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Assessment of uranium resources and supply

Proceedings of a Technical Committee Meeting held in Vienna, 29 August – 1 September 1989

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FOREWORD

Uranium as nuclear fuel is an important energy resource, which generated about one-sixth of the world's total electricity generated in 1989. The current nuclear electricity generating capacity of 318 GW(e) is expected to grow by over 38% to 440 GW(e) in the year 2005. The world's uranium requirements are expected to increase similarly from about 52 000 t U in 1989 to over 70 000 t U in 2005. Beyond this time the uranium requirements are projected to reach over 80 000 t U in 2030.

In view of the significance of uranium for the current and future energy supply, the International Atomic Energy Agency has long standing interest in the assessment of uranium resources and their adequacy.

One of the products which results from this involvement is the report Uranium Resources, Production and Demand, also referred to as the Red Book which since 1969 is periodically prepared by the Nuclear Energy Agency of OECD and the International Atomic Energy Agency.

It was the objective of the Technical Committe Meeting on Assessment of Uranium Resources and Supply, organized by the IAEA and held in Vienna, between 29 August - 1 September 1989, to attract specialists in this field and to provide a forum for the presentation of reports on the methodologies and actual projects carried out in the different countries. Of special interest was the participation of specialists from some countries which did not or only occasionally co-operate with the IAEA in the projects related to the assessment of uranium resources and supply.

The IAEA would like to express its gratitude to the participants and especially to those who presented papers at this meeting, which are compiled in the present report. Thanks are also due to Dr. Fritz Barthel, Federal Institute for Geosciences and Natural Resources, Hannover, Federal Republic of Germany, who kindly agreed to chair the meeting.

The IAEA staff member responsible for this meeting was E.Müller-Kahle, Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

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SUMMARY OF THE TECHNICAL COMMITTEE MEETING

Since the beginning of the peaceful use of nuclear energy in the sixties, the collection of data on uranium exploration, uranium resources and supply as well as their analyses and future supply projections became a concern as nuclear power plant planners required long term assurance of uranium supply.

It was then when the ground work for methodologies for uranium resource assessment and uranium resource classification was laid. These applied and refined methodologies and the collection and dissemination of uranium data made uranium one of the best known and best documented commodities. One of the publications which helped to reach this stage is the periodic report Uranium Resources, Production and Demand, also known as the Red Book, prepared by the Nuclear Energy Agency of OECD and the International Atomic Energy Agency.

Motivated by rather optimistic forecasts on nuclear power development, uranium exploration, development and production as well as uranium prices boomed in the second part of the 1970s and began a lengthy adjustment process, which apparently is still continuing.

Exploration refers to the activities related to the search of uranium and determines the existence of known resources in the future. Therefore the continuous recording and analyses provide early indication for future supplies.

Data collected on uranium exploration expenditures indicate that between 1972 1979-1980 these expenditures increased from about US$ 80 million (current) to over US$ 750 million and declined again to US$ 140 million in 1989. This decrease affected a large number of countries. In the USA, for example, the exploration expenditures, between the peak year and 1989 declined by 95%. A similar or even more drastic development occurred in a number of developing countries, especially in Africa (Algeria, Gabon, Niger, Somalia, Tanzania, Togo, Zambia, Zimbabwe) and Latin America (Argentina, Bolivia, Brazil, Colombia, Mexico, Paraguay).

In 1989, available data show that over 93% of the total expenditures are spent in the five countries Australia, Canada, France, India and USA averaging US$ 26 million. The remaining 7% are distributed in 13 countries with an average of about US$ 750 000 per country.

The future trend may be a further decline of these expenditures, as the uranium market, with which exploration expenditures are closely related, does not provide any incentive to carry out exploration. The consequences are that mining companies wishing to replace reserves depleted by production begin to abstain from exploration and rather acquire known reserves.

For countries considering to carry out uranium exploration, the following criteria may be observed under which uranium exploration may be justified:

- if it is part of a regional, low density multimineral resource assessment,
- if it is part of a balanced nuclear fuel cycle and power programme, and/or
- if, considering uranium for export, high grade, low cost uranium deposits can be expected which can compete with supplies from established producer countries.

Uranium resources are classified according to two criteria: the geological confidence in their existence (known vs. undiscovered) and the economic attractiveness expressed by recovery costs. At present, known and undiscovered resources are further subdivided into 4 categories, referred to as Reasonably Assumed Resources (RAR) and Estimated Additional Resources-Category I (EAR-I), which comprise the known resources, and Estimated Additional Resources-Category II (EAR-II) and Speculative Resources (SR) which make up the undiscovered resources. The cost categories currently include the 3 categories, up to US$ 80/kg U, US$ 80 - 130 and US$ 130 - 260/kg U.

At present market conditions only the up to US$ 80/kg U cost category is of interest, as spot price (US$ 25/kg U) and average long term price (US$ 60/kg U) are below this level. The best known resources of the up to US$ 80/kg U cost category in WOCA amount to about 1.5 million t U or expressed in relation to the annual reactor requirements, 30 times the annual requirements.

This number appears very high at first glance. A closer look, however, reveals that not all of these resources for a number of reasons do belong into this category or represent prospected supply to fill future reactor related uranium requirements.

These reasons include the following:

- Over one third of the total mentioned above represent old estimates. Urgently needed updates especially of the cost category may show that all or a portion will have to be moved into a higher cost category.

- Although over 90% of the resources are located in important producer countries, not all of these resources may be developed and made available as supplies for economic or political reasons. In fact, large portions of the resources in Australia, Canada, France, Namibia, Niger, South Africa and the USA may remain "dormant" for the foreseeable future.

- The lowest cost category of up to US$ 80/kg U introduced in 1977 when the uranium spot price was US$ 110/kg U, does not reflect the current market conditions reflected as shown above by a spot price of US$ 25/kg U and an average long term price of US$ 60/kg U. As shown in this meeting, only 10 or 35% respectively of the 1987 WOCA production from conventional sources can be produced at costs equal to or below these prices.

The consequences of the low uranium prices are a declining production; in 1980 the WOCA production was over 44 000 t U and decreased gradually to about 35 000 t U in 1988. While through about 1984 the production was higher than the requirements, the contrary is the case now. This development is leading to production cut-backs in individual mines but also to closures of mines and mills with the corresponding losses of resources, assets and employment.

An additional consequence of the gap between higher production costs and lower spot prices is that producers find it more advantageous to buy uranium on the spot price than to fill contracts from uranium produced in their mines and mills.

Over the period of uranium production for civil purposes through about 1984 there has been an overproduction in relation to the demand. WOCA's cumulative total is not exactly known, but estimates are 150 000 t U. This material together with imported supplies from China, the USSR and Eastern European countries is being used to fill the production gap which developed with growing tendency after 1985 and reached about 7 800 t U in 1989.

With the growing participation of China, the USSR and Eastern European countries in the WOCA uranium market, the resource situation in these countries becomes very important. Unfortunately, the information is still very scarce, although China at this meeting provided some numerical resource information regarded as a start. Apart from other reasons, why uranium data is still not available, the WOCA resource assessment and classification systems are orientated towards supply at a specific cost-price, while the non-WOCA systems, as is the case with certain WOCA countries, aim at supplies at any cost. Application of the market economy principles in resource assessment and classification are required if results are to be compatible with the WOCA data.

The expected trend of uranium resource development in China, the USSR and the Eastern European countries will depend on the economic system chosen. Currently, available information indicate that the resources and productions in China, the USSR and the Eastern European countries Bulgaria, CSFR, Hungary and Romania are high cost and probably not competitive under present market conditions.

Based on this data, these supplies are thought to be only competitive on WOCA markets under special economic conditions. These include the need for hard currency and the disregard of sunken costs in the case of uranium inventories.

The uranium demand projections depend mainly on the projected nuclear electricity generating capacity. For WOCA this capacity is expected to grow from 264 GW(e) in 1989 to about 350 GW(e) in 2005. This increase is equivalent to a total of nearly 25% or of 1.5% p.a. In terms of natural uranium requirements, without considering the use of reprocessed

U and Pu, the demand is projected to grow from about 41 500 t in 1989 to nearly 53 000 t U in 2005.

The corresponding data for non-WOCA are a nuclear electricity generating capacity of about 44 GW(e) in 1989 projected to increase by 51 GW(e) to 95 GW(e) in 2005. This growth is equivalent to 116% or about 5% p.a. The uranium requirements are estimated at between 8 000 - 10 000 t U in 1989 growing to about 17 000 - 19 000 t U in 2005.

