergamo) and in the northern part of the Latium (Province of Viterbo). Other works - such as driving levels and drilling - are now under way but it is not yet possible, however, to modify the general situation concerning Italian resources which remain virtually the same as before. Nevertheless, as a result of the work already performed, it is possible to think that most probably, in the very near future, uranium resources will increase. In particular, as far as the northern part of the Latium is concerned, it will be possible to obtain positive results when the problem of the ore processing is solved (it is, in fact, a very low-grade mineralization).

The operations carried out abroad by the ENI Group (Hydrocarbons State Agency) can be summarised as follows:

- a) Exploration permit concerning large areas in Somalia and Zambia;
- b) Joint venture with several companies for exploration in the USA and Australia;
- c) Shareholdings in SOMAIR, in Niger.

Resources

The estimates of reasonably assured resources, which are to be found in sandstone deposits, still amount to 1,200 t of uranium workable at less than \$10/lb U_3O_8 .

Production

None.

JAPAN

Recent Developments

At the Tono mine, Gifu Prefecture, prospecting has continued in the known deposit areas. An exploration shaft of some 140 metres has been sunk for a feasibility study of mining.

At the Ningyo-toge mine, an electrolytic reduction plant to investigate the "PNC Process" was set up in 1972. This processing method successfully produced UF_4 directly from ores without passing through the intermediate stage of yellowcake produced by conventional methods.

The Power Reactor and Nuclear Fuel Development Corporation and private companies carry out prospecting activities in Australia, Canada, Niger and the United States.

Reasonably Assured Resources

The resources figures are classified within the \$10 and the \$10 - 15 ranges as in the previous report. The figures for each price range are calculated according to crude ore grade of some 0.10 per cent U_3O_8 (0.08 per cent U) or less. During the past two years, the amount of uranium was increased by some 25 per cent at a cut-off grade of 0.03 per cent U_3O_8 .

It would be feasible to extract, at a cost of less than \$10/lb, 2820 tonnes uranium (3,665), and 4,151 tonnes uranium (5,394) in the price range of \$10 to \$15/lb.

The Toyota deposit, western part of Honshu, was discovered in November 1966 by airborne survey, and exploration was continued in 1972. During that period, uranium findings were made sporadically in an area of 30 by 40 km along a structural zone in the Cretaceous formations.

The Okujiri deposit, a remote island off Hokkaido, was discovered in 1963, and intensive field work has been carried out since 1969. Uranium deposits have been found to date in tuffaceous sandstone and shale with occasional carbonaceous material from the Miocene to the Pliocene ages. Uranium mineralization was discovered in an area 4 by 4 km. The uranium content ranges from 0.04 to 0.08 per cent uranium, and up to 3.9 per cent in places.

Production

A production plant at the Ningyo-toge mine site with an installed capacity of 30 tonnes U (40) started production in 1970.

MEXICO

Resources

Known deposits in the Nuevo Leon area of north eastern Mexico are presently being re-evaluated to determine to what extent they will be worth exploiting. The reserve figures include material from this area and also from the area of Chihuahua where secondary uranium minerals occur in brecciated rhyolitic rocks. Systematic field prospecting followed by extensive drilling and mining work has confirmed the existence of 1,000 tonnes uranium (1,300) in the under \$10 per lb category and 920 tonnes uranium (1,200) in the \$10 - 15 per lb category of reasonably assured resources.

Production

Present production capacity of U_3O_8 concentrates is 30 tonnes uranium (40) per year but by 1975 it is expected that this will be increased to 225 tonnes uranium (300) and a production capacity of 340 tonnes uranium (450) will be reached by 1978.

NIGER

Resources Workable at Less than \$10/lb U_3O_8

Systematic prospecting of the Tin mersoï Basin was begun in 1959 by the French Commissariat à l'Energie Atomique and the first find (1966-1967) of commercial value was the Arlit deposit, which is now mined by the Société des Mines de l'Air. This prospecting work has been continued in recent years, particularly within the context of collaboration between the Government of Niger, the French Commissariat à l'Energie Atomique and a consortium of Japanese industries (Overseas Uranium Resources Development).

As a result of this recent overall exploration, the reasonably assured resources in Niger have been increased considerably. Although no specific economic study has yet been made on these new deposits, it is certain that within the limit of \$10/lb U_3O_8 , the reasonably assured resources inventoried at present in Niger amount to 40,000 tonnes uranium (52,000).

On the basis of the results of drilling surveys over a widely-spaced grid, the same region of Niger also has estimated additional resources of 20,000 tonnes uranium (26,000) within the same price range.

Resources Workable at \$10 to \$15/lb U₃O₈

There have been no new developments in recent years concerning present resources in this price range. It is therefore recalled that several deposits were discovered and evaluated prior to 1967: the characteristics of these mineralizations, i.e. the type of ore and the nature, size and location of the mineralised bodies are such that it cannot at present be contemplated to work them to obtain the oxide at less than \$10/lb U₃O₈. The reasonably assured resources in this price range remain at 10,000 tonnes uranium (13,000), and the estimated additional resources amount to 10,000 tonnes uranium (13,000).

Geologically all these resources are in deposits of the sedimentary type contained in sandstone or continental pelitic formations belonging to the Carboniferous and, to a lesser extent, Jurassic systems.

Production

Production in Niger is currently being carried out by the Société des Mines de l'Air (SOMAIR). The company started operating in 1971 and in that year produced 430 tonnes uranium (560) contained in a sodium uranate concentrate.

The annual production capacity of the plant is at present 750 tonnes uranium (975) and will reach 1,500 tonnes per year (1,950) by 1975.

Consideration is currently being given to the creation of additional capacity in Niger as a result of work carried out in collaboration with Japanese industry. But this additional production would take place only beyond 1978.

PORTUGAL

Resources

Systematic prospecting in the regions considered as geologically favourable to the occurrence of uranium deposits has been carried out in Portugal since 1955. About 380 deposits or uranium occurrences have been revealed in the highly tectonized zones, either in monzonitic Hercynian granites, or in metamorphic contact schists of the ante-Ordovician complex. The radiometric survey of the Ceno-Mesozoic contact zones and, specifically, the continental facies formations, was made by car mounted scintillometer. In 1971, preliminary prospection was made of these Ceno-Mesozoic borders applying special geochemical methods followed by stratigraph studies and analysis of paleogeographic correlations. With the results obtained, a larger research programme has been organised for the coming years. Intense reconnaissance through drilling and mining work has been carried out on about 35 per cent of the deposits, selected as the most promising, and made up of veins or impregnations in the schists. It was possible to define the reasonably assured resources by this reconnaissance.

The mining work carried out in the Cunha Baixa mine and its surroundings has confirmed the results obtained by the drilling work. Active mining exploitation began during 1971.

The results obtained from the "leaching in situ" which is being carried out in the Urgeiriça mine have already allowed an increased in the estimated additional resources in the price ranges "\$8/lb U_3O_8 " and "\$8 - \$10/lb U_3O_8 ", since it has been discovered that it is possible to recover the uranium contained in low-grade ores below 0.04 per cent uranium (0.05 per cent U_3O_8) existing in as yet unexploited deposits and even in those which have been worked out by conventional mining methods.

After 1971 prospecting work has increased significantly in the overseas provinces of Angola and Mozambique, accomplished by the JEN alone, in association with private enterprises by carborne and airborne prospection and by geochemistry. The results already obtained have shown that there were several anomalies in Angola.

In Cabinda (Angola) the "Companhia dos Fosfatos de Angola" is carrying out complementary reconnaissance drilling work in the

phosphate deposits of Maestrichtian and Eocene, to obtain a better definition of the reasonably assured resources. The distribution of the uranium content is very irregular; however, high uranium contents are known. Provisionally, the estimated additional resources of this deposit are evaluated at 13,000 tonnes uranium (17,000).

Price Range < \$10/lb U₃O₈

Reasonably Assured Resources		Estimated Additional Resources	
10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium
8.3	6.4	7.7	5.9

Price Range \$10-15/lb U₃O₈

	Reasonably Assured Resources		Estimated Additional Resources	
	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium
Europe	1.3	1.0	13	10
Portugal				
Angola	-	-	17	13

ESTIMATED RESOURCES OF URANIUM
(Distribution by ore type)

Type of deposit	< \$10/lb U ₃ O ₈				\$10-15/lb U ₃ O ₈			
	Reasonably Assured Resources		Estimated Additional Resources		Reasonably Assured Resources		Estimated Additional Resources	
	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈	10 ³ tonnes uranium	10 ³ short tons U ₃ O ₈
Intragranitic deposits	4.0	5.2	3.1	4.1	-	-	3.1	4.1
Impregnation in schists	2.4	4.4	2.8	3.6	1.0	1.3	7.0	9.1
Phosphates	-	-	-	-	-	-	12.7	16.5
Total	6.4	9.6	5.9	7.7	1.0	1.3	22.8	29.7

Production

The production capacity of uranium in Portugal will be mainly determined by the national consumption of nuclear fuels. The possibility of exporting is also being considered. Although a construction programme for nuclear power stations has not yet been established, it is foreseen that between 1981 and 1985 about 2,000 MWe of nuclear capacity could be installed. It is expected that the present installed production capacity will be increased in the near future to 170 tonnes uranium per year.

INSTALLED CAPACITY AND CURRENT PRODUCTION IN PORTUGAL

Plant Location	Installed Capacity*		Current Production	
	short tons U ₃ O ₈ /year	tonnes U/year	short tons U ₃ O ₈ /year	tonnes U/year
Urgeiriça	130	100	88	68
Senhora das Fontes	17	13	17	13

* Based on an average uranium content of about 0.20% U₃O₈.
The above-mentioned plants belong to the Junta de Energia Nuclear of Portugal.

SOUTH AFRICA

Recent Developments

The Karoo formation covers more than 40% of South Africa and also extends into South West Africa and Angola. During the past year, uranium mineralisation of variable grade was discovered near the surface in sandstone and conglomeratic mudstone of the Lower Beaufort Member, and in a number of deep boreholes drilled for oil. These new discoveries are under investigation and average grades around 0.05%, over variable widths, have been established. At this stage ore deposits are too small and mineralisation too sporadic to justify exploitation, but exploration is proceeding.

Since the previous report was published, spectrometric and magnetic aerial surveys of 25,000 kilometres of well exposed terrain to the north and east of Swakopmund revealed the presence of a number of anomalies. Ground surveys indicated that the radioactivity is due to the presence of secondary uranium minerals in surficial material, and that the uranium was derived from primary uraninite associated with granitic material. Extensive diamond drilling has indicated the existence of a low-grade deposit at Rössing. Exploration of all these anomalies is in progress.

Since the previous estimates were published in September 1970, exploration by means of core drilling of uraniferous conglomerates present in the basal sedimentary rocks of the Dominion Reef Formation was undertaken by the mining industry. In all, 142 boreholes, with a total depth of 67,000 metres, were completed. The boreholes varied in depth from less than 100 metres to more than 1,500 metres. Although fairly extensive deposits of uranium of good grade were proved, associated gold values are very low. The economic mineability of these deposits would therefore be heavily dependent on a satisfactory price for uranium, based on long-term contracts. No working mines exist.

Reasonably Assured Resources

South Africa's reasonably assured resources of uranium comprise reserves in a number of ore deposits which are basically of three types: quartz pebble conglomerate, carbonatite, and intrusive alaskite.

Uranium production has in the past depended almost entirely on current gold mining operations. In estimating the resources of uranium in the Witwatersrand Formation, the life of the gold mines, based on projections of annual production of gold (at a price of 52 US dollars an ounce in 1973, escalating at 7% per annum) and of by-product uranium, was taken into account. The exercise also entailed estimates of uranium in the basal sedimentary rocks of the Dominion Reef Formation west of Klerksdorp in the Transvaal. Also included in the study was the uranium contained in the low-grade uranothorianite associated with the copper-vermiculite-magnetite deposits present in the carbonatite intrusive pipe at Phalaborwa (where uranium is recovered as a by-product), as well as uranium contained

in a low-grade deposit of alaskitic rocks at Rössing in the Swakopmund District of South West Africa, which will be mined by open-pit methods.

However, the recent substantial increase in the price of gold can be expected to have a marked effect on the lives of South African gold mines, and hence on the South African uranium resources, since uranium is a by-product of gold production in the Republic. On the other hand, the escalation in working cost per tonne milled also has important implications and a completely fresh assessment of uranium resources has become necessary. The estimated resources of uranium are given in the first table.

Uranium in Quartz Pebble Conglomerates

Important concentrations of uranium minerals occur in auriferous conglomerates present in four contiguous Precambrian Formations, namely, the Dominion Reef, Witwatersrand, Ventersdorp and Transvaal, of which the two first-named are important because of their relatively large uranium resources. These four formations do not conform to one another, and cover some tens of thousands of square kilometres in the Provinces of the Transvaal and Orange Free State.

The Dominion Reef Formation comprises a basal group of conglomeratic, arkosic and quartzitic rocks up to 100 metres thick, covered by about 900 metres of lava of andesitic or acidic composition. The group of sedimentary rocks forming the base is, from an economic point of view, the most important part of the Dominion Reef Formation.

In the Witwatersrand Formation economically important uranium and gold-bearing conglomerate bands occur on flat planes of intraformational diastems, disconformities, and unconformities. Each of these conglomerates represents a deposit formed after a break in the process of sedimentation. They obviously consist largely of reworked and resorted detritus derived from the erosion of underlying pebble and quartzite beds. The remarkably close relationship of the concentrations of the gold and uraninite with sedimentary features strongly suggests that the gold and uraninite were deposited at the same time as the pebbles and other detrital components of the conglomerate.

To summarise, the uranium which is intimately related to gold occurs in bedded conglomerate and quartzite near the margin of a continental structural basin which is situated well within the boundaries of what is regarded as a uranium province. The assumption is

that the uranium and the gold were precipitated together as an integral part of the sedimentary series, but that this occurred after the conglomerate was laid down, having been transported by water no very great distance to the north and south from an original source which has yet to be discovered.

The conglomerate ore-bodies contain a fairly uniform and consistent percentage of uranium. However, the grade is low, averaging around 0.03%. Uranium recovered from the Bird Reef Zone in old established mines on the West Rand have grades twice as high.

Uranium in Alaskite

It has been known ever since World War I that uranium and copper mineralisation is associated with alaskitic pegmatites which have intruded into schist, granulite, quartzite and marble of the Damara and Nosib Formations. Near Swakopmund in South West Africa, uranium occurs in the form of primary, very fine-grained uraninites, and as bright yellow, secondary, complex oxides in a large alaskite body which underlies the entire mineralised area. Uraninite is the major radioactive mineral present, and the secondary minerals derived from it are metatorbernite, metahaiweeite, uranophane, betauranophane, carnotite, thorogummite and gummite.

The alaskites containing uranium occur in a high-grade metamorphic environment where they have intruded into gneiss, schist, amphibolite, quartzite, marble and various other reconstituted sedimentary rocks of the Damara System and Nosib Formation. The alaskites are unzoned, homogeneous rocks similar to very coarse-grained leucocratic granite. They are composed almost entirely of quartz, microcline and microcline perthite. The grain size of the alaskite is invariably between 1 and 5 mm, and that of the unweathered uraninite between a few microns and 0.3 mm. The fact that the mineralised pegmatites are of very uniform composition, and occur as dykes in the host rocks of very variable composition, suggests a magmatic origin rather than segregations.

The deposit at Rössing has been under intensive investigation, including diamond drilling, during the past five years and an extensive low-grade uranium deposit, which will be mined by open-pit methods, has been delineated.

Uranium in Carbonatites

The Palabora Igneous Complex in the northeastern Transvaal has become known not only for the academic problems in petrogenesis that it poses, but more especially for its mineral wealth.

The complex consists of pyroxenite, syenite, olivine-diopside-phlogopite-pegmatoid, fennite and carbonatite.

At present copper, apatite, vermiculite and magnetite are mined intensively, and baddeleyite and uranium are being recovered as by-products. Reserves of copper available for an open-pit mine to a depth of 400 metres, at a grade of 0.7%, are estimated at several hundred million tonnes, thorium, at a grade of 0.01%, at 36,000 tonnes, and uranium, at a grade of 0.004%, at 11,000 tonnes.

Estimated Additional Resources

The reason for the low figure on estimated additional resources for South Africa is that only those resources which are definitely known to be available and recoverable, and which could be evaluated by extrapolation of information gleaned from reasonably assured resources, are included in the higher price category. No attempt was made to evaluate resources where exploration or investigation were inadequate, regardless of geological favourability.

Uranium mineralisation has been discovered recently in the Karoo Formation and in young surficial deposits in the Namib desert. However, it is too early to predict its significance and no allowance has been made for its potential. Drilling programmes are in progress in both areas and, from the limited information available, it would appear that they are mainly shallow, flat-lying deposits.

Production

Annual production of uranium rose to a peak of some 5,000 tonnes uranium (6,500) in 1959/60, at which time there were 26 mines producing uranium-bearing ore for treatment in 17 extraction plants. Thereafter, as the demand for uranium waned, stretch-out agreements were made with Britain and the United States, and annual uranium production decreased to some 2,230 tonnes uranium (2,900) in 1965, by which stage only 12 mines were producing ore for treatment in 7 extraction plants. At present, 9 mines are producing uranium for

treatment in 10 extraction plants, since Zandpan merged with Hartebeesfontein and Western Reefs merged with Vaal Reefs.