The WOCA uranium supply-demand projection is determined by the consequences of the weak market described above and the resulting production deficit which in 1989 is estimated at 7 800 t U and projected to grow to about 25 000 t U in the year 2005, assuming a future expected production from existing and committed mines producing from US$ 80/kg U known resources.

The production deficit through 2005 totalling over 250 000 t U is believed to be filled by material held in inventories both in WOCA and non-WOCA. While the available WOCA inventories under this supply-demand scenario will suffice to compensate for the production through about the second part of this decade, the non-WOCA material would be able to fill the gap for a larger period, depending on stockpiles and marketing policies.

Assessing this situation, it becomes obvious that the civil uranium market is becoming a world market comparable to a number of other commodity markets. Accompanied is this development by a more sober treatment of uranium as an energy resource.

It can be concluded, that the situation resulting from

- large inventories in WOCA and China and the USSR,
- lower than expected uranium demand projections and
- new suppliers in Eastern Europe

will continue to overshadow the WOCA uranium industry.

Low prices, further reduction of higher cost uranium production, further decline of exploration and resource development are expected to be problems the industry has to cope with for a number of years to come.

The point in time, when industry can expect a balanced supply-demand situation coupled with higher prices depends upon the drawdown of uranium inventories to desirable levels. It will also depend on the inventory and export policy of China and the USSR which because of the estimated size of these stocks can become a significant factor in the future world uranium market.

URANIUM PRODUCTION AND DEMAND PROJECTION FOR THE ARGENTINE REPUBLIC

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Abstract

Historical and current uranium activities by the Argentina Atomic Energy Commission, its predecessor organization and some private parties are described. In six production centres, Don Otto, Los Adobes, Malargue, San Rafael, Los Gigantes and La Estela, a cumulative total of nearly 2000 t U have been produced between 1952 and 1988. Future nuclear electricity generating capacities for Argentina are projected to increase from 940 MW(e) to 2460 MW(e) in the year 2000 and to between 13340 and 13940 MW(e) in 2020. It is concluded that the presently known resources are sufficient to supply the projected nuclear programme through the end of the century. For the first twenty years of the next century, however, it is estimated that additional resources have to be discovered in, or even before, the year 2000 to allow for their timely development.

1. INTRODUCTION

The first studies on uranium deposits in the country began in 1938 in the provinces of Cordoba and San Luis.

In 1950 the National University of Cuyo and the then National Atomic Energy Directorate made a study of the economic possibilities of uranium exploration.

In 1952 activities to produce uranium concentrate at experimental scale were initiated at a plant in Cordoba and around the mid 1950's the first uranium concentrate on an industrial scale from the Cu-U ore from the Huemul mine (Mendoza province) was produced in the Malargue plant.

The year 1961 marked the beginning of systematical efforts covering prospection, exploration, evaluation and development of uranium production techniques. In 1964 the Marlargue ore processing plant was built using indigenous technology. This plant, the first of its type in Latin America, worked for more than 20 years applying conventional process. Simultaneously, the heap leaching technique on an industrial scale was developed at the Don Otto plant (Salta province).

Since 1970 the Comision Nacional de Energia Atomica (CNEA) has received the responsibility to supply the necessary uranium for Argentina's nuclear programme and at the end of the 1970's there were in operation four uranium production centres belonging to the CNEA in different provinces.

Today, three of these production centres have already exhausted their deposits and only one remains in operation; they include "Complejo Minero Fabril San Rafael" in Sierra Pintada (Mendoza province). In addition there are two other privately owned production centres that exploit deposits in the provinces of Cordoba and San Luis which started production in 1983 and 1985 respectively.

The uranium concentrate coming from the different centres is sent to the Cordoba refinery to produce uranium dioxide which is then used to manufacture the fuel elements in the Ezeiza plant (Buenos Aires).

2. URANIUM PRODUCTION CENTRES IN ARGENTINA

For the purpose of demonstrating the evolution of the production of uranium concentrate in Argentina, a description of the centres where operations have already terminated (Don Otto, Los Adobes and Malargue) will first be made. Then the present situation will be described making reference to the centres currently in operation (San Rafael, Los Gigantes, La Estela).

Tables 1 and 2 show the main characteristics of the centres that have ceased operation and the centres still active. Table 3 shows the total production of uranium concentrate in the country during the period 1952-1988.

2.1 Don Otto Mining and Milling Complex

This production centre, also referred to as Tonco, is located 150 km southwest of the city of Salta and was in operation during the period 1963-1980.

The first uranium ore bodies in the area were found in the year 1959 and the most important mineralization was the Don Otto

TABLE 1. URANIUM PRODUCTION CENTRES IN ARGENTINA — SHUTDOWN PLANTS

Name	Don Otto	Los Adobes	Malargue
Operator	CNEA	CNEA	CNEA
Start up Date	1963	1977	1964
Shut down Date	1981	1981	1986
Mining operation type	Underground	Open pit	Underground (Huemul) Open pit (Sierra Pintada)
Nominal Production Capacity. t U/year	15	50	60-70
Metallurgical process	Acid heap leaching ion exchange	Acid heap leaching ion exchange	Conventional acid
Average ore grade % U	0.076	0.101	0.140

deposit, where U-mineral species such as meta-tyuyamunite, metautunite, autunite etc. have been confirmed. An additional important deposit in the area was "Los Berthos".

Ore from both uranium deposits was processed in the Don Otto plant using heap leaching and fixed bed ion exchange resin recovery techniques.

The plant produced uranium ammonium diuranate with an output capacity of 15-20 t U per annum.

TABLE 2. URANIUM PRODUCTION CENTRES IN ARGENTINA PRESENTLY IN OPERATION

Name	San Rafael	Los Gigantes	La Estela
Operator	CNEA	private	private
Start up Date	1979	1982	1985
Mining operation type	open pit	open pit	open pit
Average grade of mineral % U	0.09	0.03	0.07
Nominal production Capacity t U/year	120	80	20
Metallurgical process	Acid heap leaching Ion exchange	Acid heap leacbing Ion exchange	Acid heap leaching Ion exchange
Ore type	Sandstone	Granite	Granite

This centre from commencement of operations has processed 480,000t of mineral with an average grade of 0.76% U and recovered a total of 265 t U.

2.2 Los Adobes Mining and Milling Complex

This production centre also known as Pichiñan operated during the period 1977-1981.

It is situated 430 Km west of the city of Trelew and 40 Km north of the Paso de Indios village in Chubut province.

The main mineralized bodies, "Los Adobes" and "Cerro Condor" located essentially in conglomerates, sandstones, tuffs and clays, include uranophane, schroeckingerite and phosphuranylite. Heap

TABLE 3. ARGENTINE URANIUM PRODUCTION FROM 1952 TO 1988

Year	t U	Year	t U	Year	t U
1952	0.025	1965	19.7	1977	97.6
1953	0.44	1966	28.7	1978	109.3
1954	0.16	1967	14.8	1979	133.5
1955	2.18	1968	14.2	1980	186.8
1956	4.56	1969	21.7	1981	122.8
1957	2.03	1970	30.3	1982	153.0
1958	2.54	1971	30.1	1983	133.6
1959	1.69	1972	24.7	1984	88.9
1960	0.84	1973	24.4	1985	85.2
1961	0.55	1974	30.4	1986	132.7
1962	2.96	1975	22.6	1987	69.6
1963	7.20	1976	38.1	1988	106.7
1964	11.6				

(Values including CNEA production only)

Total production CNEA : 1,756.17 t U

Total production Los Gigantes : 201.58 t U

Total production La Estela : 20.70 t U

Total Argentine production : 1,978.45 t U

leaching and fixed bed ion exchange resin were the recovery techniques. Since the beginning of operations, this centre has processed 201,000t ore with an average grade of 0.101% U, producing a total of 151 tU.

2.3 Malargue

Located at Malargue, 430 Km south of Mendoza, capital of the province of the same name, this production centre began working in 1954 producing a sodic concentrate which was purified in the Cordoba refinery.

During the years 1961 and 1962, the CNEA carried out laboratory and pilot plant studies to build a conventional ore processing plant with a capacity of 100 tpd ore.

This plant started up in 1964 and produced copper as a by-product, from ore mined in the Huemul and Agua Botada mines which were exhausted in 1975.

From this date onwards the plant was supplied with ore from the Sierra Pintada district.

In 1978, due to the growing demand of yellow cake, the CNEA expanded the plant and in 1979 the enlarged plant with a capacity of 250 tpd ore and 70-80 t U per annum started operation.

This plant processed ore from Tigre III and Tigre I-Terraza from the Sierra Pintada District, until 1986 when it was shut down. Over the period 1954-1986 this centre produced 710 t U.