In response to a quickening demand for nuclear power since the mid-1960s, South African uranium production increased steadily until 1971 when 3,220 tonnes uranium (4,180) were produced. It is estimated that this figure will decrease to around 3,000 tonnes uranium (3,900) for 1972. South African production is continually curbed by the ever evasive firm demand for uranium, and it is therefore anticipated that production for the next two years will be kept at approximately 2,700 tonnes uranium (3,500) per annum. The industry is, however, poised for a rapid expansion of production whenever prospects improve. The new plant at President Brand is ready to commence production at short notice. Certain gold mines have also been planning to erect plants and start production as soon as it becomes economically feasible. In the meantime, residual slimes from the gold-producing plants are continuously sampled, and those with the higher U_3O_8 contents are stored on separate slimes dams in such a way as to facilitate reclamation for treatment at some future date. Furthermore, research is being directed into improved methods of extracting low-grade uranium from newly mined ores, and possibly even from tailing dumps and slimes dams. The latter possibility may well prove economical within a few years, but firm assumptions of future production rates, based on this contingency, are at present not possible as a great deal depends on rising price trends.

The Palabora Mining Company has installed a plant to extract small tonnages of uranium and baddeleyite from the final concentrator tailings at its copper mining complex in Transvaal. Estimated production is of the order of 100 tonnes uranium (130) annually.

SUMMARY: ESTIMATED RESOURCES OF URANIUM ($\times 10^3$)

	Tonnes U		Total	Sh.tons U_3O_8		Total
	< \$10	\$10-15		< \$10	\$10-15	
Reasonably Assured	202	62	264	262.6	80.6	343.2
Estimated Additional	8	26	34	10.4	33.8	44.2
Total	210	88	298	273	114.4	387.4

URANIUM ORE PROCESSING PLANTS ON GOLD MINES IN SOUTH AFRICA

Plant Location	Date of Commencement of Operations	Nominal Capacity, Tonnes U per annum		Production Tonnes U per annum		
		1972	1975	1970	1971	1972
West Rand Consolidated	September 1952	470	- ^{c)}	448	414	381
Hartebeestfontein	November 1956	553	553	193 ^{a)} 289	184 256	470
Vaal Reefs North	May 1956	591	746	498	550	780
Vaal Reefs West ^{b)}	September 1953	346	346	385	279	
Buffelsfontein	July 1957	600	600	648	627	585
Virginia	November 1955	346	346	202	132	129
Harmony	April 1955	253	253	242	275	247
Blyvooruitzicht	January 1970	115	115	146	180	160
West Driefontein	January 1971	231	231	-	193	189
Western Deeps	January 1970	162	162	116	130	135
President Brand	^{d)}	461	461	-	-	-
Totals		4128	3813	3167	3220	3076

- a) Zandpan merged with Hartebeestfontein 1-7-1972
 b) Previously Western Reefs now merged with Vaal Reefs
 c) West Rand Consolidated to close plant down in September 1973
 d) President Brand plant to start production at later date.

SPAIN

Recent Developments

Since publication of the 1970 report, the Spanish Junta de Energia Nuclear has continued to press ahead as actively as possible with prospecting in potential uranium-bearing areas throughout Spain, and with the investigation of promising finds. As noted in the earlier report, the emphasis has shifted from granite terrains and the surrounding metasediments in which the country's largest measured resources have so far been located, towards the continental sedimentary formations - essentially Triassic, Lower Cretaceous and Tertiary - where mining and geological assessment of the considerable occurrences brought to light is in progress. Assessment has not yet advanced far enough to justify modifying the figures either for overall resources or for estimated additional resources: this would still be premature though the prospects at present appear favourable.

By mid-1972 an area of 95,000 square kilometres throughout Spain had been covered by field prospecting (with mobile equipment or on foot) and a further 156,500 square kilometres examined by aerial survey, bringing to the total 230,000 square kilometres taking into account the overlapping of the areas covered by both methods. This means that approximately half the country has been explored, and appropriate general and regional studies have been effected according to the value suggested by the evidence discovered. Detailed studies have only been partially completed, particularly for the continental sedimentary formation, in which prospecting and exploration have been undertaken most recently. Broadly speaking, it is felt that prospecting will have to be extended to two-thirds of the area of the country which are believed to possess the geological characteristics for uranium-bearing deposits.

The possibility is not ruled out of returning to areas regarded as having already received preliminary exploration, particularly the metamorphic granite terrains explored earlier, with more up-to-date tests and detectors.

Apart from prospecting as such, the exploration of promising areas discovered is proceeding with all the techniques appropriate to each case. In the same way, apart from the hundreds of test

bores and other mining research work, between September 1970, when the previous report was published and the present time, a total of 40,700 metres have been drilled for core samples and another 88,700 metres have been wagon-drilled.

The present status of Spanish uranium resources corresponding to each of the two price ranges considered is shown below:

Reasonably Assured Resources

In the price range of less than \$10/lb U₃O₈ the figure of 8,500 tonnes uranium (11,000) included in the September 1970 report in the category of "Reasonably Assured Resources" is being maintained. This comprises deposits of two types: (a) veins enclosed in granite and (b) metamorphic rock masses near to the surface mineralised in the first 35 to 50 metres down, but covering a wide area, brecciated and weathered following tectonisation and metallisation. These reserves are distributed in the following pattern:

URANIUM RESERVES (TONNES U)

	Granite	Shale
Ciudad Rodrigo	500 (Valdemascano, Villar de Peralonso, etc.)	6,000 (Fe-1, Fe-3 D, Alameda, etc.)
Badajoz (Don Benito)		750 ("El Lobo" area)
Caceres	900 (Ratones and others)	
Tajo	100 (Navalcan Carretero, etc.)	50 (Gargüera, Ojaranzo)
Galicia	100 (Brecha Incognita, Bacurin, etc.)	
Catalonia	100 (Darnius)	
Total	1,700	6,800

The grades of the veins enclosed in granite vary between 0.13 and 0.21% of uranium (0.15 and 0.25%), while average grades for the shale deposits vary between 0.10 and 0.14% of uranium (0.12 and 0.17%). The cost of recovering the uranium naturally depends on the costs of underground and surface mining and on processing costs and yields,

which means that the grade of the ore is only one factor to be taken into account in studying the viability of a particular deposit.

In the price range between \$10 and \$15, the resources associated with the Calaf basin lignites, consisting of intercalations in Lower Oligocene lutites, and some deposits associated with low-grade sedimentary areas are still included. It is estimated that there are 7,700 tonnes uranium (10,000) in the category of reasonably assured resources.

Production

Production forecasts quoted in the September 1970 report for uranium concentrates in Spain have been substantially modified, partly by the downward trend and uncertainty in the prices they have been fetching over the last two years, and partly by the delay in setting up the Empresa Nacional del Uranio. The present production situation so far as can reasonably be foreseen, is shown below.

So far there is only one complete processing plant in Spain, at Andujar (Jaén). It has been in operation for the last twelve years and will continue for some years more. Its output capacity is of the order of 50 tonnes uranium (66).

In addition to this there are static leaching installations at the "Fe" mine at Ciudad Rodrigo (Salamanca) and at the "El Lobo" mine at Don Benito (Badajoz); owing to their experimental nature, their output is at present small.

No final decision has yet been taken by the Empresa Nacional del Uranio on the construction of the large facility at Ciudad Rodrigo. The most probable outcome appears at present to be that the existing installation will be replaced by a larger leaching plant with an output now expected to be of the order of 65 tonnes uranium (83) per year from mid-1973.

Consideration is also being given to a much smaller experimental leaching plant for the "El Lobo" mine at Don Benito, to acquire experience of the behaviour of the marginal minerals from this mine which are unusually clayey. The foreseeable output would be of the order of 13 tonnes uranium (16) per year from 1974.

The foregoing remarks on Spain's production of concentrates can be summarized in tabular form as follows:

URANIUM PRODUCTION

PRODUCTION	Andujar Plant		Leaching Installations				TOTAL	
	tonnes U	short tons U ₃ O ₈	C. Rodrigo		Don Benito		tonnes U	short tons U ₃ O ₈
			tonnes U	short tons U ₃ O ₈	tonnes U	short tons U ₃ O ₈		
1970 Production	49.14	63.87	1.25	1.63	0.73	0.94	51.12	66.44
1971 Production	58.24	75.71	1.16	1.51	0.59	0.77	60.00	78.00
Forecast for 1972	57.7	75.0	1.1	1.4	0.6	0.8	59.4	77.2
Forecast for 1973	59.5	77.0	32.0	41.5	-	-	91.5	118.5
Forecast for 1975	55	71.5	63.5	82.5	13	16.5	131	171

SWEDEN

Resources

Alum shales are found in nearly all geological systems from the Cambrian to the Tertiary and occur in great thicknesses at a number of places. The Swedish alum shales are typical stagnation sediments and can be described as dark, bituminous shales. They are widely distributed in the Southern part of the country, and are found in the mountain chain to the West.

The shales with the greatest uranium content occur in the upper Cambrian, particularly in the zone of *Peltura scarabaeoides*. Uranium contents of 0.02% or over occur only in the shales of the middle and lower parts of the *Peltura scarabaeoides* zone.

The alum shales are fine-grained, bituminous, brownish-black to black shales with a density of about 2.1 g/cm³. The composition is a mixture of hydrogen-rich and oxygen-poor organic substances together with pyrite, quartz, illite, feldspar and kaolinite. The uranium is present in a dispersed condition and has not yet been traced to any given mineral.

Uranium resources in the most important areas of South Sweden are 0.9 x 10⁶ tonnes (1.2 x 10⁶) in Västergötland and at an average grade of 0.03% and 0.15 x 10⁶ tonnes (0.2 x 10⁶) in the Närke region at a grade above 0.02%.

If allowance is made for availability, percentage of ore extraction in the mine by the room-and-pillar method and percentage recovery through treatment in the mill, it is estimated that a maximum of 35% of the uranium content of these "uranium-rich" zones of the shale deposits in the provinces of Västergötland and Närke is recoverable.

Uranium resources of shale formations in the Caledonian chain are very little known.

The Geological Survey of Sweden has increased its programme for uranium prospecting over the last few years. Several promising prospects have been found in Precambrian rocks.

ESTIMATED RESOURCES OF URANIUM

Geological Distribution	Price Range \$10-15 per lb U ₃ O ₈			
	Reasonably Assured Resources		Estimated Additional Resources	
	10 ³ tonnes U	10 ³ short tons U ₃ O ₈	10 ³ tonnes U	10 ³ short tons U ₃ O ₈
Shales	270	350	40	52

Production

AB Atomenergi owns a pilot mill in South-Central Sweden at Ranstad with a capacity of 120 tonnes uranium (155) per year. The milling is based on the large uranium shale deposits in the Billingen area. At the present plant capacity production costs are considerably higher than the world market price due to the low uranium content in the shale.

In a technical and economic study of large-scale exploitation of resources, which was carried out for the Swedish Government, account was taken of experience from plant operation and process development. The study (1971) confirmed that there was a possibility of reaching a product price close to the low limit of the indicated price range at plant capacities of 1,000-1,500 tonnes uranium (1,300-2,000) per year. A three-year programme is now under way for the development and verification of the production improvements necessary in order to take full advantage of an exploitation of the above magnitude. With enlarged and improved facilities at the present site it would be possible to produce a total of at least 30,000-40,000 tonnes uranium during a 20-25 year period. The existing Ranstad pilot plant is now used only to the extent necessary for the development programme.

Although the Billingen deposit is very large, only a few mills of the capacity mentioned above can be visualized, as the ore-handling and landscape preservation are limiting factors. The Billingen deposit must therefore be considered primarily as a domestic reserve to be utilised to cover part of the total Swedish demand.

TURKEY

Reasonably Assured Resources

a) Salihli-Köprübaşı Region

The deposit is located 150 kilometres north-east of Izmir and occurs in the poorly consolidated Neogene sandstones.

Study of this region has been completed and two types of ore have been found. They differ mineralogically and as regards their concentration possibilities as shown in the following Table.

URANIUM DEPOSITS OF THE SALIHLI-KÖPRÜBAŞI
REGION: GRADE AND TYPE

	Grade 0.038% U	Grade 0.017% U	Total Deposit (tonnes U)
Kasar Type Ore (tonnes U)	754	280	1,034
Tasharman Type Ore (tonnes U)	794	197	991
Total (tonnes U)	1,548	477	2,025

i) Kasar Type

In this part of the region, close to the uranium occurrences, gneisses are replaced by numerous faults. Tertiary sediments, represented by continental or lake formations, overlie the gneisses unconformably. Sediments surrounding metamorphic massive formations show horizontal bedding and are composed of fluviatile continental (bottom) and lake sediments (top).

Positive results have been achieved from the concentration experiments carried out by the Mineral Research and Exploration Institute of Turkey. Because of the concentration process of the ore of 754 tonnes and 0.038% U grade and its convenience for operation, it seems very possible to obtain U_3O_8 at world market prices.

ii) Tasharman Type

Gneisses forming the base are overlaid by Mesozoic crystalline limestones or continental clastic series such as conglomerate, sandstone, and silt of Myocene age. These layers underlie marl, clay-sand limestone-tuffite and cherty limestone layers of Upper Myocene age. In the north-east of the area, post-orogenic Tertiary andesite exposures are found.

b) Uşak-Güre Region

Study of uranium, found near Fakili village in the marl, clay and with tuff series dating from the neogen period has been completed and deposits of 250 tonnes of uranium were discovered. The grade of this bed is about 0.04%.

The concentration experiments carried out here, by the Mineral Research and Exploration Institute also gave positive results. By employing a small amount of acid, the uranium dissolves and passes into water.

c) Ayvacik-Küçükkuyu Region

In this particular region deposits of 212 tonnes uranium were found associated with tuff and rhyolite. The average grade is about 0.07% U.

d) Giresun-Şebinkarahisar Region

In the Eocene sediments formed around granite masses deposits of 255 tonnes uranium with an average grade of 0.034% U were discovered.

Accordingly, up-to-date figures of the uranium deposits are shown in the following Table.

	Economic Deposits (tonnes U)	Low Grade (tonnes U)	Total Deposits (tonnes U)
Salihli-Köprübaşı	1,548	475	2,023
Uşak-Güre	212	-	212
Ayvacic-Küçükkuyu	212	-	212
Giresun-Şebinkarahisar	255	-	255
Total	2,227	475	2,702

As seen from the above, deposits of about 2,700 tonnes uranium were found. But only 2,227 tonnes are convenient for production.

Production

Studies are still continuing of installed pilot plants with a capacity of 2 tonnes U_3O_8 /year, to inspect the concentration condi-

tions of the beds and to give operation parameters for the industrial installations to be built. It is hoped that this pilot installation will soon start operation with the joint help of the Turkish Atomic Energy Commission and the Mineral Research and Exploration Institute.

UNITED STATES

Recent Developments

During the three years since the last report, uranium exploration in the United States has declined. Drilling totalled 7,160 kilometres (23.5 million feet) in 1970, 4,730 kilometres (15.5 million feet) in 1971, and 4,700 kilometres (15.4 million feet) in 1972 compared to 9,110 kilometres (29.9 million feet) drilled in the peak year, 1969. In the three years, 134,000 holes were drilled to an average depth of 120 metres (400 feet).

During 1970, 1971 and 1972, 98,000 tonnes of uranium (127,000) were added to \$10 reasonably assured resources and 31,000 tonnes of uranium (40,000) were mined, resulting in a net increase from 192,000 tonnes uranium (250,000) on 1st January 1970 to 260,000 tonnes uranium (337,000) on 1st January 1973. Estimated additional resources increased during this period from 460,000 to 540,000 tonnes uranium (600,000 to 700,000). Additional resources continue to be found, primarily within or as extensions to known uranium districts. The rate of resource additions has been adequate to satisfy near-term requirements but more rapid expansion of resources will be required to meet long-term demand.

Reasonably Assured Resources

Reasonably assured resources comprise the reserves in individual ore deposits estimated by U.S. Atomic Energy Commission personnel from data developed by the uranium exploration and mining companies. The estimates were made using generally accepted reserve estimating procedures. The overall estimate is believed accurate within $\pm 20\%$. Recovery of in-place reserves has been high and well within the limits of accuracy of the estimates. Therefore, no factor for mining and milling losses has been applied. All material included in the

estimates is calculated to be producible at a total cost of \$10 or less per lb U_3O_8 in concentrate taking into account anticipated operating costs of mining, milling, haulage and royalties and amortisation of forward capital investments. Costs of exploration and profit are not included; therefore all of the resources may not be available at a \$10 price.

Reasonably assured resources comprise more than 900 deposits containing 182 million tonnes (200 million) of ore with an average grade of 0.14% uranium (0.17%). The largest 10% of the deposits contain about 85% of the uranium. About 80% of the deposits are at a depth of less than 90 metres (300 feet), but these deposits contain only one-third of the uranium. Open-pit mining methods are expected to be used to produce about 45% of the uranium. The Colorado Plateau (Arizona, Colorado, New Mexico and Utah) is the largest United States uranium area with 54% of the reasonably assured resources. An additional 42% is located in the basins of Wyoming and the coastal plain of Texas. About 96% of the reasonably assured resources of the United States are in irregular, stratiform deposits and in "roll" deposits in sandstone. A few deposits are in other sedimentary rocks including limestone, conglomerate and lignite. The remainder are veins and related types. The resources designated by type of deposit are shown below:

U.S. RESOURCES, \$10/lb U_3O_8 OR LESS (EXCLUDING BY-PRODUCT)
1st January, 1973

Type of Deposit	Reasonably Assured		Estimated Additional	
	Tonnes U	Short Tons U_3O_8	Tonnes U	Short Tons U_3O_8
Sandstone	250,000	325,000	500,000	650,000
Vein	1,080	1,400	26,300	34,500
Others	8,150	10,600	11,900	15,500
Total	259,000	337,000	538,000	700,000

Reasonably assured resources at costs up to \$15 per lb are estimated to be 400,000 tonnes uranium (520,000) including the resources at \$10 per lb or less. These resources are almost entirely in the deposits containing the \$10 resources. However, because less detailed

information is available, the estimates often are based on statistical relationships established from well-sampled deposits in the same area. Some of the resources in the \$10 and \$15 increments will be lost when mining material below the \$15 cost level.