The Malargue plant, working for more than 30 years, provided the CNEA with an important experience in uranium ore processing.

Also in this centre, during the period 1977-1979, the heap leaching techniques were applied to Sierra Pintada ores, obtaining operational and project parameters which were used to build the San Rafael plant.

2.4 San Rafael Mining and Milling Complex

This complex is located in the Sierra Pintada district, 35 Km from San Rafael city and 240 Km from Mendoza, capital of the province.

The first uranium occurrences in the area were discovered in 1956 and in 1960 uranium reconnaissance surveys were carried out. In 1968, systematic aerial and ground surveys were done and some radioactive deposits were found.

The most important mineralized bodies of the area are : Tigre I - La Terraza, Tigre II, Tigre III, Gaucho I - II - III, Media

Luna I, II, III and IV etc., all of them belonging to Dr. Baulies and Los Reyunos sandstone type deposits. Mineral species such as brannerite and uraninite have been confirmed. Uranophane is present as a secondary mineral.

To date, Tigre III and Gaucho I - II ore bodies have been exploited and currently the most important ore bodies, Tigre I-Terraza, are being worked. Due to geological reasons they are divided into 3 partial sections referred to as bodies A, B, C, which contain, in situ resources of 11,269,426 t ore at an average grade of 0.099% U.

The exploitation of this body is being carried out taking into account the parameters obtained in Tigre III and Gaucho I - II exploitation and adapting them to the present operation.

An open pit system is being used with a 10:1 waste to ore ratio and final slope angle between 40-50^{o}.

For the present annual production of uranium concentrate, considering 0.034% U cut off grade, the open pit output is:

790,000 m^3 per annum waste
7,800 m^3 per annum low grade ore
64,000 m^3 per annum higher grade ore

After extraction the higher grade ore is classified by radiometric methods and divided into 3 grade classes from which an average ore grade of 0.09% U is blended for processing in the heap leaching plant.

The San Rafael plant started in 1979 using the heap leaching method with uranium recovery by fixed ion exchange resin, ammonium nitrate elution and ammonia precipitation.

Liquid waste management includes the adding of a 15% lime solution.

At the beginning of the operation the plant capacity was 60 t U per annum, processing the low grade ore from the

Tigre III and Gaucho I - II open pits, with an average ore grade of 0.06% U.

As a result of the closure of the the Malargue plant in 1986, the expansion of the San Rafael plant was carried out which presently has a production capacity of 120 t U per annum from the processing of 180,000 t per annum ore.

Over the period 1979-1988 the San Rafael plant has processed more than 1,300,000 t ore and recovered 588 t U.

2.5 Los Gigantes

This operation is located in the Cordoba province in the Cerro Los Gigantes about 80 Km from Cordoba city and 25 Km from Tanti village.

Mining and uranium concentrate production are being undertaken by a private firm. The mineralization is located within an altered granitic rock and consists of Autunite and metautunite.

This production began in 1983 using heap leaching and fixed bed ion exchange recovery techniques.

Over the period 1985-1988 Los Gigantes has produced 20.7 t U in concentrates.

3. URANIUM RESOURCES AND DEMAND

The future uranium demand is related to the construction plans of nuclear power plants. The Energy Secretary requires the CNEA to provide a definition of the most desirable power plant size necessary to satisfy the energy demands specified in the National Energy Plan 1986-2000.

Accordingly, in 1987 the CNEA concluded that during the period 1986-2000, 700 MW (e) of nuclear capacity should be added to the current capacity of 940 MW (e) in addition to Atucha II [700 MW (e)] which was projected for start up in 1992 but will be delayed to 1994.

The CNEA has also prepared energy projections for the National Energy Plan over the period 2000-2020 (Table 4). The hydraulic, thermic and nuclear share of installed power for high and low projection are also shown in this table.

Even considering a moderate growth it is anticipated that it would be necessary to add about 10,000 MW (e) of nuclear capcity for the referred period, the first reactor being added in 2004.

The current nuclear share of electricity generation within the national grid amounts to 7.8% and it is anticipated this will reach between 15-18% in the next 20 years.

Table 5 shows the projected dates of plant construction start, beginning of commercial operation, as well as the generating capacity for the high and low projections.

The CNEA has arrived at some important conclusions which are :

1) The most adequate size for the plants entering service up to 2010 is 700 MW(e).

2) The most adequate size for the plants entering service over the period 2010-2020 is 1 300 MW(e).

3) Due to the significant increase of nuclear power that is expected to take place by 1998 it will be necessary to stimulate exploration efforts in order to assure the required uranium supply.

With reference to the uranium resources in Argentina it could be said that the CNEA has adopted the classification proposed by the IAEA which considers known resources the Reasonably Assured Resources (RAR) - and Estimated Additional Resources - Category I (EAR-I) below $130/Kg U.

In Argentina, as at 01-01-89 the RAR amounted to 11,650 t U and EAR-I to 3991 t U.

Finally, we can mention the Estimated Additional Resources Category II (EAR-II) which are additional resources to EAR-I and which

TABLE 4. HIGH AND LOW PROJECTIONS OF INSTALLED ELECTRICITY GENERATING CAPACITY FOR THE PERIOD 2000-2020

	YEAR									
HIGH PROJECTION	2000		2005		2010		2015		2020	
	Power	%	Power	%	Power	%	Power	%	Power	%
HYDRAULIC	6408 MW(e)	55.14	11978 MW(e)	66.25	14796 MW(e)	60.77	16841 MW(e)	49.39	16841 MW(e)	36.06
THERMIC	2750 MW(e)	23.66	3310 MW(e)	18.31	5360 MW(e)	22.01	9815 MW(e)	28.78	15915 MW(e)	34.08
NUCLEAR	2463 MW(e)	21.20	2793 MW(e)	15.44	4193 MW(e)	17.22	7455 MW(e)	21.83	13945 MW(e)	29.86
TOTAL	11621 MW(e)	100.00	18081 MW(e)	100.00	24349 MW(e)	100.00	34101 MW(e)	100.00	46701 MW(e)	100.00
LOW PROJECTION										
HYDRAULIC	6408 MW(e)	55.14	11978 MW(e)	68.91	14796 MW(e)	64.33	16841 MW(e)	55.30	16841 MW(e)	41.63
TERMIC	2750 MW(e)	23.66	2610 MW(e)	15.02	4010 MW(e)	17.44	6765 MW(e)	22.22	10265 MW(e)	25.38
NUCLEAR	2463 MW(e)	21.20	2793 MW(e)	16.07	4193 MW(e)	18.23	6845 MW(e)	22.48	13345 MW(e)	32.99
TOTAL	11621 MW(e)	100.00	17381 MW(e)	100.00	22999 MW(e)	100.00	30451 MW(e)	100.00	40451 MW(e)	100.00

TABLE 5. HIGH AND LOW PROJECTIONS OF NEWLY INSTALLED NUCLEAR CAPACITY FOR THE PERIOD 2000-2020

YEAR	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
DATE IN SERVICE				700		700			700			700		1300	1300	1300	1300	1300	1300	1300	(1)
OUT OF SERVICE				-370										-618							
DATE IN SERVICE				700		700			700			1300		1300	1300	1300	1300	1300	1300	1300	(2)
OUT OF SERVICE				-370										-618							

(1) Low projection

(2) High projection

TABLE 6. URANIUM RESOURCES IN ARGENTINA

COST CATEGORY	BELOW 80 US $/Kg.U	80 - 130 US $/Kg.U	BELOW 130 US $/Kg.U
Reasonably Assured Resources (R.A.R) (t U)	9052	2598	11650
Estimated Additional Resources-Category I (EAR-I) (t U)	843	3148	3991
Estimated Additional Resources-Category II (EAR-II) (t U)	1568	3489	5057

Estimates include mining and milling losses.

offer less reliable estimates than the previous categories. They amount to 5,057 t U.

In Table 6 the uranium resources of Argentina as of 01-01-89 are summarized.

Considering the balance between requirements and resources we can say that there are sufficient uranium resources to feed Atucha I, Embalse, Atucha II which is is being built, and Central IV which is projected to enter service at the end of the century. However these resources could be almost exhausted by that time.

If it is desired to continue with a self-sufficiency policy and to have sufficient resources to fuel future nuclear power plants (period 2000-2012) with a total estimated consumption of 12,000 t U, new resources would have to be located before the year 2000.

Referring to the near and mid term (period 1986-2000) the uranium requirements, which are at present 150 t U per annum, would increase to 240 t U per annum when Atucha II begins operation and to 340 t U per annum when Central IV starts working.