RESOURCES IN THE \$10-15/lb U₃O₈ COST RANGE
(EXCLUDING BY-PRODUCT)
1st January, 1973

Type of Deposit	Reasonably Assured		Estimated Additional	
	Tonnes U	Short Tons U ₃ O ₈	Tonnes U	Short Tons U ₃ O ₈
Sandstone	137,000	178,200	212,000	275,000
Vein	770	1,000	14,200	18,500
Others	2,900	3,800	5,000	6,500
Total (Rounded)	141,000	183,000	231,000	300,000

By-Product Uranium

An estimated 54,000 tonnes of uranium (70,000) might be recovered from phosphoric acid through the year 2000. Investigations by the AEC and phosphate-producing companies indicate improved technology can increase recovery of uranium and reduce costs below those experienced previously. Additional process testing is planned. Plans for installation of recovery circuits by the late 1970s are being developed.

Uranium contained in copper leaching solutions is a potential source of 15,000 tonnes of uranium (20,000) through the year 2000.

Estimated Additional Resources

Estimated additional resources were assessed by extrapolation of information on reasonably assured resources to areas having demonstrated geological favourability taking into account the extent and adequacy of exploration. These resources are primarily in unexplored extensions of known deposits or in undetected deposits within or adjacent to uranium areas. No attempt has been made to estimate possible resources that may occur in areas for which adequate geological information is not available or where there are no known occurrences of uranium. Expansion of presently known uranium

areas and discovery of new districts with similar geology can be expected in the future. In addition, there is the chance that deposits in new geologic environments will be discovered. Therefore, the estimates should not be considered to represent the ultimate potential for uranium in the United States.

Production

During 1972, 9,900 tonnes of uranium (12,900) in concentrate were produced in the United States. 5.8 million tonnes (6.4 million) of ore with an average grade of 0.18% uranium (0.21%), were processed in 20 uranium mills. Three new plants began operation in 1972. Ore was shipped from 178 mines, 79% of which were underground, but open-pit mines produced 58% of the uranium. About 150 tonnes of uranium (200) were recovered from mine waters and heap leaching operations.

United States uranium ore processing plants are listed in the following table. Their nominal capacity totals 29,000 tonnes (32,000) of ore per day. Considering available ore supplies this corresponds to a capability of 14,600 tonnes uranium (19,000) per year, although actual capability in 1973 may be somewhat less.

Reasonably assured resources as of 1st January 1973 could justify construction of additional milling capacity which would add 3,100 tonnes of uranium (4,000) production in 1975 and 4,600 tonnes uranium (6,000) in 1976. Production capability in those two years would then aggregate 17,700 and 19,200 tonnes uranium (23,000 and 25,000) per year respectively. These production rates, however, would exceed projected United States demands in those years. Construction of a number of additional mills is under study by industry but no firm plans have been announced.

Uranium sales commitments by United States producers to domestic buyers totalled 66,400 tonnes uranium (86,300) as of 1st January 1973. An additional 33,500 tonnes uranium (43,500) had been delivered to foreign buyers through 1972. Commitments call for delivery of 9,500 tonnes uranium (12,300) in 1973, 9,600 tonnes uranium (12,500) in 1974, 12,200 tonnes uranium (15,800) in 1975, and 5,500 tonnes uranium (7,600) in 1976. Additional sales commitments to supply reactors already on order may increase actual 1975 and 1976 deliveries. Commitments for delivery to foreign buyers in 1973 and later total an additional 1,600 tonnes uranium (2,100).

Uranium stocks held by the AEC in excess of needs, 38,500 tonnes of uranium (50,000) will be fed to the gaseous diffusion plants (permitting a tails assay increase) and will not be disposed of by direct sale. Utilities and manufacturers report inventories of 11,100 tonnes of uranium (14,400) as of 1st January 1973. Uranium producers had finished product inventories of 2,800 tonnes of uranium (3,700) at that date.

An AEC survey of exploration activities provided data from 84 companies which performed 97% of the 4,720 kilometres (15.4 million feet) drilled in 1972. The companies reported expenditure in 1972 of \$32 million on uranium exploration of which \$18 million was for drilling. Plans for future drilling aggregated 18.5 million feet in 1973 and 20.3 million feet in 1974.

URANIUM MILLING COMPANIES AND PLANTS

Company	Plant Location	Nominal Capacity			
		Tonnes Ore/Day	Short Tons Ore/Day	Tonnes U/yr	Short Tons U ₃ O ₈ /yr
The Anaconda Company	Grants, New Mexico	2,700	3,000		
Atlas Corporation	Moab, Utah	1,350	1,500		
Continental Oil Co. - Pioneer Nuclear Inc.	Falls City, Texas	1,600	1,750*		
Cotter Corporation	Cannon City, Colorado	400	450		
Dawn Mining Company	Ford, Washington	450	500		
Federal-American Partners	Gas Hills, Wyoming	850	950		
Exxon Co.	Powder River Basin, Wyo.	1,800	2,000*		
Kerr-McGee Corporation	Grants, New Mexico	6,350	7,000		
Mines Development, Inc.	Edgemont, S. Dakota	600	650		
Petrotomics Company	Shirley Basin, Wyoming	1,350	1,500		
Rio Algom Mines, Ltd	La Sal, Utah	450	500*		
Susquehanna-Western Inc.	Falls City, Texas	900	1,000		
Susquehanna-Western Inc.	Ray Point, Texas	900	1,000		
Union Carbide Corporation	Uraven, Colorado)	1,800	2,000		
" " "	Rifle, Colorado)				
Union Carbide Corporation	Natrona County, Wyoming	900	1,000		
United Nuclear - Homestake Partners	Grants, New Mexico	3,200	3,500		
Utah International	Gas Hills, Wyoming	1,100	1,200		
Utah International	Shirley Basin, Wyoming	1,100	1,200		
Western Nuclear, Inc.	Jeffrey City, Wyoming	1,100	1,200		
Total		28,900	31,900	14,600	19,000

* 1972 Startup.

YUGOSLAVIA

Recent Developments

In the area of Slovenia systematic radiometric surveying and geochemical prospecting has been carried out continuously since 1960 by the "Institut za geološko-rudarska istraživanja i insptivanja nuklearnih sirovina, Beograd"* and since 1970 by the "Geološki zavod Ljubljana". The survey has revealed that the principal uranium deposits are exclusively in the Val Gardena strata of the Middle Permian rocks. These rocks are composed of two facies, the gray and the red series. The gray, being the older of the two facies, is overlain by the red. The gray series contains the uranium mineralisation and is composed of sandstones and conglomerates with intercalations of red sandstone of variable thickness.

According to data known up to now, there are six regions where uranium ore deposits of economic value might be found.

Reasonably Assured Resources

Out of the six regions where uranium ore occurs, up to now only the Zirovski Vrh deposit has been explored in detail, and its ore reserves determined. All of the reasonably assured resources are in irregular, stratiform deposits in gray sandstone. Uranium resources are computed from the various data obtained by underground mining and test boring, the cut-off grade being 0.02% uranium (0.03%). At present, for costs of less than US \$10/lb U_3O_8 the amount of reserves is 6,000 tonnes uranium (7,800) with an average content of 0.13% uranium (0.15%).

Estimated Additional Resources

Estimated additional resources of uranium ore for exploitation at costs of less than \$10/lb U_3O_8 are estimated at 10,000 tonnes of uranium (13,000). One part of this total is attributable to inferred reserves, while the remaining resources are surmised to occur in unexplored extensions of Zirovski Vrh.

* Institut for geological and mineralogical research and analysis of nuclear material, Belgrade.

Various occurrences outcropping on the surface, and found by drilling, exist also in five other regions. The geological context is known, at least in general outline, and so is the type of deposit, but the amounts of ore reserves were not yet defined.

Production

A yellowcake production of approximately 300 t/year is foreseen, starting in 1976.

ZAIRE

The resources situation is stated in the following table. In the absence of information on exploitation costs, these resources have been included in the lower price-bracket.

URANIUM RESERVES IN TONNES U

DEPOSITS	Ore Reserves	Prospected Ores	Probable Ores	Possible Ores	Comments
<u>1. Exclusively Uranium-bearing</u>					
Swambo	-	460	-	-	Vein-type ore known to 120 metres depth. Content between 0.1 and 1% U_3O_8 .
Shinkolobwe extension	-	-	770	-	Extension of old deposit to 300-400 metres depth. Content of the order of 0.1 to 0.2% U_3O_8 .
Kiswishi	-	77	-	-	Ore found by boring. Content: 0.13% U_3O_8 .
East Kasompi	-	990	-	-	Ore found by underground mining and boring. Content: 0.09% U_3O_8 .
<u>2. With copper</u>					
Kalongwe	-	77	77	230	Vein-type ore known to 60 metres depth. Content: 0.1% U_3O_8 , exceptionally 1% U_3O_8 .
Kamoto Main	-	-	540	-	Ore known below level 300 in open-pit mine worked for copper. Varying contents.
West Kambova	2	8	-	77	Ore known in open-pit mine worked for copper. Content: 1.1% U_3O_8 .
Musonoi	188	-	-	-	Uranium-bearing pocket found when working copper. Ore at 0.3% U_3O_8 .
<u>3. In coal</u>					
Iuena	-	-	-	For reference	Prospecting just started.
TOTAL	190	1,612	1,387	307	

2. EXPLORATION ACTIVITIES IN COUNTRIES WITHOUT KNOWN MAJOR URANIUM RESERVES

In Austria, from 1969 to present, a private firm is conducting a comprehensive, exploration programme in many parts of the Alps and the Bohemian Massif. Carborne-and-foot prospecting, shallow and medium depth core drilling, trenching and tunnelling resulted in the discovery of at least two sizeable deposits. The reasonably assured reserves in the Forstau area (Salzburg) amount to several hundred tonnes of uranium, bound to uraniferous layers in quartzites and sericite schists. Scientists from Innsbruck University investigated geologically favourable sectors in Tyrol and detected uranium concentrations in Lower Triassic sandstone. The results are interesting enough to render further exploration feasible. In 1970 and 1971, exploration for uranium was conducted in the copper mine of Mitterberg (Salzburg), carried out as joint venture by the Mining Company, the Geological Survey, the Mining University Leoben and an Austrian Company. Besides the detection of a previously unknown pitchblende-gold-mineralisation, several promising anomalies were found in the country rock of the copper deposit. Further investigations are being conducted.

Uranium deposits of economic significance in Austria are bound to the following geologic formations:

- Lower Triassic sandstones at the base of the Northern Limestone Alps (Buntsandstein and Werfener Schichten).
- Permo-Carboniferous sandstones ("Grüne" and "Violette Schichten von Mitterberg"; Permian Grödener Sandstone; Permo-Carboniferous sandstones of the Southern Alps).
- Quartzites and quartz-rich sericite schists of presumably Upper Paleozoic to Lower Mesozoic age of the Central Alps.
- Permo-Scythian quartzites of the Lower-Alpine Mesozoic sequence (Semmering-Quartzites).

All known occurrences of uranium concentrations are related to traces of carbonaceous plant matter.

In the Arab Republic of Egypt, uranium has been discovered in both basement rocks and in sedimentary rocks. In the basement rocks, chalcedony veins in granites contain pitchblende, while fracture systems in bostonites carry pitchblende and coffinite. In the sedimentary cover rocks uranium occurs in bedded shales and sandstones. Exploration is continuing in these environments in the Eastern Desert area and also in sedimentary rocks in the Western Desert. In addition, large amounts of high-cost uranium exist in the rock phosphate deposits of the Eastern Desert and in the monazite bearing beach sands of the Mediterranean coast.

In the Federal Republic of Germany, uranium prospecting since 1956 has indicated the existence of some small (several hundred tonnes of U_3O_8) uranium deposits. These deposits, however, are not in the category of ores workable at less than \$10/lb. Prospecting activities in recent years have been predominantly in Bavaria; but they are now to be carried out mainly in the Black Forest. About US \$1 million is spent every year on prospecting activities in the Federal Republic of Germany.

Apart from these home activities, German mining companies are participating in joint ventures with foreign companies and with government organisations in uranium prospecting schemes in Australia, Austria, Canada, Switzerland, Togo and the USA. In addition, German companies participate in the working of uranium deposits in Niger (Arlit) and in Canada (Rabbit Lake). About US \$7 million are spent annually on prospecting work abroad.

In Greece, the Atomic Energy Commission, in co-operation with the UNDP*/IAEA, began in 1971 a large-scale reconnaissance exploration project in Central and Eastern Macedonia and Thrace. The project area is being covered by a carborne total-count scintillometer survey, backed by other prospecting methods for use if and where anomalous levels of radioactivity are discovered. The first phase of this work will be completed by the end of 1973.

* United Nations Development Programme.

In Iran, investigations to date have established various radioactive indications. Some of these became evident during a preliminary survey in 1961, by the former Ministry of Industry and Mines and with the collaboration of a French expert. A further and more intensive search for radioactive minerals was conducted during 1970 and 1971 by the French Atomic Energy Commission in co-operation with the Geological Survey of Iran. However, even this was essentially no more than a reconnaissance survey, and it is not possible therefore to appraise the commercial possibilities at present. Nevertheless some of the observed surface indications are expected to lead to commercial results after more detailed surveys in the future.

In Korea, radioactive minerals mainly from pegmatites have occasionally been surveyed over the past 18 years by the Geological Survey of Korea. More recently, more intensive prospecting has been carried out by the Geological Survey, including airborne radioactive surveys conducted over metasediment strata of the Okchon Series around Daejeon. The surveyed area was about 2,620 square kilometres. In 1969, uranium deposits were found in the region by this airborne survey, and the Geological Survey is now undertaking reconnaissance, detailed surveys, gamma-ray logging and boring in the promising areas.

In Norway, uranium prospecting activities are very modest and limited to half a man-year annually. However, in view of new equipment acquired in the last few years and the fact that uranium has been found in a number of places in Sweden near the Norwegian border, it is likely that prospecting activities will be considerably increased in the future.

In Switzerland, prospecting for uranium began in 1956; since 1967 investigations have been co-ordinated and funded almost entirely by the Confederation (Division of Science and Research, Federal Department of the Interior). Prospecting has predominantly been directed to continental detrital sediments and acid volcanic rocks, both of Permian age, as well as to the Hercynian granitic massifs and their surrounding metamorphic formations.

Several uranium-bearing mineralisations were detected, in particular in the Rhone Valley area (Iséables, Naters, Embd, Emosson) and

in the Upper Rhine Valley (Trun). Further reconnaissance of the Iséribles and Trun deposits by trenching, drilling and tunnelling showed that the uranium mineralisations (associated with fractured and sheared zones in gneissic rocks) are spread over a fairly large area, but that the average ore grade is considerably below the values warranting economic exploitation.

In the Emosson area, detailed investigation of the uranium mineralisation, confined in fissured granitic rocks and mylonites, is still going on. In a few other regions, general prospecting is continuing and will probably be completed in 1974 or 1975.

In the United Kingdom, a five-year reconnaissance programme has been completed at cost of \$600,000 by the Institute of Geological Sciences for the United Kingdom Atomic Energy Authority. During the period five regions considered on geological grounds to be favourable for uranium mineralisation were investigated by radiometric and geochemical techniques. Numerous anomalies were detected and the presence of widespread but low-grade uranium enrichments was established in Caithness and Orkney in Devonian sediments resting on granitic and metamorphic basement rocks. Much of the uranium is concentrated in thin phosphatic horizons, but local enrichments were discovered and tested to shallow depth in arenaceous sediments and discordant structures. Resources in the latter type of occurrence amount to a few thousand tons of U_3O_8 probably coming within the \$10-15 price range.

A re-examination of the South West region of England led to the discovery of uranium concentrations associated with wrench faults in proximity to Hercynian granites. These new occurrences have not been tested, thus resources cannot be estimated with any degree of accuracy, but uranium values are locally high and some structures show evidence of continuity sufficient to indicate resources of the order of hundreds of tons of U_3O_8 .

3. ALLOCATION OF RESOURCES TO GEOLOGICAL ORE TYPES

As was done in previous reports, it has been found useful to allocate to geological ore types, the resources in the four price categories considered. The following four ore types have been chosen:

- Sandstones,
- Quartz pebble conglomerates,
- Vein type, and
- Others.

The results are given in Table 4. The Secretariat has compiled the table from individual countries' contributions and used its judgement for those cases where exact figures were not available.