With regard to the long term, it is estimated that cumulatively 60,000 t U would be required to fuel future nuclear plants over the period 2000-2020. This estimate could be lower if techniques such as uranium enrichment and plutonium recycling were applied.

4. PLANNED URANIUM PRODUCTION CAPCITY - SIERRA PINTADA PROJECT

The Sierra Pintada project is responsible for the present concentrate production capability to future demand.

To satisfy the projected needs a 340 t U per annum conventional plant should be installed in Sierra Pintada where the most important uranium deposits up to now have been discovered. This mill is scheduled to start producing when the Atucha II begins working.

At present the basic engineering of the ore processing plant employing the conventional process which consists of size reduction, leaching, solid-liquid separation and uranium recuperation by solvent extraction is being developed. Special emphasis is being placed on the leaching stage in order to obtain the highest efficiency recovery.

In this sense, besides the heap leaching and conventional leaching techniques in agitated tanks applied in the mills, the Pachuca leaching technique has been developed on a pilot scale in Malargue. This technique resulted in the highest extraction and has therefore been adopted for the new plant.

Special attention is being given to waste management and the final location of tailings has already been decided.

Studies on the possibility of obtaining a nuclear purity product as a final product, which would be transformed to uranium dioxide, are being carried out.

5. ARGENTINE EXPERIENCE ON THE PRODUCTION OF URANIUM CONCENTRATES

To summarize, it could be said that Argentina through more than thirty years of producing uranium concentrate, has gained a thorough knowledge of the uranium production techniques.

The heap leaching and uranium recovery by ion exchange resin techniques have been applied in the Malargue, Don Otto and Los Adobes plants and are currently being applied in the San Rafael, Los Gigantes and La Estela plants.

These methods have the advantage of low investment and operating costs and have been successfully applied in the following cases:

- low grade deposits which would be extremely costly to treat in a conventional mill. (Los Gigantes)

- medium to average grade deposits having small reserves which could not beart the high costs of a conventional mill. (Tonco, Pichiñan).

- large deposits with medium grade ores. In this case heap leaching techniques can be applied to the low grade ore fraction, lowering the cut-off grade of mining, thus increasing the ore grade to feed the conventional mill.

This procedure, which allows a better utilization of the resources, was applied to Sierra Pintada deposits where the low grade fraction was processed in the heap leaching San Rafael plant and the high grade fractions in the Malargue conventional plant.

The conventional process applied in the Malargue plant enabled the CNEA to attain a high level of knowledge on the following techniques; agitated tank leaching, counter-current continuous decantation and solvent extraction.

These techniques, which are the basis of uranium ore processing using conventional methods are applied in the leading uranium-producing countries.

GEOLOGICAL ENVIRONMENTS AND PROSPECTING UNITS OF RADIOACTIVE RESOURCES IN CHILE

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Abstract

Between 1975 and 1981 the Chilean Nuclear Energy Commission with the assistance of IAEA and the financial support of UNDP carried out a geological reconnaissance for uranium. At the same time systematic studies and the recording of geological data related to the regional favourability for uranium were undertaken. This study was completed in 1986, and resulted in the definition of favourable environments and prioritised prospection units. The new targets for regional investigation are:

a) Acid volcanic environments consisting of rhyolitic rocks of late Tertiary-Quaternary age, widely underlying areas of the Pre-Cordillera in Northern Chile.

b) Permo-triassic magmatic environments, occurring between Copiapo and La Serena, spreading eastwards into Argentine.

c) Late Cretaceous-Tertiary magmatic environments, present throughout the country which contain numerous uranium occurrences and anomalies.

Up to the present, about 150.000 Km^2, equivalent of 20%, have been prospected in the national territory, from a total continental area of 756.252 Km^2.

INTRODUCTION

The purpose of this article is to show the geological, mineralogical and technical considerations and methods applied in prospection activities in Chile, which are carried out by the Chilean Nuclear Energy Commission (CCHEN). Exploration started in 1950, but it was at a relatively low level until 1974. At this time the Chilean Government approved the National Radioactive Resources Plan, the basic objective of which is to evaluate the country's uranium resources and to make plans for their possible extraction (1).

From 1975 until 1981 under an IAEA/UNDP project, a total of 105.000 km^2 in seven areas of the country were systematically surveyed using conventional exploration techniques (airborne radiometric prospecting, geological and ground radiometric survey, and geochemical investigation of sediments, water and soils).

Meanwhile, the country was analysed according to national and South American standards, in agreement with the guidelines established by the Regional Uranium Evaluation Programme (PREU) sponsored by the Nuclear Energy Inter-American Centre (CIEN) of the Organization of American States. The systematic studies and the collection of geological data related to the uranium favourability index of the country was completed in 1986, and the definition of Prospecting Units carried out (2). The new programmes of regional mapping (194.700 Km^2 (3)) requiring detailed studies include:

a) Acid volcanic environments of late Tertiary-Quaternary age, spread in areas of the Pre-Cordillera of the northern part of Chile. These geological environments are similar to those of Macusani (Peru) and Agiliri (Argentina).

b) Permo-triassic magmatic cycle, widely present at the boundary zone Copiapo ($27^{o}15'$ SL) and La Serena ($29^{o}45'$ SL), spreading eastwards to Argentina, with the deposits Los Gigantes and Sierra Pintada in a similar environment.

c) Late Cretaceous-Tertiary age magmatic cycle, widely spread out throughout the territory where uranium occurrences and anomalies have been found, including the Productora Prospect.

Up to the present, using different prospecting techniques, about 150.000 Km^2 (20%) have been prospected in the national territory, of a total continental area of 756.252 Km^2. (3).

Estimates of uranium resources show 1.694 tons as Reasonably Assured Resources (RAR), 524 tons as Estimated Additional Resources (EAR), and 3.515 tons as Speculative Resources (SP) (4). The potential resources related to evaporitic environments of the northern part of Chile, and the potential related to the acid magmatism of the Andean cycle are not included in these figures ((3), Table 1).

TABLE 1

PRINCIPAL OCCURRENCES OR DISTRICTS	TYPE OF OCCURRENCE	RESOURCES CLASSIFICATION (tonnes U) RAR	EAR	SR	ORE GRADE % U_3O_8	PRINCIPAL MINERAL (25)*
Uranium Occurrences						
Salar Grande	Superficial, associated with salt	28	---	100	0.023	Carnotite
Estacíon Romero						
- Carmen	Disseminated	---	---	---	0.018	Davidite
- Productora	Vein and disseminated	32	11	225	0.028	Autunite Torbernite
Pejerreyes	Disseminated magmatic	---	---	130	0.011	Torbernite
Sub-Total		60	11	455		
Copper Deposits with Uranium as By-Product						
Sagasca **	Secondary hydryogenetic copper	(164)	---	---	0.0018	Chrysocolla Cu oxides
Huinquintipa	Secondary hydrogenetic copper	46	---	---	0.0010	Chrysocolla Cu oxides
Chuqui - Sur (Exótica)	Secondary hydrogenetic copper	950	---	---	0.0007	Chrysocolla Cu oxides
Chuqui - Norte - Ripios	Oxidized porphyry copper	--- ---	--- ---	1,000 2,000	0.0008 0.0002 0.0008	Cu oxides Cu oxides
Carrizal Alto **	Hydrothermal copper vein	---	---	(500)	0.025	Cu sulphide
Algarrobo - El Roble	Hydrothermal copper vein	---	513	---	0.04	Cu sulphide
Sierra Gorda	Breccia pipe	---	---	60	0.002	Mixed Cu
Sub-Total		996	513	3.060		
Phosphate Deposits with Uranium as By-Product						
Mejillones ***	Phosphate (55 million tonnes)	(1,300)	---	---	0.0026 (7% P_2O_5)	Collophane
Bahía Inglesa	Phosphate (20 million tonnes)	638	---	---	0.00612 (18% P_2O_5)	Collophane
T o t a l		1,694	524	3.515		

* (25) 1983, Modified 1989 (26)
** Exploited only for copper
*** Not considered

CLASSIFICATION AND DISTRIBUTION OF URANIUM PROSPECTS IN CHILE

Uraniferous occurrences are distributed throughout Chile (Fig. 1). This chapter will deal with the classification of these occurrences:

- Sedimentary Occurrences: fluvio-lacustrine/saline and phosphate deposits.
- Contact Metamorphic Occurrences: mineralization occurring in altered and metamorphosed host rocks.
- Hydrothermal Polymetallic Vein Deposit emplaced within intrusive complexes.
- Exotic Type Deposits formed by the leaching of porphyry copper deposits.