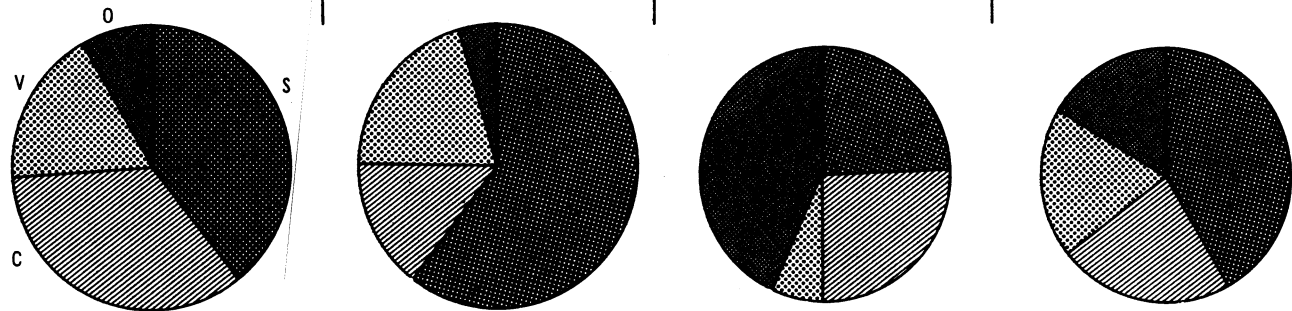
The figures show that about 73% of low cost reserves are contained in almost equal parts in sandstones (mainly USA, Niger and Gabon) and quartz pebble conglomerates (Canada, South Africa). A further 18% are distributed in veins and related types (Australia, Canada, France and other countries) and the remaining 9% are in pegmatites, phosphates and others. The major part of the estimated additional resources, as well as of the higher priced resources, is contained in sandstones (mostly located in the USA). Very considerable resources are furthermore allocated to quartz pebble conglomerates (Canada, South Africa) and vein-type deposits (Australia, Canada and other countries).

Table 4

ALLOCATION OF WORLD RESERVES AND RESOURCES TO GEOLOGICAL ORE TYPES

ORE TYPES	PRICE RANGE \$ 10/lb U ₃ O ₈				PRICE RANGE \$ 10-15/lb U ₃ O ₈			
	1. REASONABLY ASSURED RESOURCES (RESERVES)		2. ESTIMATED ADDITIONAL RESOURCES		3. REASONABLY ASSURED RESOURCES		4. ESTIMATED ADDITIONAL RESOURCES	
	10 ³ tonnes U	%	10 ³ tonnes U	%	10 ³ tonnes U	%	10 ³ tonnes U	%
Sandstones (S)	336	39	555	61	161	24	256	41
Quartz-pebble Conglomerates (C)	302	35	133	15	172	26	150	24
Vein and Related Types (V)	152	17	188	20	45	7	125	20
Others (O)	75	9	35	4	292	43	96	15
Total	865	100	911	100	670	100	627	100

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4. THORIUM RESOURCES

For the sake of completeness, as in the previous report, some information is given here on thorium resources. Despite recent orders for several high-temperature reactors (a reactor type which can operate on the thorium fuel cycle) no significant thorium requirements are expected in the 1970s and no large commercial thorium market exists at present. For this reason, the information available on thorium resources is scarce and far less reliable than that on uranium deposits dealt with in the previous chapter.

BRAZIL

In Brazil the only thorium production, at present, comes from monazitic beach sand deposits. Monazite occurs associated with ilmenite, zircon and rutile, along the eastern and south-eastern Atlantic coast. Thorium is obtained as a by-product from the rare earths extraction. Known Brazilian thorium resources, from monazitic beach sands, recoverable at a price range up to US \$10/lb of ThO_2 , are:

- Reasonably Assured Resources: 1,200 tonnes of Th (1,485 short tons ThO_2);
- Estimated Additional Resources: 880 tonnes of Th (1,100 short tons ThO_2).

Other possible sources occur as thorite and thorogummite in the Morro do Ferro deposit, at Poços de Caldas plateau, State of Minas Gerais, in highly decomposed alkalic igneous rocks. Thorium is associated with rare earths and the grade ranges from 1.4 to 2.36% of ThO_2 . Around 31,000 tonnes Th are estimated as reasonably assured resources.

In the niobium deposit of Araxá, State of Minas Gerais, thorium appears associated with pyrochlore and monazite. This deposit is

of a very low grade, averaging 0.09% of ThO_2 . The thorium reserve is about 26,000 tonnes Th as reasonably assured resources and it could be produced as a by-product of the niobium exploitation.

Other deposits in alkaline intrusions areas are known in Salitre, Serra Negra, and Tapira alkaline pipes, all in the State of Minas Gerais. There are no figures on resource estimation available.

Other thorium sources could be the monazitic fluvial sand deposits and the monazitic bearing pegmatites, known in the States of Minas Gerais, Goiás and Rio Grande do Norte. Estimated additional resources are about 2,200 tonnes Th.

CANADA

Thorium, in both soluble and insoluble form, is closely associated mineralogically with both conglomeratic and pegmatitic uranium ores in Canada. Although soluble thorium oxide to uranium oxide ($\text{ThO}_2 : \text{U}_3\text{O}_8$) ratios are quite variable in the case of Elliot Lake deposits, those associated with present and past producing deposits are generally about 1:1. Uraniferous conglomerates in the Agnew Lake area, however, have soluble $\text{ThO}_2 : \text{U}_3\text{O}_8$ ratios in the order of 2:1 to 3:1. At the Faraday Mine, in the Bancroft area, they are quite constant at about 1:2.

In response to a demand for various industrial uses, thorium concentrates were produced as a by-product of Rio Algom's Elliot Lake uranium operations, from 1959 to 1968. The product was in the form of thorium sulfate, grading from 31 to 35% Th (35 to 40% ThO_2), and was recovered at relatively low cost. Since there is at present little market for thorium, it is not now recovered and goes to tailing dumps. Although thorium in these dumps can technically be considered a reserve, it is doubtful that the material will be recovered in the foreseeable future.

It is estimated that reasonably assured resources of ThO_2 , associated with uranium reserves in the \$10/lb U_3O_8 category, total some 80,000 tonnes Th (100,000 short tons ThO_2). Estimated additional resources of ThO_2 , again associated with the \$10/lb U_3O_8 resources in the same category, are also estimated at about 80,000 tonnes Th (100,000 short tons ThO_2).

ARAB REPUBLIC OF EGYPT

Thorium has been assessed in the outcropping Mediterranean beach sands of Nile origin using aerial and ground radiometric methods, drilling and mineral analysis. In the top metre the reasonably assured resources (reserves) are 14,700 tonnes Th (16,700 tonnes ThO_2) contained in monazite which constitutes about 1% of the total heavy mineral content including ilmenite, magnetite, zircon, rutile, monazite and garnet. The Th assays 5.3% (6.04% ThO_2) in the monazite. In the 19 metres underlying the outcropping top metre of beach sands the estimated additional resources are 280,000 tonnes Th (317,900 tonnes ThO_2). Great resources are expected to be present under the shallow waters of the Mediterranean and the lakes.

Other discoveries of Th occurrences include the beach sands containing monazite of Sinai, the uranothorite mineralisations in granite gneisses, felsites, bostonites and granites, and the thorumite mineralisations in syenite. All these occurrences with the exception of the first one are found in the basement.

INDIA

The chief source of thorium is monazite which occurs widely in the Precambrian granites and gneisses of Peninsular India. The weathered detritus of these rocks is carried by the drainage to the sea where it is deposited along with other economic minerals, such as ilmenite, rutile, sillimanite, kyanite, zircon, etc.

The mineral rich sands are lifted from the sea bed by the scouring action of the waves, particularly during the monsoons, and deposited on the beaches. From here they are lifted by winds and redeposited to form the coastal sand dunes in which these minerals are also concentrated. The mineral content of the sands varies from place to place along the coast.

Indian monazite has a Th content of 7 to 9% (8 to 10.5% ThO_2) and a uranium content of 0.25 to 0.35% (0.3 to 0.4% U_3O_8). The thorium resources in the different monazite-bearing sand deposits are estimated at 300,000 tonnes Th (378,000 short tons ThO_2).

SOUTH AFRICA

Although the ore potentialities have by no means been fully investigated, monazite in detrital deposits in the Karoo Formation is in excess of 180,000 tonnes and contains over 6.0% thorium. Another 150,000 tonnes contain between 5 to 6% Th. In addition, it is estimated that upwards of 25,000 tonnes of monazite, containing 5.3% Th, are still extant in the vein deposits of Steenkampskraal in the Vanxhynsdorp Division of the Cape Province. Furthermore, low-grade uranothorianite is associated with the copper-apatite-magnetite deposits encountered in the carbonatite-foscorite-pyroxenite intrusive pipe at Phalaborwa. It has been estimated that, for open-cast mining, approximately 36,000 tonnes at a grade of 0.01% are available and are recoverable as a by-product of copper mining.

Data on ore processing plants on the gold mines in South Africa are given in a table in Part II.1.

SRI LANKA (CEYLON)

The Island of Sri Lanka is a part of a thorium-rich province which includes the extreme south-west corner of Peninsular India. The principal mineral exploited in recent years was monazite from beach sands which are seasonal concentrates in the south-west of the Island. Due to hazards of marine erosion of this coastal belt the collection of these seasonal concentrates has been discontinued from 1970 onwards and there is no production of monazite at present. However, with the expansion of the Beach Minerals project at Pulmoddai it is expected that further tonnages of monazite concentrates would be available from 1975 onwards but the actual quantities cannot be forecast at present as the separation processes of monazite from the tailings of the Pulmoddai deposit have not been finalised (this work is now at the pilot plant stage).

Other potentially important radioactive minerals include thorianite and thorite which have been detected in a number of localities in stream gravels as well as beach sands.

TURKEY

In the Eskisehir-Beylikahir region, associated with the volcanic breccia, some 4,000 tonnes of Th with 0.16 % Th average grade was found. Having wide geological facilities, the deposits can be increased if the boring is continued.

UNITED STATES

Estimates of U.S. resources of thorium have been revised since the 1965 ENEA report, to include additional information on known orebodies, regional geology and economics of production. Reasonably assured resources total 52,000 tonnes thorium (65,000 short tons ThO_2) at \$10/lb, and estimated additional resources total 265,000 tonnes thorium (335,000 short tons ThO_2). About 72% of the reasonably assured resources and almost all of the estimated additional resources are in vein-type thorite deposits in Idaho and Montana. Remaining reserves are in monazite placer deposits in Idaho and Montana and in the south eastern U.S. The minor quantities of thorium currently produced in the U.S. are all from placer deposits.

Part III

URANIUM AND SEPARATIVE WORK DEMAND

Table 5

WORLD NUCLEAR POWER GROWTH

Installed Nuclear Capacity in GWe (net) at end of each year

Countries	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1985	1990
Austria							0.7	0.7	0.7	1.4	1.4	3	6
Belgium				0.4	1.3	1.7	1.7	1.7	2.3	2.3	3.0	5.5	10
Denmark											0.7	1.5	4
Finland							0.4	0.4	0.4	0.8	1.3	4.6	8
France	1.5	2.4	2.6	2.8	3.2	3.8	4.4	6.8	8.9	10.7	13.4	32.5	67
Germany	0.8	0.8	2.1	2.1	4.9	4.9	9.3	11.5	13.5	16.0	19.0	38	75
Greece											0.7	1.5	3
Italy	0.6	0.6	0.6	0.6	0.6	1.5	1.5	1.5	2.5	3.5	6.0	18	44
Netherlands				0.5	0.5	0.5	0.5	0.5	1.1	1.1	1.7	3.7	8
Norway											1.0	2	4
Portugal												2	3
Spain	0.1	0.6	1.1	1.1	1.1	1.1	2.5	4.2	6.0	6.0	8.0	12	24
Sweden		0.4	0.4	0.4	2.6	3.2	3.2	4.1	5.0	6.8	8.3	16	24
Switzerland	0.4	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.9	1.9	2.6	8	16
Turkey											0.4	1	2
United Kingdom	3.4	4.3	4.5	7.0	7.6	8.8	10.7	11.3	11.3	12.5	13.8	35	75
TOTAL EEC	6.3	8.1	9.8	13.4	18.1	21.2	28.1	33.3	39.6	46.1	57.6	134	283
TOTAL OECD EUROPE	6.8	9.8	12.3	15.9	22.8	26.5	35.9	43.7	53.6	63.0	81.3	184	373
Australia									0.5	0.5	1.0	3	6
Canada	0.2	1.2	2.0	2.5	2.5	2.5	3.3	4.0	4.8	5.5	6.5	15	31
Japan	1.3	1.3	1.8	3.1	5.2	8.6	12.6	17.3	20.6	24.5	32	60	100
U.S.A.	5.2	11.8	15	28.9	42.3	54.2	61.2	69.3	86.7	103.3	132	280	508
TOTAL OECD	13.5	24.1	31.1	50.4	72.8	91.8	113.0	134.3	166.2	196.8	252.8	542	1018
Other countries*	0.4	0.5	0.7	1.0	1.2	2.0	3.0	4.0	6.1	8.2	11.0	25	50
TOTAL	14	25	32	51	74	94	116	138	172	205	264	567	1068
Upper limit + %							1	2	3	4	5	11	20
Lower limit - %							5	6	7	8	9	16	25

* Countries considered: Argentina, Brazil, Formosa, India, Israël, Korea, Mexico, New Zealand, Pakistan, Philippines, South Africa, Thailand.

1. BASIS FOR THE CALCULATION OF URANIUM AND SEPARATIVE WORK REQUIREMENTS

Introduction

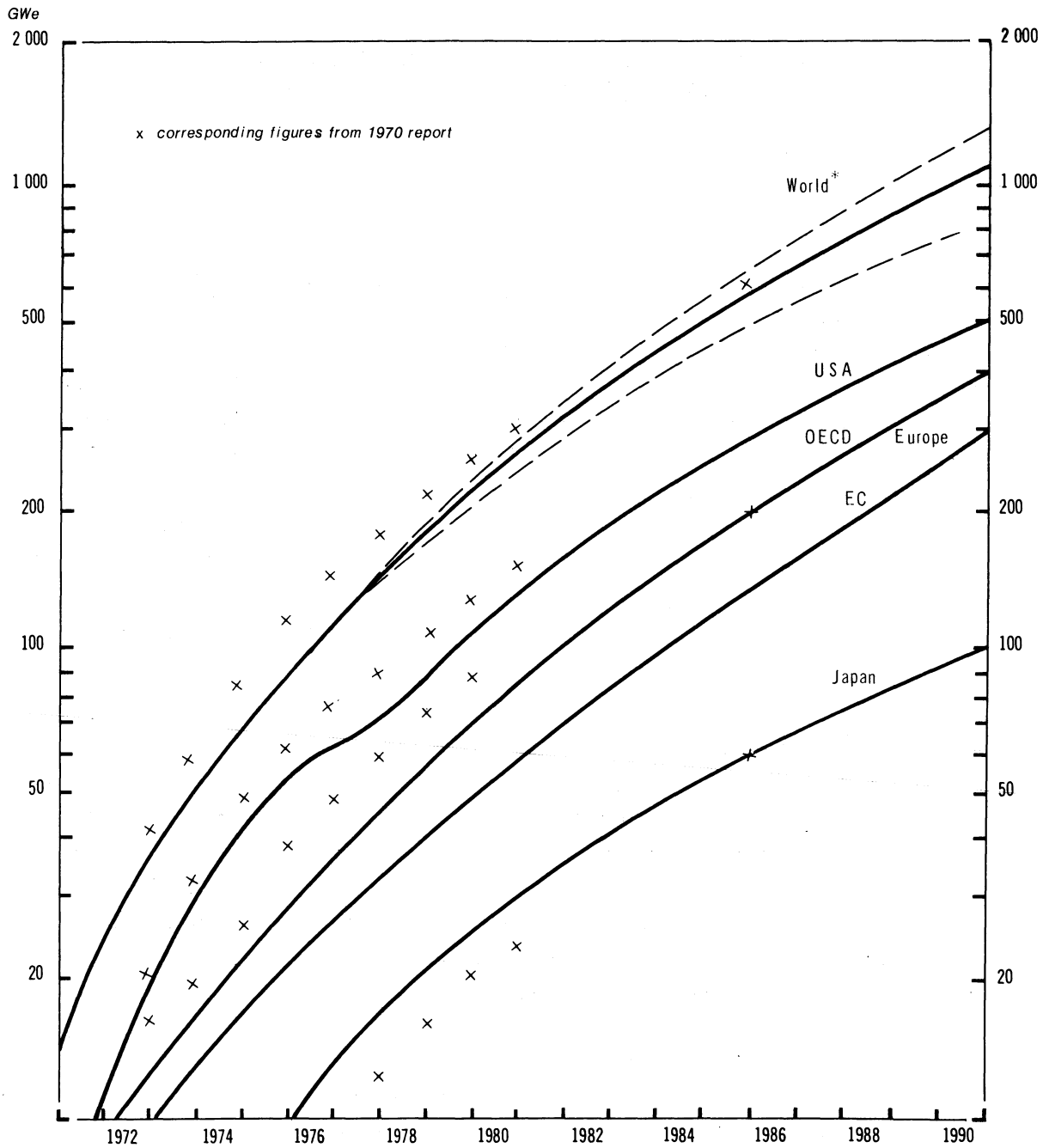
As explained in the foreword to this report, a special Working Party on Uranium Demand was set up to prepare the forecasts of nuclear power growth and uranium demand. This made it possible to improve and considerably extend the scope of the demand calculations compared with those contained in the previous report. The following chapters contain the results of these calculations for low, medium and high power growth cases, taking also into account plutonium recycling in thermal reactors and some variations in reactor strategies. A more detailed picture of the influence of various reactor strategies, the effect of plutonium recycling and that of changes in enrichment plant tails concentrations can be seen from the diagrams shown in the Appendix.

Nuclear Power Growth

For the purpose of this study, the Working Party obtained latest nuclear power growth forecasts (April 1973) for the period up to 1990 from national authorities of most of the countries listed in Table 5. The information from Table 5 is represented in Figure 3 both for the world as a whole and separately for the USA, the OECD European area, the European Community and Japan. Figure 3 also shows, for comparison, the corresponding forecast figures from the previous report of September 1970.

It is to be noted that the new forecasts for the period until 1980 for Europe and for the United States have again had to be revised downwards due to slippage in construction schedules and delays in licensing procedures. In Table 5 and Figure 3, this trend has been taken into account by choosing a larger uncertainty range on the lower side of the forecast than on the upper side. In other words, provi-

Figure 3
 WORLD* NUCLEAR POWER GROWTH
 (Net figures)



* World in the present report means all countries with the exception of the USSR, Eastern Europe and China.

sions have been made that decreases in the totals of the individual country forecasts, due to the delaying factors mentioned, are considered more likely to occur than increases due to acceleration in nuclear power programmes for the immediate future. This trend could be expected, however, to be reversed in the longer term due to further improvements in nuclear technology and planning, especially if unfavourable price developments in the fossil fuel market persist. The possibility that an accelerated nuclear programme might be instituted in many countries to overcome an energy shortage was not considered in this study.

Breakdown of Power Growth Figures by Reactor Types

For the present decade the distribution of reactor types in the various nuclear programmes is relatively clear. Nuclear power plans are known and the major part of the newly installed capacity will be LWRs*. For the period from 1980 up to 1990 it is necessary to make certain assumptions, which however, can be based to some extent on present trends. It has thus been estimated that LWRs will continue to play a leading role, but that advanced reactor types such as HTRs*, FBRs* and, to some extent also, natural uranium HWRs*, will take an increasing share of the total reactor market. (No specific allowance was made for the role which the SGHWR* might play, since no firm plans for the installation of this type of reactor have yet been announced. It was, however, noted that the separative work requirements of this reactor were, in any case, similar to those of LWRs (see Table 9)).

Variations in the assumptions made concerning the market share of these advanced reactor types are shown in Table 6. The "low" cases are reasonably conservative extrapolations of present trends and announced plans - but do not represent minima - particularly regarding fast reactors. The "high" cases, in contrast, are intended to be interpreted as "maxima" to illustrate the greatest effect changes in the present reactor mixes can reasonably be expected to have within the period considered.

-
- * LWR = Light Water Reactor
 - HTR = High Temperature Reactor
 - FBR = Fast Breeder Reactor
 - HWR = Heavy Water Reactor
 - SGHWR = Steam Generating Heavy Water Reactor

Table 6

ADVANCED POWER REACTOR CAPACITY

		1981-1985		1986-1990	
		Low	High	Low	High
A. Annual commissioning rate (averaged over each five-year period), expressed as a percentage of the total new nuclear capacity installed annually.	FB	1.3	8.4	7	22
	HWR	3.9	6.5	4	12
	HTR	2.6	12	6	22
B. Installed advanced nuclear capacity in GWe at the end of the five-year period (mean total nuclear power growth).	FB	5	30	40	140
	HWR	23	33	43	93
	HTR	10	40	40	150

The application of these percentages to the power growth forecasts in Table 5 results in upper and lower limits for advanced reactor capacity. Based on these assumptions, the Working Party has defined a number of different reactor strategy cases, varying the penetration rate of advanced reactor types as shown in Table 7. This table also lists variations in power growth and enrichment plant U 235 tails concentrations. The corresponding 15 different strategy cases were chosen for final computer calculations of natural uranium demand, separative work requirements and plutonium production.

Table 7

REACTOR STRATEGIES

	Case	Installed Capacity of Advanced Reactor Types			Nuclear Power Growth	Enrichment Tails Assay
		FB (1)	HWR (2)	HTR (3)	(4)	% U 235
Variations in Reactor Strategies	A	Low	Low	Low	Mean	0.25
	B	High	Low	Low	Mean	0.25
	C	Low	High	Low	Mean	0.25
	D	Low	Low	High	Mean	0.25
	E	High	High	Low	Mean	0.25
	F	High	Low	High	Mean	0.25
	G	Low	High	High	Mean	0.25
Variations of Power Growth Forecasts	A ₁	Low	Low	Low	Low	0.25
	A ₂	Low	Low	Low	High	0.25
	B ₁	High	Low	Low	Low	0.25
	B ₂	High	Low	Low	High	0.25
Variations of Tails Assay	A ₃	Low	Low	Low	Mean	0.20
	A ₄	Low	Low	Low	Mean	0.30
	B ₃	High	Low	Low	Mean	0.20
	B ₄	High	Low	Low	Mean	0.30

LWR capacity is always the difference between totals in Table 5 and sum of FB, HWR, HTR, GG* and AGR* capacity. Table 8 shows one example. The terms low and high in columns (1), (2) and (3) refer to minima and maxima given in Table 6. In column (4) low, mean and high refer to the totals and their upper and lower limits as described in Table 5.

The relation between PWRs and BWRs was assumed to be 3:2, based on actual trends in the USA (2:1) and Europe (1:1). As an example of results obtained, Table 8 shows installed nuclear capacity for one of the 15 cases, namely Case A: the installation rates for all the other cases can be derived from the foregoing definitions.

* GG = Gas-Cooled Graphite-moderated Reactors
 AGR = Advanced Gas-Cooled Reactor

Table 8

INSTALLED NUCLEAR CAPACITY (IN GWe)
CASE A (HIGH LWR, MEAN POWER GROWTH)

Year	Magnox ¹⁾	AGR ¹⁾	FB	HWR	HTR ²⁾	PWR ³⁾	BWR ³⁾	Total ⁴⁾
1970	5			1		4.8	3.2	14
1975	7	4.3		4		49.0	32.7	97
1980	7	6	1.0	11	2	146	97	270
1985	7	6	5	23	10	317	212	580
1990	7	6	40	43	40	563	376	1075

- 1) Magnox and AGR capacities are same in all cases.
- 2) 50% high enriched HTR. 50% low enriched HTR.
- 3) Relation PWR:BWR = 3:2.
- 4) As a result of last minute changes in the forecasts of some individual countries, the total nuclear capacities used for the calculations differ somewhat from the total mentioned in Table 5.

Power Reactor Characteristics

The power reactor characteristics collected and used by the Working Party are the most up-to-date available, but they may not reflect any very recent changes in fuel design towards smaller diameter pins at given specific power. A distinction was made for LWRs between those installed before and after 1980. Two sets of performance data were used for HTRs, one for low enrichment (4% to 6% U 235) and the other for high enrichment (93% U 235) fuel cycles. In the absence of more reliable indications, the relationship between these two reactor types was assumed to be 1:1. A summary of all characteristics used for thermal reactors is contained in Table 9. As concerns fast breeder reactors, the Working Party derived from various data supplied by different contributing countries, a single self-consistent 'compromise' set of performance data. These data for FBRs are also given in Table 9.

Station Load Factors

In several recent publications, and also in the previous report (September 1970) station load factors of 80% have been used to calculate uranium and separative work requirements. This figure seemed too high to many members of the Working Party. In fact, average annual load factors for most types of nuclear stations have

Table 9

POWER REACTOR CHARACTERISTICS (FOR UNITS OF 600-1200 MWe)

	BWR	BWR	PWR	PWR	GG	AGR	HWR	HTR	HTR	SGHWR	FB	
	1970s	1980s	1970s	1980s				Dragon	USA		Core	Blanket
Thermal efficiency (%)	34	34	33	33	30	42	29	41.7	39	32	40	40
Average spec. power in fuel (kW/kg heavy metal)	22	24	38	41	3.7	12.5	22	91	73	19.7	145	6.0
Initial core: Irradiation level (MWd/kg heavy metal)	21	21	24.4	24.4			8	32.5 (20-80)	53		37.5	1.75
Fresh fuel enr. (% U 235)	2.2	2.2	2.63	2.63	Nat.	1.63	Nat.	3.95	93.15	2.13		
Spent fuel enr. (% U 235)	0.77	0.77	0.76	0.76				0.94	30			
Inventory: kg nat. U/MWe	570	519	415	384	900	576	156	175	307	655	26 ²⁾	33 ²⁾
kg SW/MWe (0.25 tails assay)	310	281	250	232		253		147	351	355		
kg Pu(E)/MWe											2.4	
Pu(E) produced ⁴⁾ (g/MWe yr)	296	296	346	346			512	141			130	
Replacement loadings: Irradia- tion level (MWd/kg heavy metal)	27.5	27.5	33	33	4	18	9.6	77	93.5	21	80	5.25
Fresh fuel enr. (% U 235)	2.56	2.56	3.19	3.19	Nat.	2.23	Nat.	6.36	93.15	2.11		
Spent fuel enr. (% U 235)	0.75	0.75	0.84	0.84	0.4	0.81		0.88	30	0.63		
Net consumption :												
kg nat. U/MWe-yr ¹⁾	157	157	175	175	300	150	131	136	88	177	1.9	-
kg SW/MWe-yr (0.25 tails assay)	115	115	138	138	-	109	-	122	95	121		
Pu(E) produced ⁴⁾ (g/MWe yr)	248	248	269	269	595	181	440	115	(U233) 227	259	130	
Operating time to reach equilibrium (yr)	4	4	3	3	3	4		7	5	4.5	3	3-7 ³⁾

1) 1 MWe-yr = 8760 MWh. Figures are based on instantaneous credit for spent fuel. Demands in this report are based on credits delayed by times shown in Table 10.

2) Depleted uranium.

3) Depends on position.

4) Allows for reprocessing losses and, where appropriate, for the decay of Pu 241.

NOTE: All plutonium figures are expressed in equivalent grams Pu 239, i.e. in Pu(E) for use in FBRs, applying the following "worth factors": 239 x 1.00; 240 x 0.18; 241 x 1.53; 242 x 0.08.

so far generally been well below this figure. Despite the general tendency for the availabilities of nuclear stations to increase - due to improvements in reliability - overall factors as high as 80% may not be reached or maintained, partly because a rather large proportion of the nuclear capacity in the beginning of the period under consideration will be taken up by plants of new design and/or of new type, and also because, in the longer term, there will be an increasing tendency for some nuclear stations to be used as medium load stations and this will lead to reduced load factors.

For these reasons, the Working Party decided to adopt the assumption that the annual load factor of all stations of all types would be 70% for the whole period under consideration.

Delay Times

The delay times between availability of natural uranium at the mine-head, or enriched uranium at the enrichment plant output, and the beginning of irradiation of the fuel in a reactor have a considerable influence on the uranium and separative work demand at a given point in time. Great care has therefore been taken to define and determine the different delay times found in current practice. These delay times are listed in Table 10, a distinction being drawn between reactors working on enriched and natural uranium, and also between initial reactor cores and replacement cores.

Table 10
DELAY TIMES (years)

	Enriched Uranium Reactors		Natural Uranium Reactors		Fast Breeder Reactors
	Initial Core	Replacement Loading	Initial Core	Replacement Loading	
Mine out - Reactor in	1.75 ¹⁾	1.5 ²⁾	1.4 ¹⁾	1.0 ²⁾	1.0
Reactor out - Reactor in		2 ²⁾			0.8
Reactor out - Reprocessing out	0.8	0.8	0.8	0.8	0.6
Enrichment plant out - Reactor in	1.1 ¹⁾	0.8 ²⁾			

1) Including commissioning (0.5 yrs.)

2) Including refuelling time.

Plutonium Production and Plutonium Recycling

It is considered that, in the longer term, plutonium will be primarily used in fast reactors. To the extent that there will be surplus plutonium available after allowing for fast reactor requirements, however, allowance has been made for the effect of recycling plutonium in thermal reactors. For the purpose of this report it has been assumed that plutonium recycling will be carried out in LWRs only and will start at the beginning of 1978 and will proceed thereafter at a rate which provides at all times for the prior needs of fast reactors and the maintenance of a continuing stock of 50 tonnes of Pu 239(E). These provisions effectively ensure a steady and progressive build-up in the amount of plutonium recycled in thermal reactors from 1978 onwards. It has also been assumed that all plutonium produced in fast reactors will be re-used in such reactors and not in thermal reactors.

All plutonium production figures are expressed in "Fast Reactor equivalent grammes Pu 239" $\sqrt{\text{Pu(E)}}$, using the following "worth factors": Pu 239 x 1.00; Pu 240 x 0.18; Pu 241 x 1.53; Pu 242 x 0.08. The plutonium $\sqrt{\text{Pu(E)}}$ available at a given time for recycling in LWRs is obtained by deducting from the total Pu(E) produced by thermal reactors, the requirements for FBRs according to the reactor strategy case in question. This stockpile is converted into fissile plutonium $\sqrt{\text{Pu(f)}}$ using the factor 0.85, i.e. 1 gramme Pu(E) corresponds to 0.85 g Pu(f).

For the calculation of savings of uranium and separative work, the following figures have been used, expressed in savings per gramme of fissile plutonium to be recycled. These figures in Table 11 have been independently checked by computer runs specially devised to show the effect of plutonium recycling (using the DISCOUNT code).

Table 11

SAVINGS PER GRAMME OF Pu(f) RECYCLED IN LWRs¹⁾

	0.20	0.25	0.275	0.30
Enrichment plant tails assay % U 235				
Nat. Uranium savings g/g Pu(f)	122	140	150	162
Separative work savings g SWU/g Pu(f)	158	140	134	127

1) Derived for PWRs, but also used for BWRs.

Calculation Methods

For the purpose of this report, computer calculations of uranium demand, separative work requirements and plutonium production were carried out in the following countries: Canada (by the Atomic Energy of Canada Ltd. with the CENTRIF computer code), Germany (by NUKEM), Italy (by CNEN with the DFAPUR code), the Netherlands (by N.V. KEMA with the FURE code), the United Kingdom (by the UKAEA with the DISCOUNT G code) and the United States (by the USAEC with the SSS code). Before the main calculations were undertaken, all participating laboratories carried out test runs on Cases A and B (see Table 7) in order to harmonize their methods, and the results obtained were in very satisfactory agreement.

In the following, for each of the 15 cases described in Table 7 at least two (and mostly three or four) independent computer runs were made, and the results presented are in all cases mean values from these independent runs.

2. REQUIREMENTS FOR URANIUM

Introduction

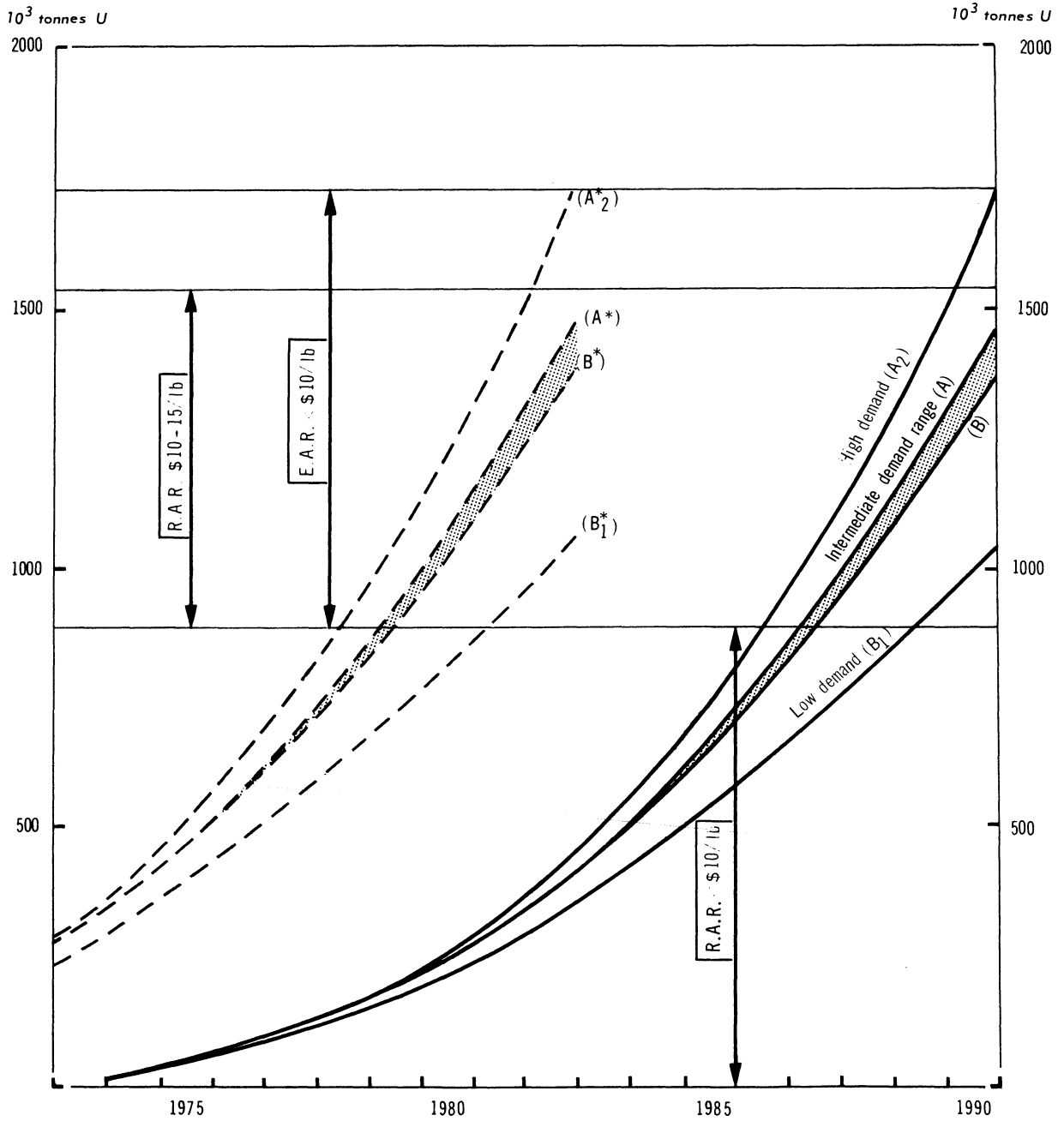
As indicated in the introduction to the previous chapter, the various influences of power growth, reactor strategies, enrichment plant tails assays and plutonium recycling are demonstrated in the diagrams in the Appendix. It is shown that the uranium demand variations due to power growth uncertainties by far exceed those due to different reactor strategy uncertainties. It can also be seen how the savings of natural uranium, due to plutonium recycling in thermal reactors, vary with different programmes and different installation rates (Figure 10 refers).