SEDIMENTARY OCCURRENCES

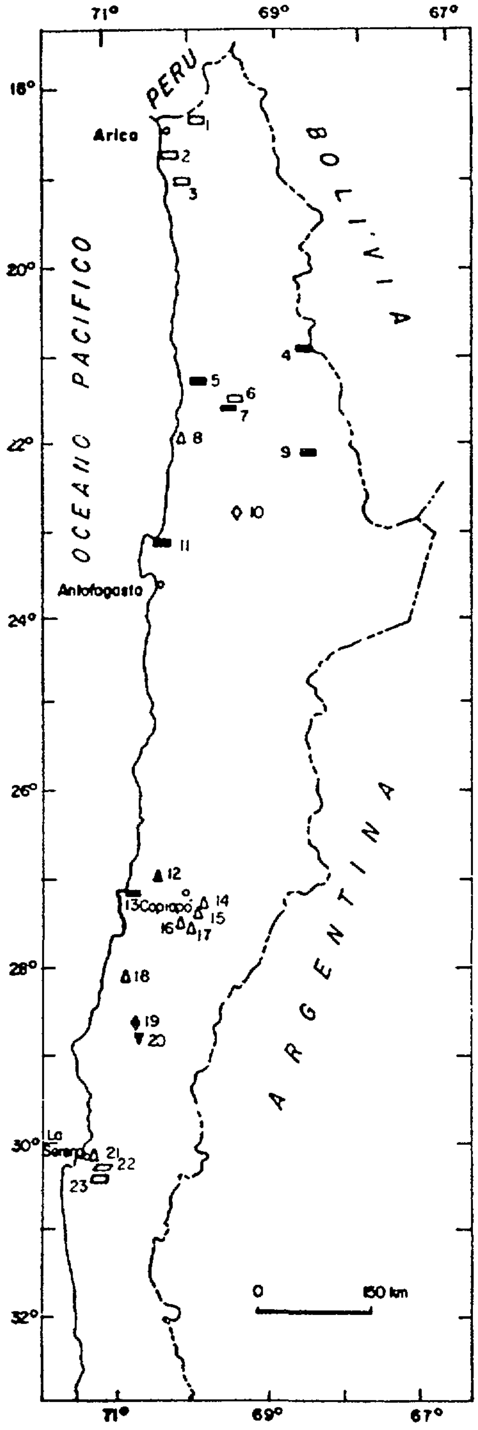
Uraniferous occurrences found in sedimentary rocks and saline deposits of Cenozoic age located in the Pampa Central and intramountain basins of Northern Chile. (5).

All these Miocene-Pleistocene sedimentary occurrences are related to continental sedimentary rocks belonging to lagoon or evaporitic environments. The host rocks of the uraniferous mineralization are diatomite, tuffites, cherts and clastic rocks cemented by blue halite.

The mineralized rocks contain carnotite and schroekingerite with grades from 150 to 1.500 ppm U_3O_8. These occurrences are well represented in Pampa Vitor, Camarones, Salar Grande, the Poconchile area and Pampa del Tamarugal (Quillagua and Prosperidad).

Fluvio-Lacustrine Occurrences

Several uranium anomalies occur in Pliocene-Pleistocene sediments (diatomite, tuffites, chert, conglomerate and calcareous shale), intercalated with gypsum and anhydrite (El Diablo and El Loa Formation) (6,7,8).



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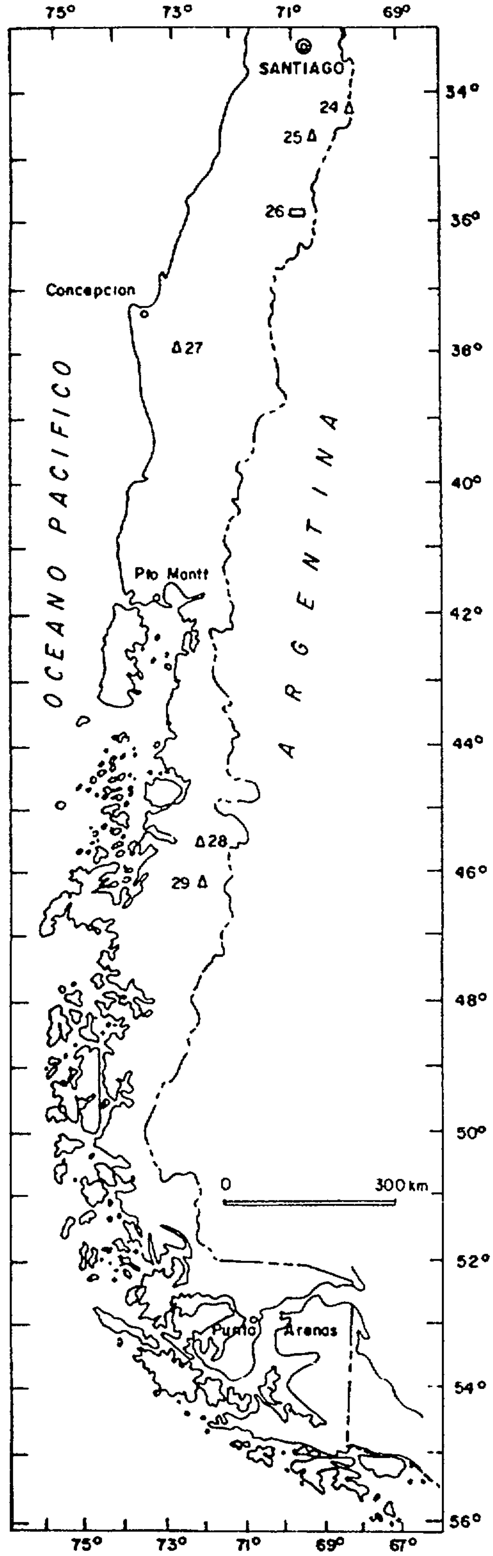
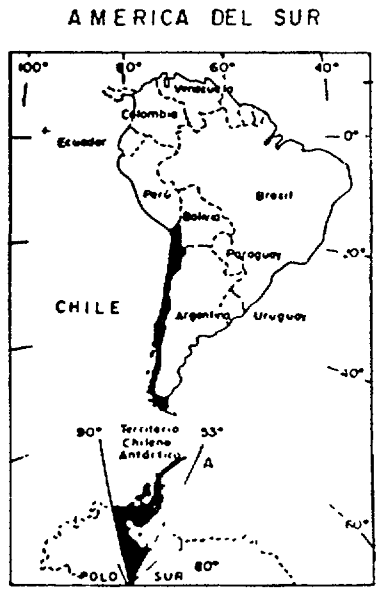
CARTA PRONOSTICO DEL URANIO 33°00'-56°00' L.S., 1986
COMISION CHILENA DE ENERGIA NUCLEAR





1 Pocomchile
2 Quebrada Vitor
3 Pampa Camarones
4 Huinquintipa
5 Salar Grande
6 Quebrada Amarga
7 Ollagua
8 Tocopilla (Cu - U)
9 Chuqui Sur (Cu - U)
10 Sierra Gorda (Cu - U)
11 Mejillones (P - U)
12 Algarrobo-El Roble (Cu - U)
13 Bahía Inglesa (P - U)
14 Los Azules (Cu - U)
15 Despreciada (Th - U)
16 Pampa Larga
17 Veneciana (Cu - U)
18 Carrizal Alto (Cu - U)
19 Carmen
20 Productora
21 Tamblllos (Cu - U)
22 Los Mantos
23 Estación Pejerreyes
24 Escalones (Cu - U)
25 Rosario de Rengo
26 Río Maule
27 Chanleo
28 Río Correntoso
29 Cerro Castillo

Modelo de Yacimiento	Pros[illegible]to	Indic[illegible]
Veta Hidrotermal	▲	△
Vetiforme Hidrogenético	▼	▽
Estratiforme	■	▭
Diseminado Supérgeno	▰	▱
Intramagmático	◆	◇
Calcreta	◗	◠

Fig. 1 - MAIN URANIUM OCCURRENCES IN CHILE

These rocks represent fluvio-lacustrine environments in which the lagoonal phases developed within small tectonic fresh water basins with cold water, shallow sedimentation and semidesertic conditions.

These fluvio-lacustrine occurrences are located near Arica (Mina Neverman, Boca Negra, Manuel Jesus, Poconchile) and approximately 100 Km SE of Iquique (Quillagua and Prosperidad).

All of them are in small lenses, controlled by E - W faults, and the host rocks are diatomite containing organic matter and silica nodules, interbedded with calcareous shale, tuffs, ignimbrite or tuffaceous materials. The main mineralization consists of carnotite grading from 150 to 1.500 ppm U_3O_8 (5,9).

Saline Occurrences

The Salar Grande located 90 km south of Iquique, occupies an inter-montane basin, within the coastal Cordillera, filled with Quaternary evaporitic deposits (Soledad Formation) containing gypsum, anhydrite and halite. At the centre of the salt pan, the halite reaches a thickness of about 200 m.

The basin is surrounded by andesite interbedded with fossiliferous marine limestones (Jurassic), Neocomian continental sediments and intrusive rocks. The uranium is related to E - W faults and shear zones within a Cretaceous granodiorite, and some isolated granites with 12 ppm U_3O_8. The uranium mineral is carnotite associated with clays (montmorillonite, illite) cemented by blue halite . Geochemical and geological prospecting of the area found values between 200 - 1.000 ppm U_3O_8 ((5), Table 1).

The leaching of the huge rhyolitic and ignimbrite outcrops in the Andean Cordillera (Oxaya Formation), is the probable origin of the uranium circulated along E - W faults or shear zones at the Eastern boundary of the lake within a hypersaline environment caused the carnotite precipitation (12).

According to Hambleton-Jones (13), "The Soledad Formation contains uranium in the form of carnotite associated with clay and iron oxide occurring within the halite, and was precipitated by adsorption and evaporitic conditions. At the Salar Grande, the anomalies are associated only with those fractures cutting granodiorite which constituted the source of the uranium".

Quebrada Vitor and Pampa Camarones

Several Km south of Arica uraniferous occurrences are related to chert and diatomite horizons (6) interbedded in sandstone, clay and mud stones partially covered by Quaternary alluvium, some of it containing halite. In general, mineralization occurs in small lenses disseminated or in fractures with carnotite and schroekingerite. (14). Samples of the area show values between 45 and 410 ppm U_3O_8, and up to 950 ppm (6,9,15).

Uranium Occurrences in Phosphate Deposits

The Bahia Inglesa located 8 Km south of Caldera, is a phosphate deposit with small amounts of uranium. In 1980, using airborne radiometric methods, CCHEN found these uraniferous anomalies.

This phosphate deposit is associated with Miocene marine sedimentary rocks, sequences of sandstones and phosphatic conglomerates. The average mineralization at Bahia Inglesa is 18% P_2O_5 and 67 ppm U_3O_8 (16 - 17) and has the same characteristics as the phosphate deposit of Mejillones, situated 100 Km north of Antofagasta, with average values of 7% P_2O_5 and 26 ppm U_3O_8 ((4,18), Table 1).

CONTACT METAMORPHISM OCCURRENCES

Carmen and Productora

The Carmen and Productora prospects 20 Km south of Vallenar, are located near or in the N-S trending metasomatic zone of the iron district, where the country rock are volcanic breccias, andesite, rhyolite, tuffs and ignimbrite of the Bandurrias Formation (Cretaceous age). These rocks are intruded by granodiorite complexes causing gradually metasomatic changes (amphibolite, hornfelses, schist, gneiss) and hydrothermal alteration (argillization, silicification, chloritization and phyllic alteration).

The supergene uranium mineralization is associated with altered acid volcanis rocks (phyllic zone) and located within a shear zone (N 80^{o}E), filled with autunite and torbernite. Significant Cu-Fe-U-and Th-mineralization is associated with the hanging wall of lamprophyr dykes. The average U-grade at the Productora prospect is about 400 ppm ranging from 100 to 23.000 ppm U_3O_8.

The supergene uranium mineralization probably has its source in the hypogene uranium minerals in the granitic intrusive of the Carmen prospect, where disseminated davidite is known within a feldspar alteration zone.((19), Table 1).

<u>Pejerreyes</u>

This occurrence is located 27 Km north of Ovalle, underlain by Cretaceous marine volcanic and continental rocks (tuff, andesite, rhyolite, conglomerate, red sandstone and fossiliferous marine limestones). They are cut by upper Cretaceous granite complexes.

The whole area is affected by thermal or regional metamorphism (green-schist facies) and a weak tourmalinization and phyllic alteration.

The main uranium anomalies are located within the altered metavolcanic rocks, where the supergene mineralization consist of torbernite and metatorbernite and subordinate amounts of copper oxides, both disseminated and in veinlets. The analyses show values from 60 to 100 ppm U_3O_8 and 0.25% Cu. (17).

The possible sources of the uranium mineralization include the acid volcanic rocks which contain davidite and the granitic rocks, with local values up to 3.000 ppm U_3O_8 (Table 1).

HYDROTHERMAL VEINS OCCURRENCES

This group includes hypothermal through epithermal veins emplaced within granodiorite-diorite plutonic complexes.

Some hypothermal occurrences are located in Tocopilla, Algarrobo-El Roble, Carrizal Alto and Tambillos districts, in the Coastal

Cordillera between 22^{o} and 30^{o} SL (20). The main orientation of the veins are N 50^{o}E to E - W. Uraninite associated with chlorite and allanite, together with pyrite, chalcopyrite, arsenopyrite, magnetite, gangue minerals as apatite and actinolite form the mineralization in these veins. Grades from 100 to 200 ppm U_3O_8 and from 0.9 to 6.8% Cu are frequent (21).

The Rio Correntoso and Cerro Castillo epithermal deposits are located in the Aysen Province. N-W and N-E trending faults and shear zones cut the granite host rock with its aplite and pegmatite phases. The occurrences are in small veins and contain pitchblende (veinlets and disseminations), pyrite, chalcopyrite, molybdenite and galena in a calcite and quartz gangue. Chemical assay results range from 0.13 to 4.0% U_3O_8 (22).

Nearby other vein occurrences associated with favourable environments can be found. According to Vergara (23), the main occurrences are associated with Mesozoic sequences: Elizalde Formation (Upper Jurassic) and Divisadero Formation (Lower Cretaceous) both containing rhyolite and tuff horizons cut by a granitic complex. The mineralization consists of pyrite, wolframite, scheelite, molybdenite and chalcopyrite.

Belonging to the vein hydrothermal associations are the breccia pipe occurrences which are emplaced within Cretaceous or Tertiary intrusives. Some of them are uraniferous such as Sierra Gorda, Cabeza de Vaca and Rosario de Rengo, which are characterized by intense phyllic alteration and abundant tourmaline (20). The mineralization contains metatorbernite, autunite, accompanied by atacamite, chrysocolla, pyrite and chalcopyrite within a quartz, sericite and tourmaline matrix.

These breccias are located to the west of the porphyry copper deposits and are genetically related with the last phase of the Tertiary magmatic cycle ((24), Table 1).

EXOTIC TYPE OCCURRENCES

Intense leaching of the porphyry copper deposits has generated "exotic" type occurrences, such as Sagasca, Huinquintipa and Chuqui Sur in Northern Chile.

These occurrences were derived from supergene processes involving:

1) Lateral copper transport by acid solutions originated from the leaching of primary copper sulphides.

2) Precipitation of copper, mainly as silicate (chrysocolla), atacamite,
copper-wad, gypsum and subordinate amounts of uranium with average values of 1.37 to 1.85% Cu and 5 to 30 ppm U_3O_8 ((25), Table 1).

The Cu-U-mineralization fills paleochannel structures with conglomerates cemented by copper silicate and oxides.

CONCLUSION

A national programme was carried out to identify and characterize the regional geological environments favourable for uranium exploration. Systematic study and the collection of geological data started in 1983, leading to the definition of the theoretical uranium favourability of the entire country. This study was completed in 1986. The biggest advance made consisted of the definition of favourable regional environments and the division of prospecting units.

About 20% of the national territory has been prospected and now much work still has to be done on the remaining 756.252 Km^2.

The origin of uranium mineralization in some sedimentary environments is highly discussed. Where are the sources ? More investigations must be done on this subject.

Contact metamorphism occurrences are delineated N - S, within the iron district.

The Carmen prospect exhibits disseminated hypogene mineralization (davidite), associated with U, V, Fe and Ti. The lack of information on the extension with depth and metallurgical problems has not yet improved.

Hydrothermal polymetallic vein occurrences are related to granitic intrusions, with the mineralization in disseminated or vein form. The mineral association is uraninite, pitchblende, wolframite, scheelite, pyrite, molybdenite, chalcopyrite and galena.

Most of the uraniferous occurrences have supergene mineralisation: carnotite, schroekingerite, autunite, torbernite; hypogene mineralization is rather scarce.

Some copper and phosphate deposits have associated uranium values.