To demonstrate the influence of the variation of the enrichment tails concentration between 0.20 and 0.30% two strategy cases were chosen, namely high LWR (case A) and high FB (case B) installation rates.

In the past, the tails assay of the enrichment plants in the United States was kept at 0.20% U 235. In March 1972 the USAEC announced that the U.S. enrichment plants were actually operating at a tails assay of 0.30% U 235, even though the transaction tails assay for enrichment contracts would still be kept at 0.20% U 235 until existing stocks of enriched uranium were used up. (This arrangement was designed to enable the USAEC to use the U.S. Government surplus stock of 38,500 tonnes U as additional feed material for the enrichment plants). Furthermore, the announcement went on to state that a minimum tails assay of 0.275% was to be considered for application after the fiscal year 1973. More recently, in December 1972, the USAEC in a statement made by the then Chairman Schlesinger, announced that it planned to operate all its existing diffusion plants with the tails assay fixed indefinitely at about 0.30% U 235.

In general, however, the choice of the tails assay at which an enrichment plant will be operated will be determined by the relative costs of the uranium fed to the plant and the separative work produced

Figure 4
 RELATIONSHIP BETWEEN URANIUM RESERVES
 AND CUMULATIVE REQUIREMENTS



* These demand curves are shifted 8 years forward.

Assuming recycling of plutonium in LWRs; the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing notional use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services; and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

by it, and the special considerations affecting current USAEC practice, as described above, do not necessarily provide the best indication of the likely tails assay values of the world's enrichment plants in the longer term.

Comparison of Uranium Demand and Supply

For the purpose of selecting a reference case for uranium requirements, it has been assumed that the existing U.S. diffusion plants would operate at a tails assay value of 0.30% (while nominally operating at 0.20%) until the U.S. Government stock of 38,500 tonnes uranium was dissipated; this will probably be the case around 1980. It has been furthermore assumed that from that date onwards all enrichment plants will run at 0.275% tails assay*. It has then been necessary to select the reactor strategies which embrace the most probable uranium demand range. The Working Group proposed to consider the range between Cases A and B for this purpose, A being the case of continuation of the present trend, while B represents high introduction rates of fast breeders. This band was chosen not necessarily because the Group believes that fast breeders will be introduced at a high rate but because the band also embraces other possible alternatives, namely high HTR penetration (Case D), high HWR penetration (Case C) and the combination of high HTR and HWR penetration (Case G). It was furthermore regarded to be probable that plutonium recycling in thermal reactors will take place on a world-wide basis beginning from 1978 onwards. Table 12 and Figure 1 give the resulting uranium requirements for the intermediate range (A-B) and also for the lowest (B_1) and highest (A_2) demand cases considered in this report.

In Figure 4 the cumulative uranium demand figures from 1973 onwards are plotted together with indications of the low-cost uranium resources not taking into account the uranium stockpile position due to lack of complete information. Since the uranium mining industry, for technical and economic reasons, has to operate on substantial forward reserves (an 8-year lead time is considered appropriate), curves are plotted in Figure 4 showing the technical reserve position if an 8-year forward requirement were adopted. These curves show

* A tails assay of 0.30% results in a 4.5% higher uranium demand in 1985 for case A.

Table 12

ANNUAL WORLD URANIUM REQUIREMENTS

Assuming recycling of plutonium in LWRs; the use of a US stock of 38,500 tonnes U to enable the existing US enrichment plants to be operated at a tails assay of 0.30% U 235 up to 1980, despite the continuing national use of a tails assay of 0.20% U 235 in all contracts for USAEC enrichment services; and the operation of all enrichment plants after 1980 at a tails assay of 0.275% U 235.

Year	Lower Limit		Medium Range				Higher Limit	
	Case B ₁		Case B		Case A		Case A ₂	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1973	16	16	17	17	17	17	17	17
1974	19	35	20	37	20	37	21	38
1975	23	58	25	62	25	62	26	64
1976	27	85	30	92	30	92	31	95
1977	31	116	35	127	35	127	37	132
1978	35	151	40	167	40	167	43	175
1979	39	190	45	212	45	212	56	231
1980	51	241	60	272	61	273	66	297
1981	56	297	67	339	69	342	76	373
1982	63	360	76	415	78	420	88	461
1983	68	428	84	499	87	507	99	560
1984	74	502	93	592	97	604	112	672
1985	79	581	103	695	108	712	127	799
1986	83	664	112	807	120	832	145	944
1987	89	753	124	931	133	965	163	1107
1988	94	847	135	1066	145	1110	181	1288
1989	98	945	145	1211	158	1268	201	1489
1990	100	1045	156	1367	173	1441	224	1713

that, assuming a medium power growth (cases A and B), the forward reserves position is adequate until 1979, i.e. new low-cost reserves will have to be proven from then onwards. If nuclear power growth is low (case B₁), the technical reserves position would be adequate until the beginning of 1981 and if nuclear power growth is accelerated (case A₂) there again, new low-cost reserves would have to be proven from 1978 onwards.

Considerations concerning the corresponding discovery rates once forward reserves begin to become inadequate, have been developed in Part I,4. of this report (see also Figure 2).

3. REQUIREMENTS FOR SEPARATIVE WORK

Influence of Reactor Strategies and Power Growth

A similar approach as for the uranium demand calculations was adopted for separative work requirements. In the Appendix, the influences of the various reactor strategies and of the high and low power growth forecasts are shown. Again, as in the uranium demand figures, the variations due to power growth uncertainties outweigh those due to different reactor strategies. However, within the different strategy cases considered, a somewhat different distribution of higher and lower demand curves is observed. For instance the introduction of HTRs (case D) does not change requirements significantly, compared to those for case A, whereas the introduction of HWRs (case C) of course results in lower requirements. Nevertheless the band defined by cases A and B can be considered as the most probable requirement.

Relation between Separative Work Supply and Demand

To interrelate separative work supply and demand, an attempt is made to add to the USAEC production figures (as given in USAEC News Releases, March 8, 1972) those from other sources, i.e. the Urenco programme and the small diffusion capacity existing in Europe. The following Table contains the known annual production capacities and plans from the above-mentioned European sources.

Table 13

EXISTING AND PLANNED SW PRODUCTION CAPACITY
IN EUROPE (TONNES SWU/YEAR)

	1973	1976	1980	1985
Urenco ^{a)b)}	50	300	2000	10000
Eurodif ^{c)}	200		5000	9000
UKAEA, Capenhurst	400			

a) J.V.L. Parry, The Tripartite centrifuge enrichment project, JAIF Conference, Tokyo, March 1973

b) URENCO (Uranium Enrichment Company) is the joint British, Dutch, German company constructing enrichment plants based on the centrifuge process.

c) EURODIF (European Diffusion Plant) is a European Study Group, initiated by the French CEA.

Other plans for new enrichment capacities inside and outside the United States have not been considered due to lack of precise information, although recent information indicates that substantial separative work capacity is available in the USSR.

Concerning separative work demand, the same reference cases have been used as in the chapter on uranium requirements, i.e. continuation of the present trend (A) and high breeder installation rates (B) together with corresponding low and high power growth figures (B_1 and A_2). It is assumed that plutonium recycling in thermal reactors will start at the beginning of 1978 on a world-wide basis, with a plutonium stock of 50 tonnes Pu(E) always being maintained. Lead times for plutonium recycling are the same as those for uranium recycling. Enrichment tails assays are assumed to be 0.275%.

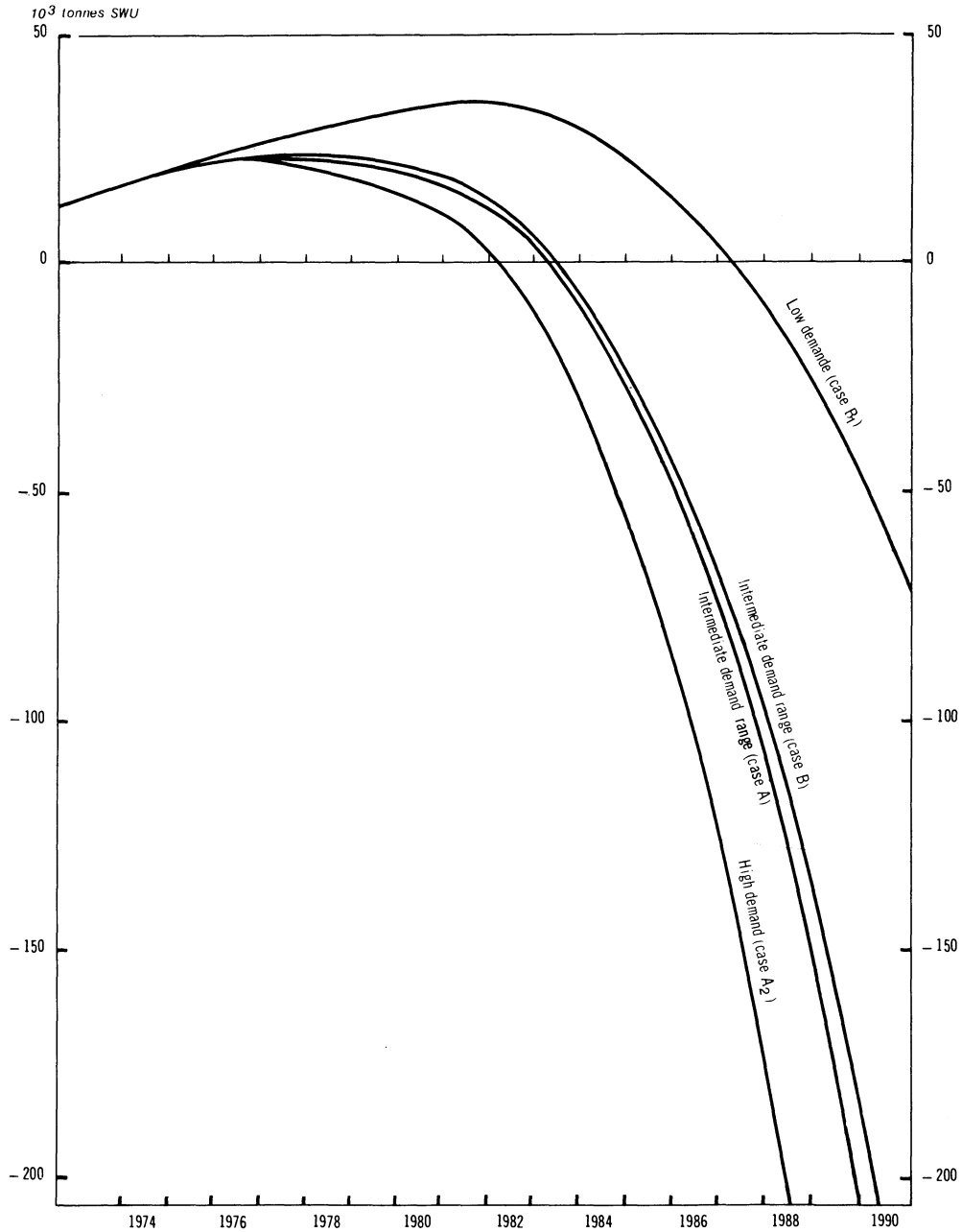
All these assumptions result in the requirements given in Table 14. To show supply/demand relations, the cumulative separative work requirement was subtracted from the total cumulative separative work production (i.e. from U.S. + European sources*) including US preproduction, and the resulting separative work stock is plotted in Figure 5.

* The figures announced by Eurodif given in Table 13 have not been included in this assessment.

Table 14
 ANNUAL WORLD SEPARATIVE WORK REQUIREMENTS
 in 10^3 tonnes SWU/yr
 (0.275% tails assay, Pu recycle)

Year	Lower Limit		Medium Range				Higher Limit	
	Case B ₁		Case B		Case A		Case A ₂	
	Annual	Cumu- lative	Annual	Cumu- lative	Annual	Cumu- lative	Annual	Cumu- lative
1973	9	9	9	9	9	9	9	9
1974	10	19	11	20	11	20	11	20
1975	13	32	14	34	14	34	14	34
1976	16	48	17	51	17	51	18	52
1977	18	66	20	71	20	71	22	74
1978	21	87	24	95	24	95	26	100
1979	23	110	26	121	26	121	29	129
1980	26	136	30	151	31	152	33	162
1981	30	166	35	186	35	187	39	201
1982	34	200	40	226	41	228	46	247
1983	37	237	45	271	46	274	52	299
1984	41	278	51	322	52	326	60	359
1985	45	323	57	379	58	384	68	427
1986	48	371	63	442	65	449	78	505
1987	51	422	70	512	73	522	88	593
1988	56	478	77	589	81	603	99	692
1989	59	537	85	674	89	692	111	803
1990	61	598	91	765	97	789	124	927

Figure 5
 SEPARATIVE WORK STOCK
 RESULTING FROM US AND EUROPEAN¹ PRODUCTION
 (0.275% tails assay with Pu recycle)



Note : If a 0.30% tails assay is assumed, the time at which demand exceeds supply would be postponed by about 15 months for cases A and B.

¹ The capacity figures announced by Eurodif are not included.

The Figure clearly shows when SW demand exceeds supply for the main cases. In the period under consideration, the influence of FB introduction rates is small and the delay between the respective cross over points is of the order of several months only (see cases A and B in Figure 5). If power growth were high, SW supply from new sources would be needed in 1982. If it were medium, this date would become 1983 and if the power growth were low, the date would be 1987.

The strong influence of the nuclear power growth on the time when new capacity will be needed suggests careful observation of this development. Indeed, as the lead times for licensing and constructing nuclear power plants are of the order of seven years, it should be possible to detect any deviation from the presently considered most probable case A (suggesting a cross over point in 1983) sufficiently early to adjust the plans for construction of additional enrichment capacities, the lead time for this being either of the same order or, in the case of centrifuge plants, somewhat shorter. (It should be mentioned that the time for preliminary negotiations can considerably extend the total lead times for providing new enrichment capacity).