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URANIUM EXPLORATION IN BULGARIA — A REVIEW

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Abstract

Uranium exploration in Bulgaria started about 1945 and resulted in the discovery of a number of uranium deposits. The conceptual models of deposits discovered are described. They include deposits associated with the contact between syenites and carbonaceous schists in the Balkan mountains, sandstone-type deposits in Oligocene sediments between the Rila and Pirin mountains in SW Bulgaria, intragranitic vein type deposits, as well as surficial deposits in Quaternary Valley fill. This discovery and the introduction of the in-situ leaching technique lead to the finding of young uranium deposits in a Miocene-Pliocene basin in Thrace. About 80% of the country was covered by ground radiometric surveys. The discovered anomalies were tested and the deposits outlined by more than 18,000 km drill holes. Exploration concentrated on sandstone type deposits, which host 75% of Bulgaria's uranium resources. As a consequence, 70% of the production is by in-situ leaching.

Exploration for uranium in Bulgaria commenced in 1945 with the evaluation of uranium occurrences at the exocontact of a syenite massive in the Balkan range. The evaluations indicated that these mineral occurrences were outcrops of ore bodies in the initial stage or erosion and after a large scale exploration programme, several deposits were discovered.

The high grade deposits were located around the syenite massive. The use of this relationship resulted in more efficient exploration. Exploration drifts were driven cross-cutting the syenite massive periphery. In 40 years over 400 km addits have been driven. The host rocks are carbonaceous Silurian schists, cut by numerous lamprophyr dykes. The country rocks are silicified, brecciated and cut by calcite veinlets. Pitchblend is the main uranium mineral occurring as fracture fillings in the host rocks and, together with calcite, as breccia matrix. The morphology of the ore bodies is irregular, vein-like, lenticular or as stockwork. The high uranium content in the syenite massive (20 ppm), served as a uranium source which was mobilized by hydrothermal solutions, that were transported along the brecciated zones to the carbonaceous schist where the uranium was trapped. Figure 1 shows the conceptual features of this deposit type.

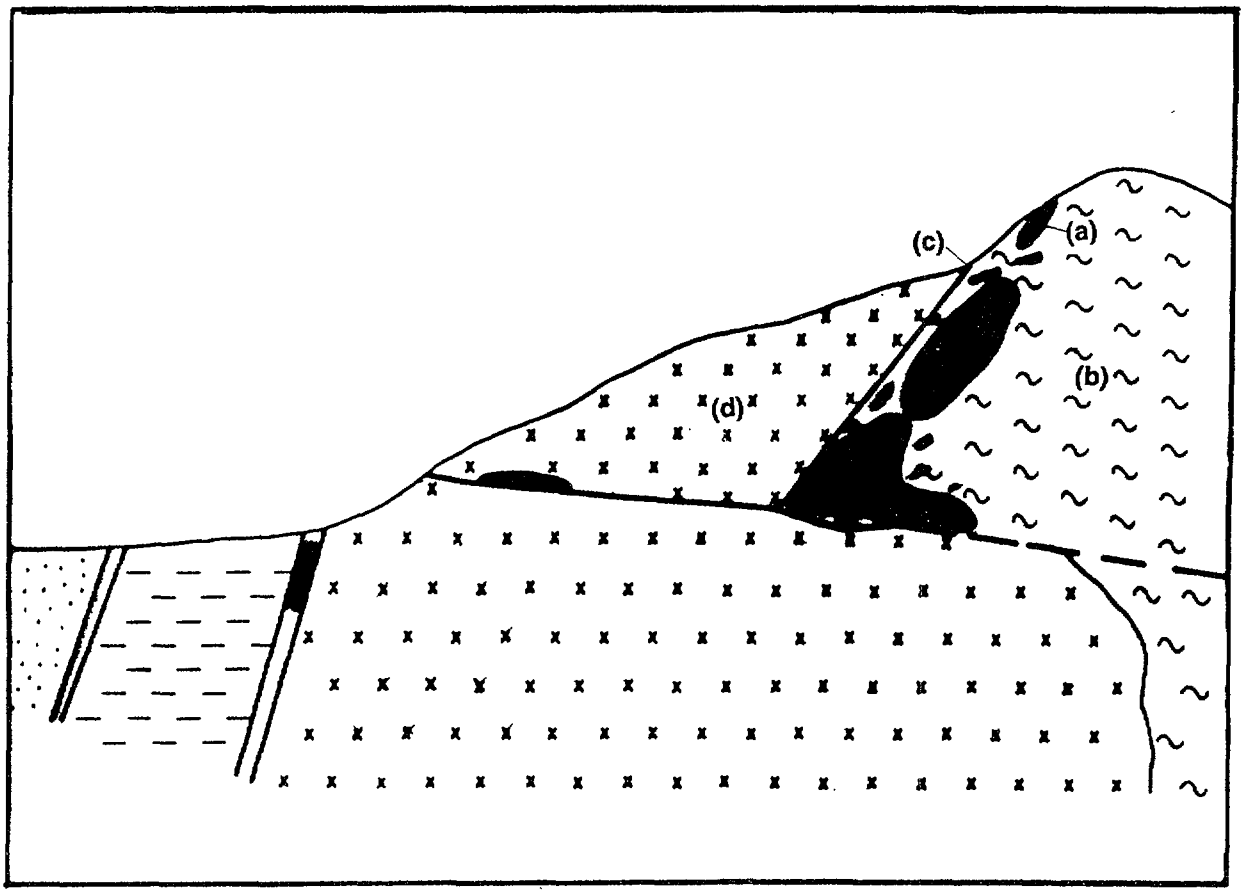

FIG. 1. Section showing uranium ore bodies (a) in carbonaceous schists (b) in fault contact (c) with syenite (d) [not to scale].

In the early 1950's, a vein type uranium deposit was discovered in a volcanic environment in the Rhodope mountains. At this time it was the first example of its kind and the discovery provoked discussions regarding its economic value. Several similar discoveries were made later in the Soviet Union where they were referred to as uranium - molybdenum formation. There were many speculations on the potential of this type of deposit in the 1960's and much money was invested in exploration in this volcanic environment. Unfortunately, only one additional, small deposit was discovered and exploration for this deposit type was terminated.

Again in the early 1950's the first discovery of a sandstone deposit was made in Bulgaria. In the initial stages the economic significance of this deposit type was underestimated and it was only the enthusiasm of the field geologists which lead to the development of this small finding into a large discovery. Several deposits forming a district are located in Oligocene molasse sediments produced by the