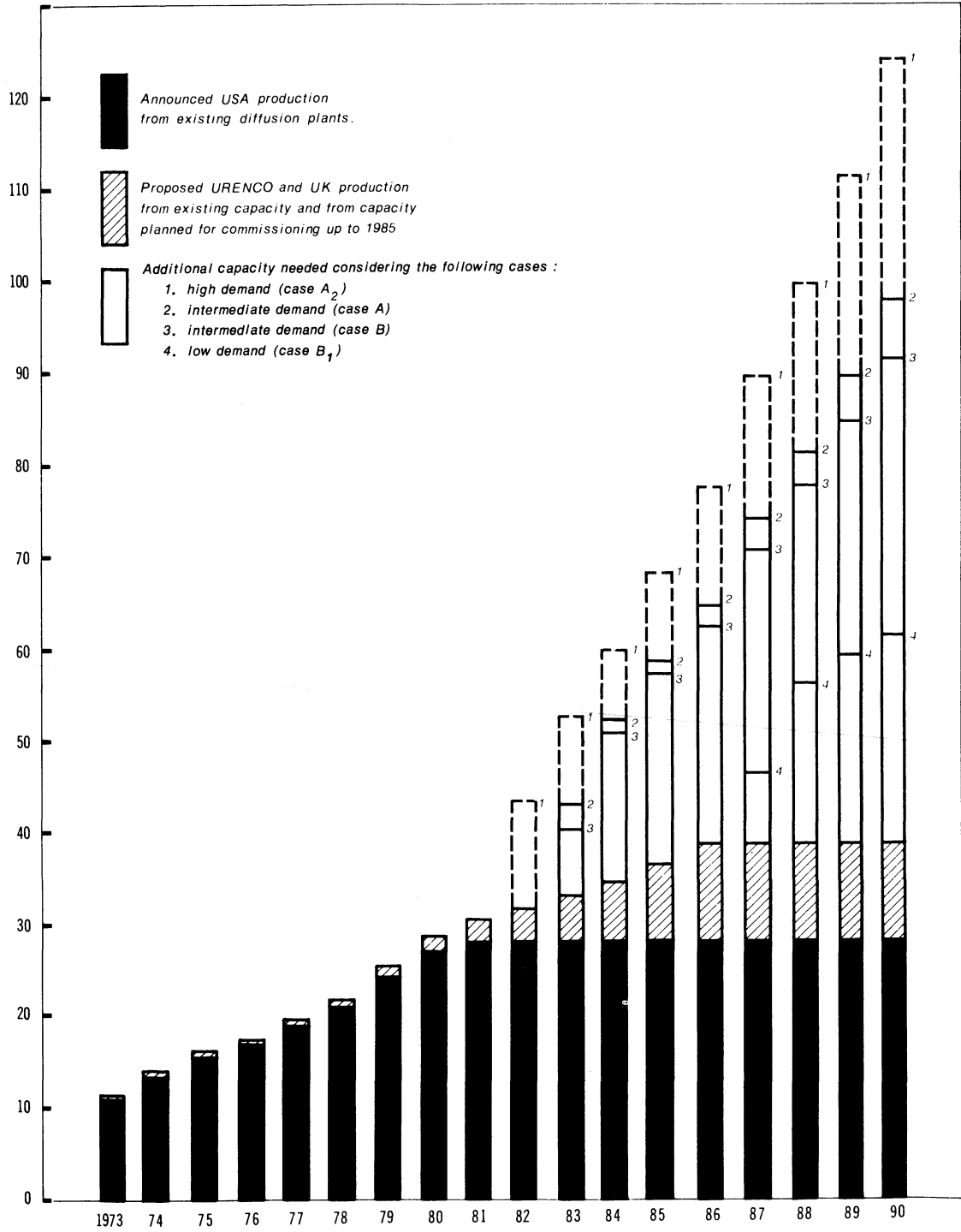
A most striking conclusion from Figure 5 is the rapid increase of need postulated for additional separative work after the crossing over points and consequently, the high installation rates for separative work plants necessary to meet these requirements. To better illustrate this situation, Figure 6 gives planned annual separative work production figures, together with the additional annual production needed after existing and planned capacities have been fully used. Assuming enrichment plant tails assays of 0.275% U 235, new enrichment plant capacity of 8,000 tonnes SWU should be available in 1987 and another 10,000 tonnes in 1988 for the low power growth case (B_1). If however, medium nuclear power growth is assumed and all other conditions remain the same (cases A and B), new capacity of some 8,500 tonnes SWU would already be required in 1983 and another 8,500 tonnes in the following year. If a high power growth is assumed (A_2) the required new SW capacity in 1982 would be 11,000 tonnes and another 9,000 tonnes in the following year.

This rapid increase of need for additional separative work can be explained by the existence of stocks due to preproduction, which tend to postpone the time when new enrichment capacities become necessary. In reality, this effect might be reduced by somewhat earlier installation of new plants than seems absolutely necessary.

Figure 6

ANNUAL SEPARATIVE WORK PRODUCTION AND ADDITIONAL CAPACITY REQUIREMENTS
(0.275 TAILS ASSAY AND Pu RECYCLE)

10^3 tonnes SWU/yr



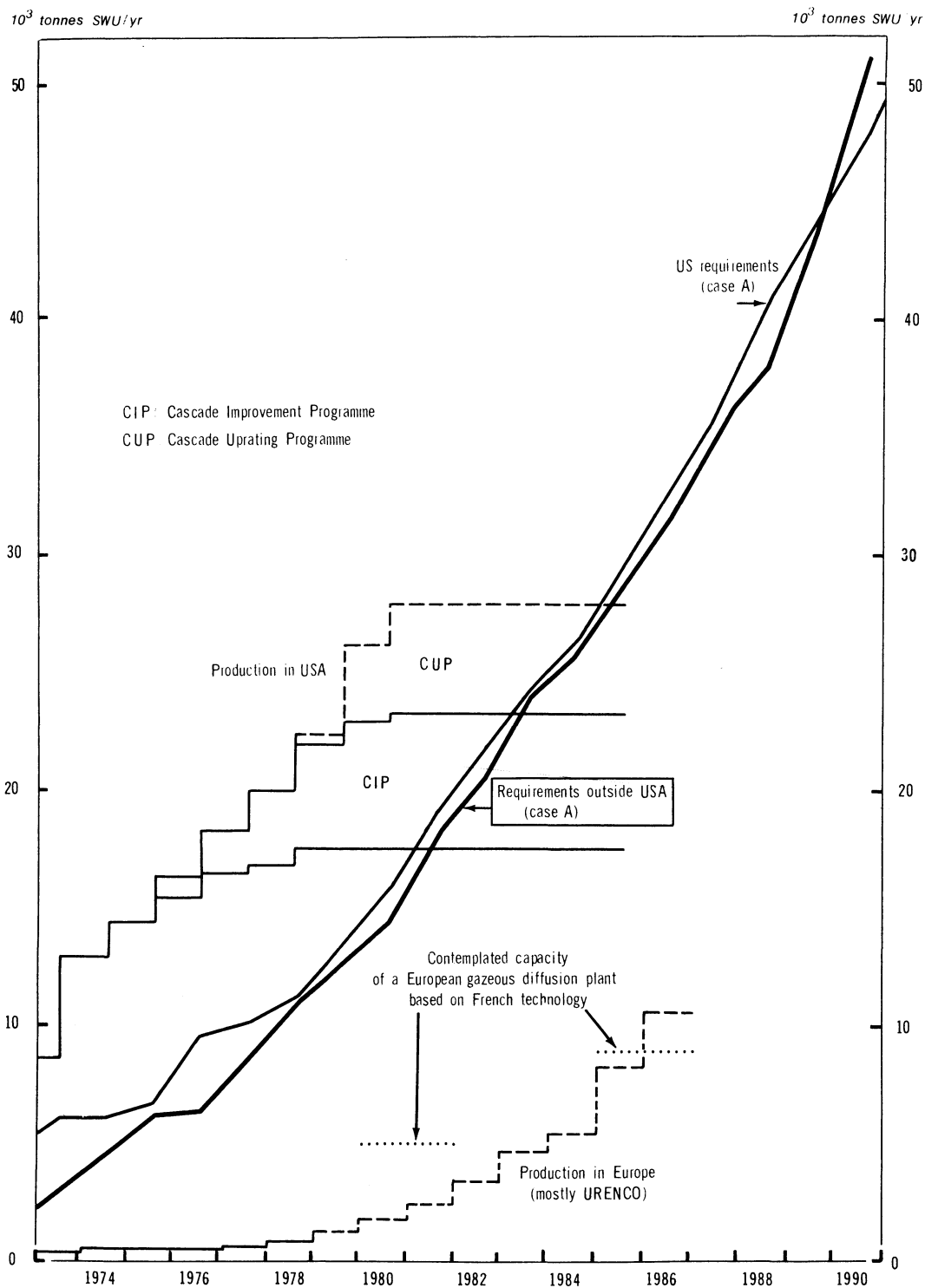
Finally, in Figure 7, an attempt is made to distinguish between non-US and US needs for separative work*. This distinction indicates that annual US enrichment demand would match US capacities in 1985, if no new plants were constructed. At that time the annual requirements outside the USA are of the same order.

It is important also to note that the recent revisions of the uranium enriching services criteria of the USAEC include a contract limitation which renders these services "subject to available capability". An additional uncertainty in the present situation on uranium enrichment results from possible offers for separative work from sources not included in the foregoing considerations, such as USSR enrichment capacity and military stockpiles.

* "The corresponding calculations were performed by the USAEC on the basis of installed capacities and other data agreed by the Working Party, using a reactor mix similar to case A".

Figure 7

ANNUAL SEPARATIVE WORK REQUIREMENTS AND PRODUCTION
(0.275 TAILS ASSAY, Pu RECYCLING)



APPENDIX

This Appendix contains tables and figures on nuclear power growth, and uranium and separative work requirements, obtained as a result of computer calculations derived from the fifteen strategy cases listed in Table 7. These figures are given to illustrate the influence of the different assumptions described in Part II of this report and should assist the reader in his own assessment of what he considers the most probable development of uranium and separative work requirements.

Table 15
 INSTALLED NUCLEAR CAPACITY (IN GWe)
 MEAN POWER GROWTH

Year	F B		H W R		H T R		all cases		Total
	Low	High	Low	High	Low	High	Magnox	AGR	
1970			1	1			5		14
1971			2	2			7		25
1972			3	3			7		32
1973			3	3			7	2.5	52
1974			4	4			7	3.1	77
1975			4	4			7	4.3	97
1976			4	4			7	6	116
1977			5	5			7	6	145
1978			7	7			7	6	180
1979		2	9	9	1	1	7	6	220
1980	1.0	4	11	13	2	3	7	6	270
1981	1.5	6	13	16	3	5	7	6	319
1982	2.0	9	15	19	4	10	7	6	375
1983	2.5	14	17	23	5.5	17	7	6	436
1984	3.5	21	20	28	7.5	27	7	6	505
1985	5	30	23	33	10	40	7	6	580
1986	7	42	26	41	14	55	7	6	663
1987	11	56	30	51	18	73	7	6	753
1988	17	80	34	63	24	95	7	6	852
1989	25	110	38	77	31	120	7	6	960
1990	40	140	43	93	40	150	7	6	1075

LWR capacity is the difference between the total and the sum of all other reactor types established for each case according to Table 7 (PWR:BWR = 3:2).

Table 16

INSTALLED NUCLEAR CAPACITY (IN GWe)
 CASES A₁ AND B₁ (LOW POWER GROWTH)

Year	F B		Both cases		All cases		Total
	Low	High	HWR	HTR	Magnox	AGR	
1970			1		5		14
1971			2		7		25
1972			3		7		32
1973			3		7	2.5	52
1974			4		7	3.1	77
1975			4		7	4.3	92
1976			4		7	6	109
1977			5		7	6	135
1978			6		7	6	166
1979		2.0	8	1	7	6	200
1980	1.0	3.5	10	2	7	6	243
1981	1.0	5	12	3	7	6	284
1982	1.5	8	13	4	7	6	330
1983	2.0	12	15	5	7	6	379
1984	3.0	18	17	6	7	6	432
1985	4	25	19	8	7	6	487
1986	6	35	21	11	7	6	547
1987	9	45	24	15	7	6	610
1988	13	63	27	19	7	6	673
1989	19	85	29	24	7	6	739
1990	30	105	32	30	7	6	806

Table 17

INSTALLED NUCLEAR CAPACITY (IN GWe)
CASES A₂ AND B₂ (HIGH POWER GROWTH)

Year	F B		Both cases		All cases		Total
	Low	High	HWR	HTR	Magnox	AGR	
1970			1		5		14
1971			2		7		25
1972			3		7		32
1973			3		7	2.5	52
1974			4		7	3.1	77
1975			4		7	4.3	97
1976			4		7	6	117
1977			5		7	6	148
1978			7		7	6	185
1979		2.0	9	1	7	6	229
1980	1.0	4.0	11	2	7	6	284
1981	1.5	6.5	13	3	7	6	338
1982	2	9.5	15	4	7	6	401
1983	3	15	18	6	7	6	471
1984	4	23	21	8	7	6	553
1985	6	33	25	11	7	6	644
1986	8	47	29	16	7	6	746
1987	13	64	34	21	7	6	858
1988	20	93	39	28	7	6	988
1989	30	130	45	37	7	6	1133
1990	48	170	52	48	7	6	1290

Figure 8
 ANNUAL WORLD URANIUM REQUIREMENTS
 FOR DIFFERENT REACTOR STRATEGIES AND POWER GROWTH
 (no Pu recycle, 0.25 tails assay)

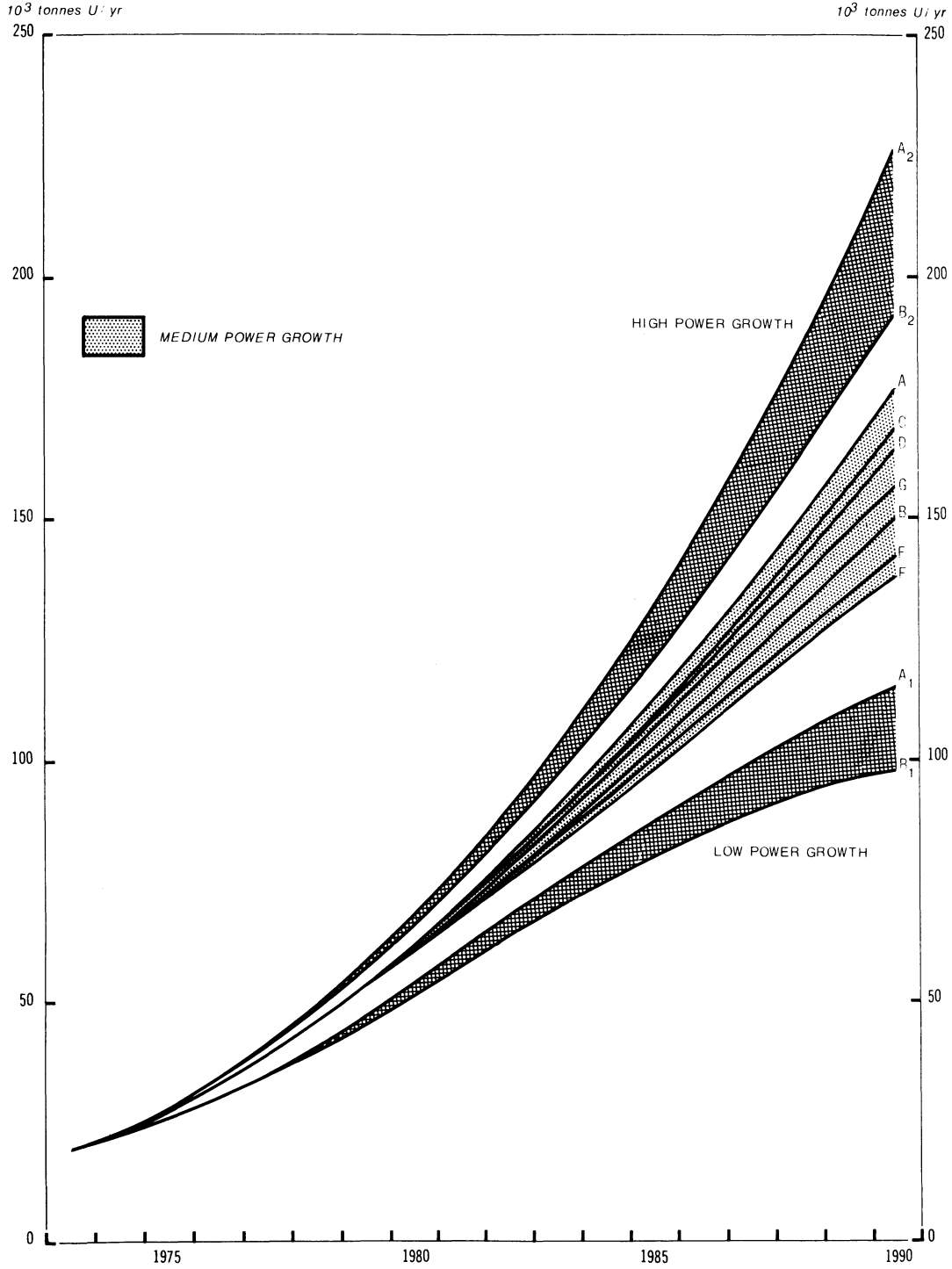


Figure 9
 ANNUAL URANIUM DEMAND FOR
 DIFFERENT ENRICHMENT TAILS ASSAYS
 (no Pu recycle)

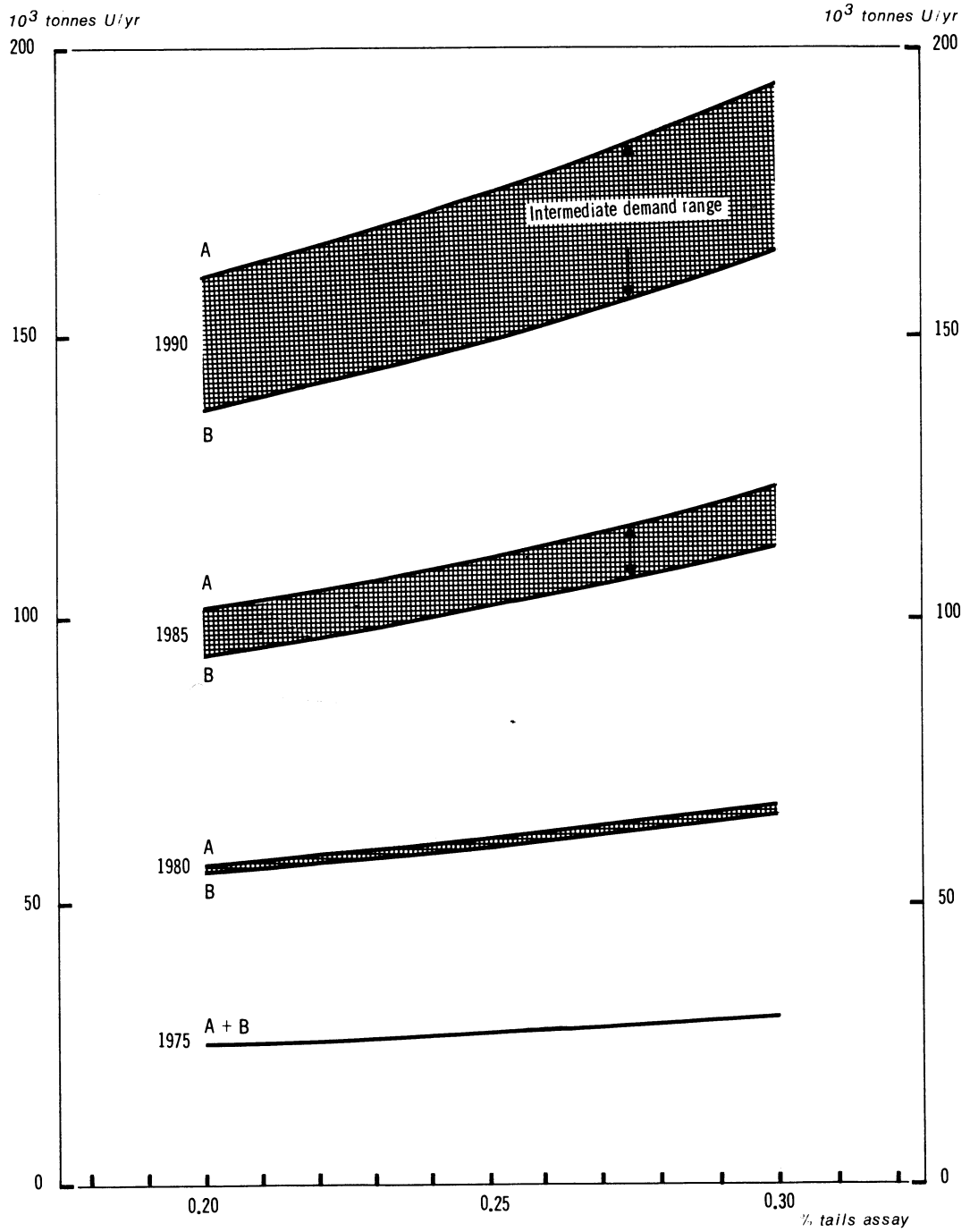


Figure 10
 Pu STOCK AFTER DEDUCTION OF FB REQUIREMENTS,
 AVAILABLE FOR Pu RECYCLE

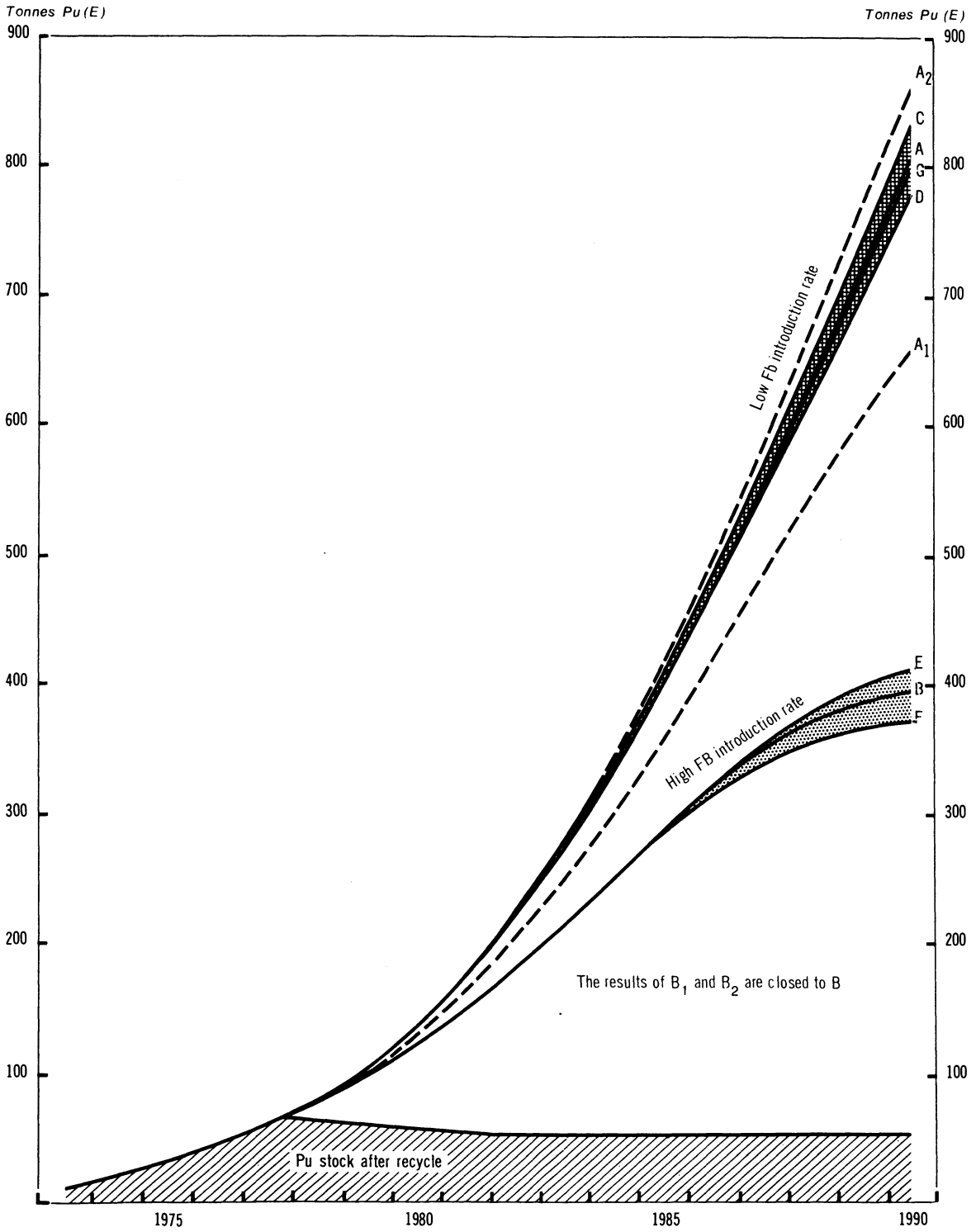


Figure 11
 INFLUENCE OF Pu RECYCLE
 ON THE ANNUAL URANIUM DEMAND
 (0.25% tails assay)

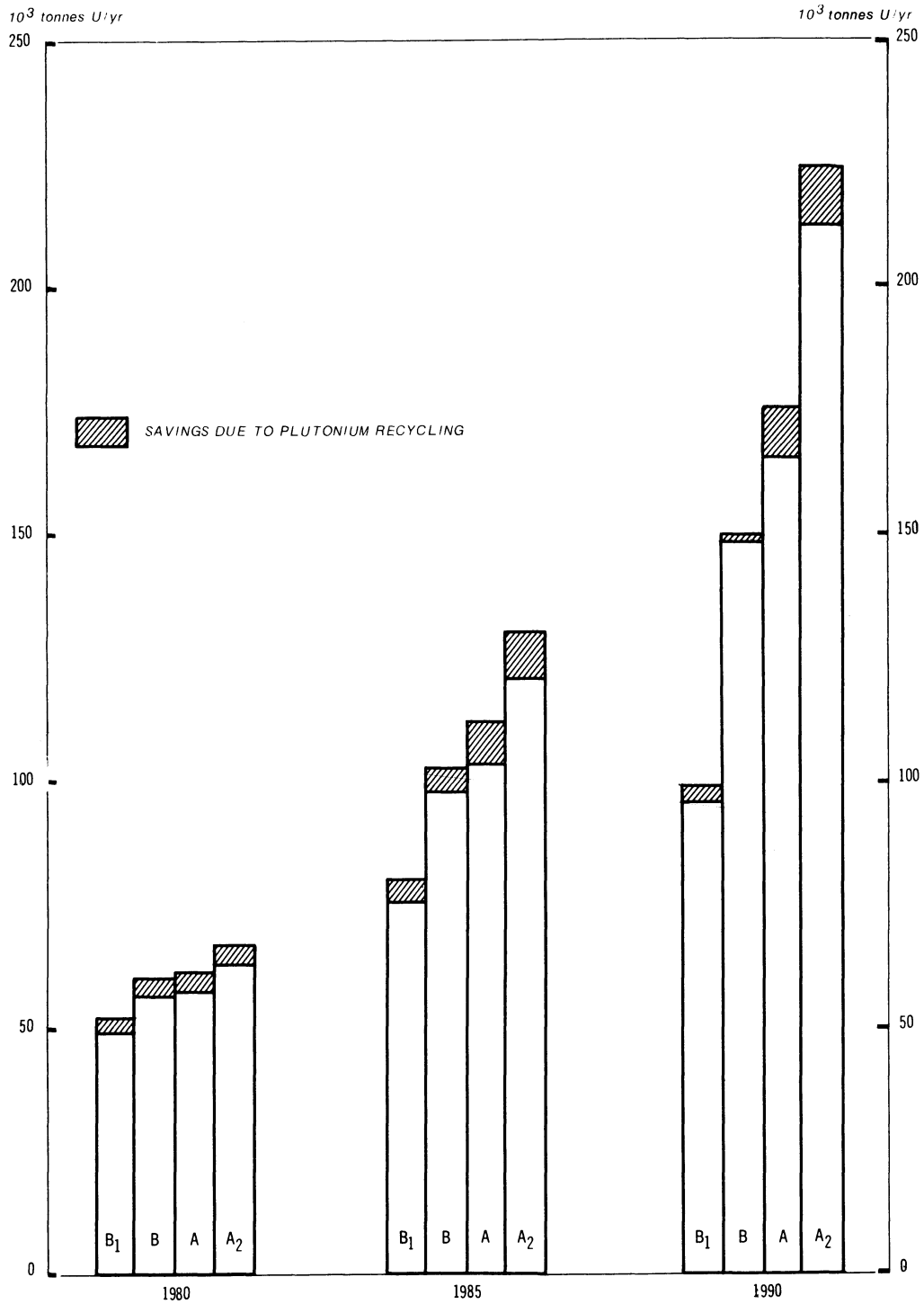


Figure 12
 ANNUAL SEPARATIVE WORK REQUIREMENTS
 FOR DIFFERENT REACTOR STRATEGIES AND POWER GROWTH
 (no Pu recycle, 0.25% tails assay)

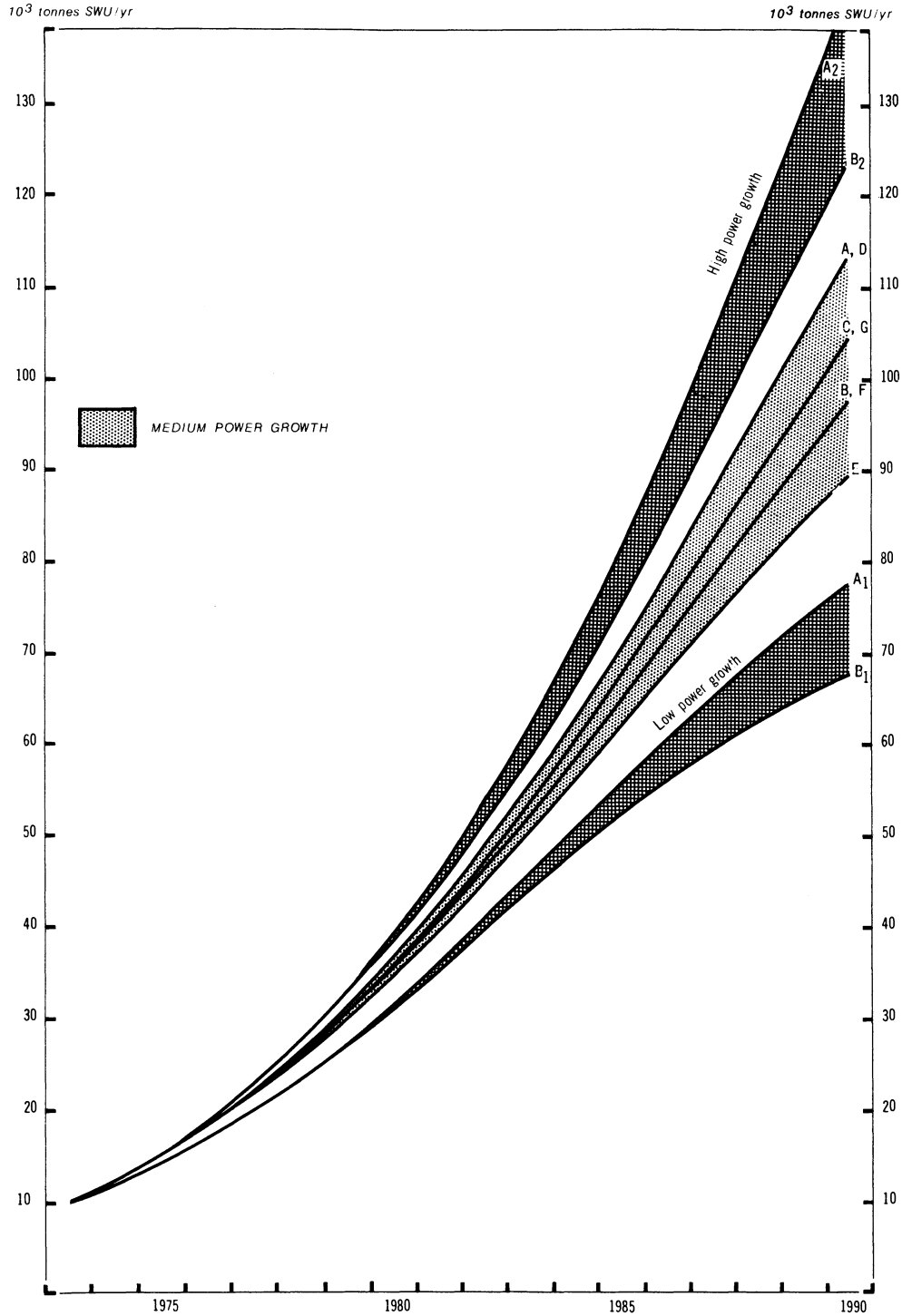
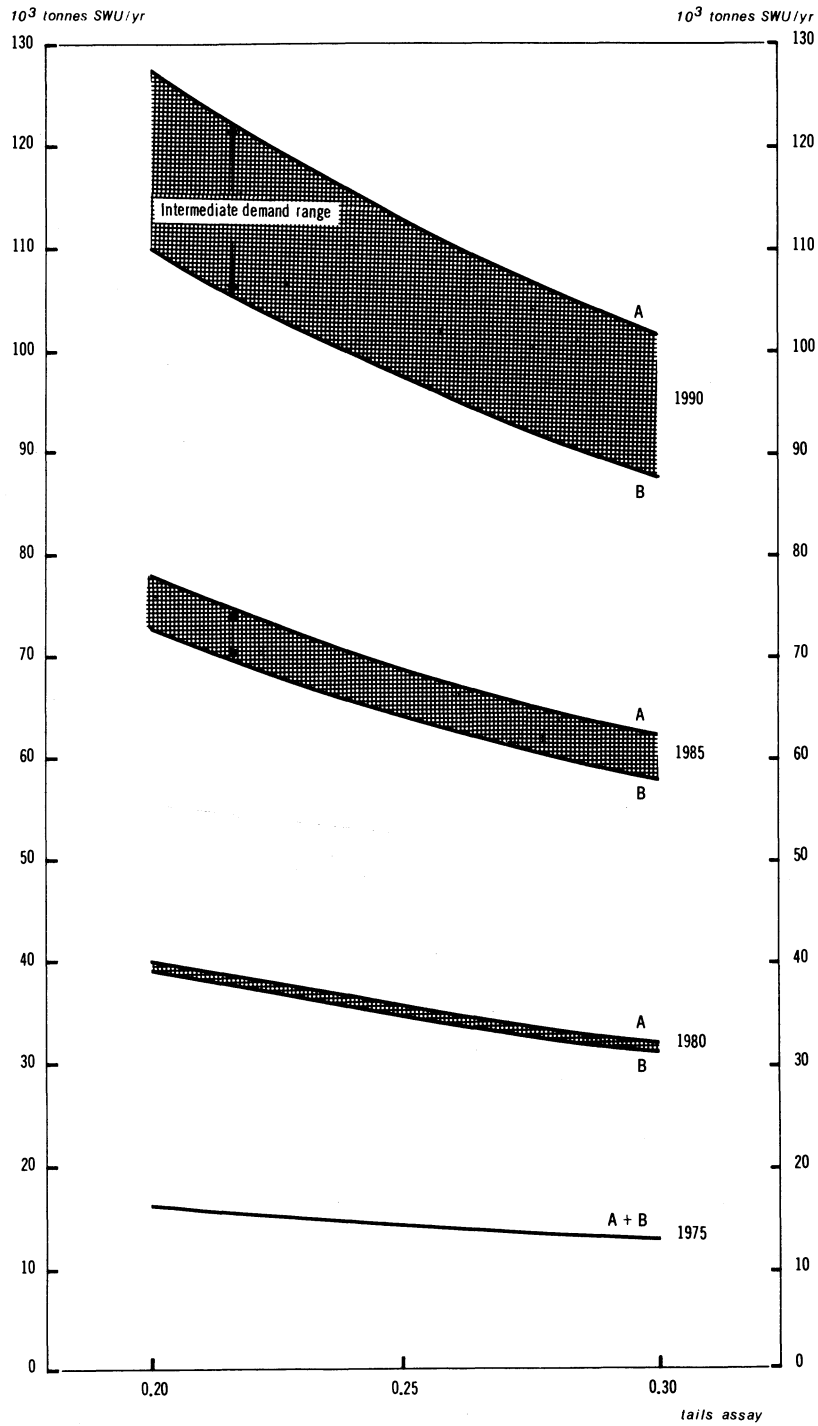


Figure 13
 ANNUAL SEPARATIVE WORK DEMAND
 FOR DIFFERENT ENRICHMENT TAILS ASSAYS
 (no Pu recycle)



ANNEXES

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