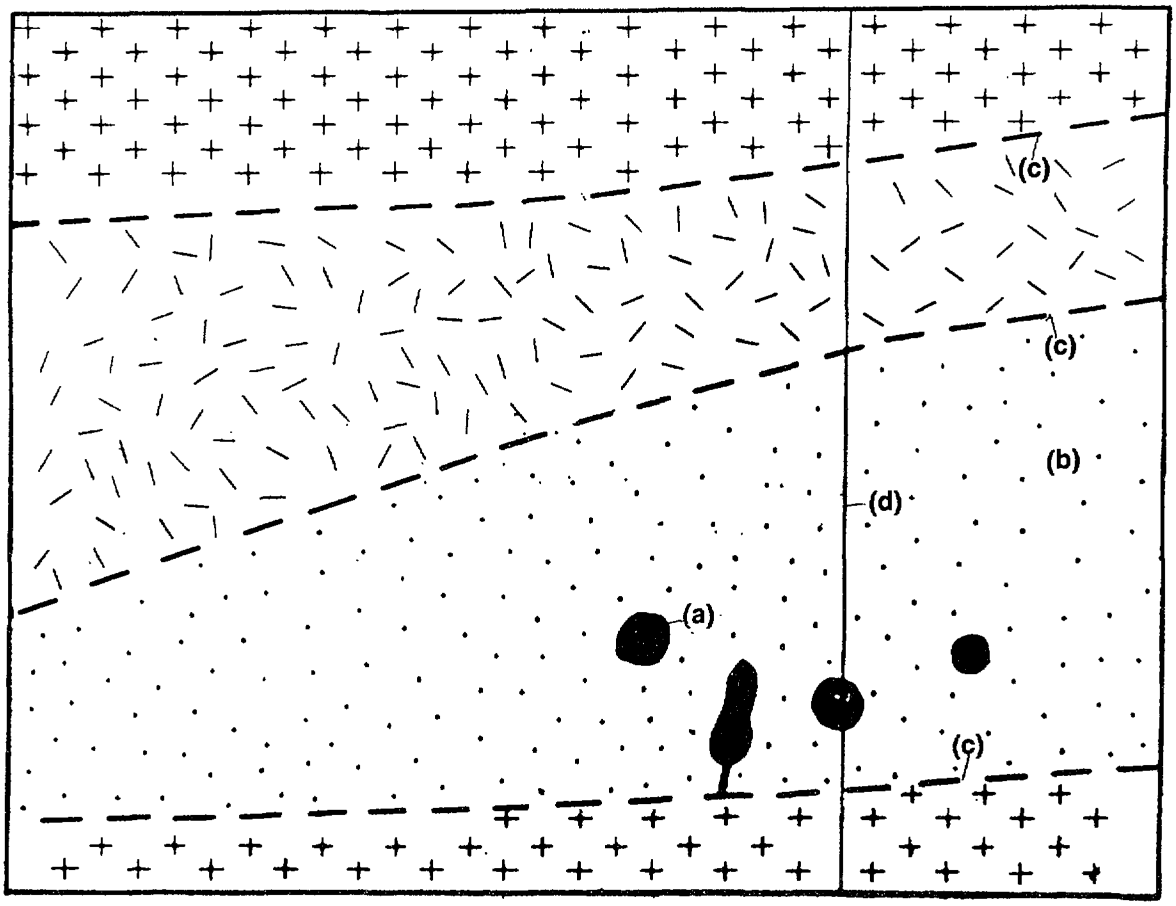

FIG. 2. Plan showing uranium ore bodies (a) in Oligocene sediments (b), faults (c), section line (Fig. 3) (d) [not to scale].

erosion of the Rila and Pirin mountain ranges and deposited in a graben developed between both mountain ranges during the later part of the Alpine orogeny. The sediments are of fluvial facies, grey in colour and flat-lying. The host rocks of the deposits are mainly arkoses located between gravels or siltstones. The ore bodies are stratiform and irregular in composition, formed at several stratigraphic horizons. It is believed that uranium was leached from the Rhodope granite which geochemically has a high uranium content and that this provided source material. The ore bodies are orientated along the graben axis, but close to the Eastern border fault, several high grade ore bodies are located at a right angle to the graben axis. It is understood this is due to another fault which served as a pathway of mineralized solutions that leached uranium from border granites, transported it along to the cross fault and deposited the uranium in carbonaceous sandstones. Figures 2 & 3 are sketches illustrating the geological position of this deposit type in plan and cross-section.

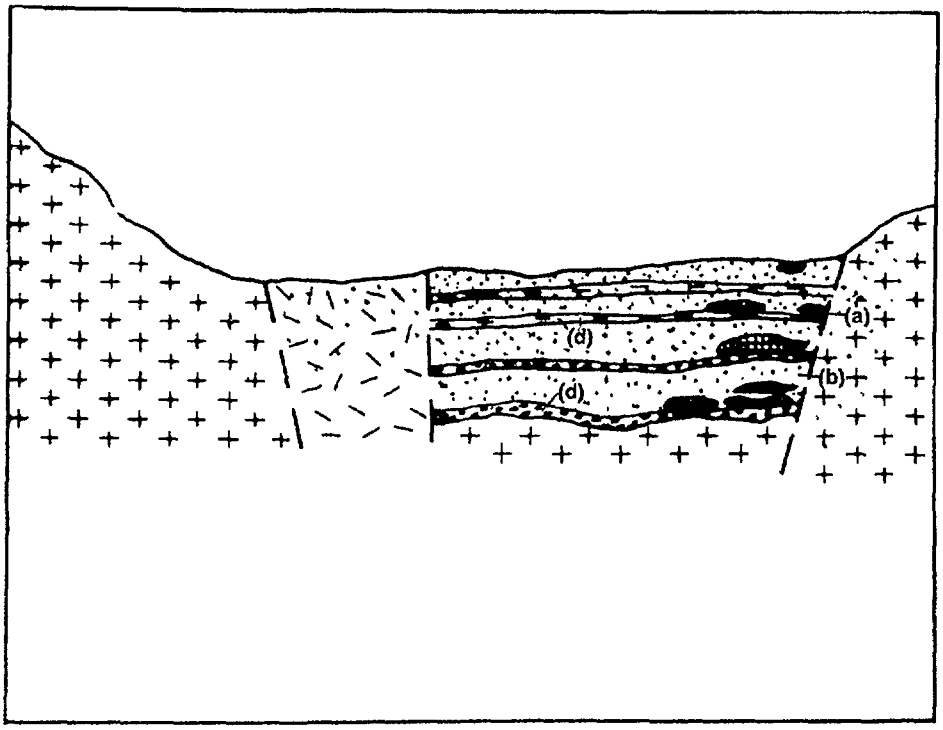

FIG. 3. Section showing uranium ore bodies (a) in Oligocene sediments consisting of sandstones (b), conglomerates (c) and shales (d) [not to scale].

Other discoveries in the 1950's included two vein type intra-granite deposits which are very high grade. The uranium is easily extractable from the ore because it is present in a secondary mineral - uranophan. The veins are banded, filled by layers of stilbite and uranophan (Fig. 4). The mineralization is very young; 1 to 2 million years

Almost all these deposits were detected by airborne gamma-ray methods. Even though the Geiger-Muller counters available at this time had low sensitivity, the survey was highly effective. Small gamma anomalies detected by the survey were immediately tested on the ground and some developed into uranium deposits. In the early 1950's, a ground gamma-ray survey was conducted using Geiger-Muller counters and to increase their sensitivity a modified approach was used. Short holes (1-1,5m deep) were drilled in the soil and logged. In the latter part of the 1950's the first scintillation detectors were used and the sensitivity of ground gamma-ray survey was improved.

Randon prospecting was undertaken using ionization - chambers. Due to its low productivity, the application of this survey was limited to the evaluation of the edges of known buried ore bodies.

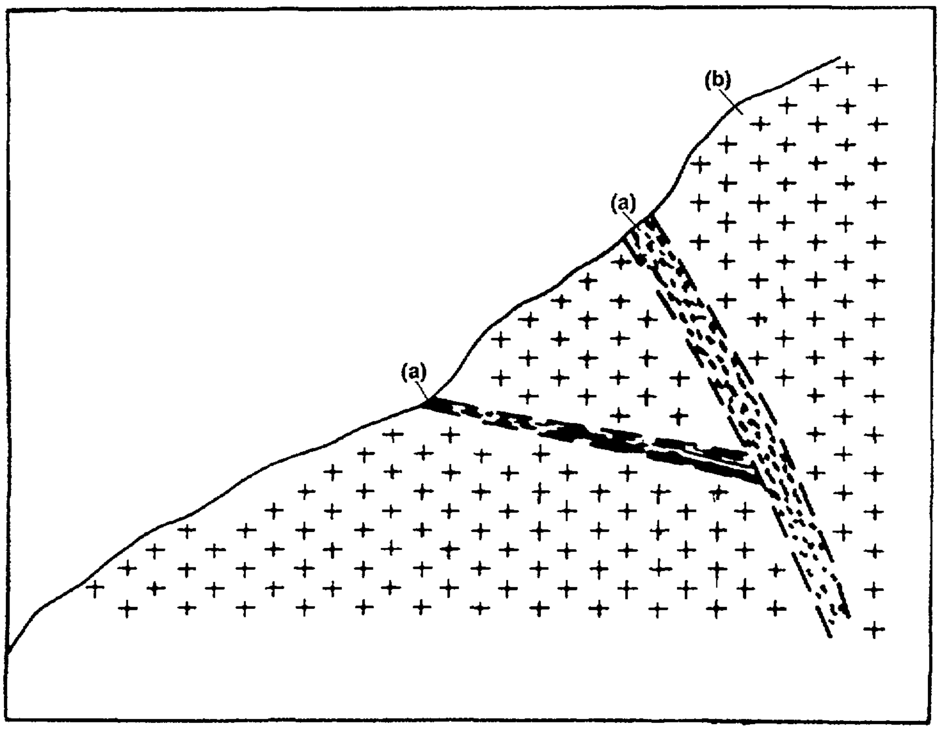

FIG. 4. Section showing vein-type uranium deposit (a) in granite (b) [not to scale].

Except for radiometric survey, it is normal practice to apply general geophysical techniques for a better understanding of the ore body structure, such as resistivity, gravity and magnetic surveys.

Two surficial uranium deposits were discovered at the beginning of the 1960's which are located in a granite environment and formed within Quaternary sands and duricrust deposits. The ore bodies are of blanket and vein-like shape formed by secondary minerals and the uranium is easily recovered by in-situ leaching. (Fig. 5)

The development of the in-situ leaching technique helped the geologist to re-evaluate uranium occurrences in a young sedimentary basin. Subsequently several sandstone type uranium deposit discoveries in the Thracian Pliocene sedimentary basin were made in the late 1960's. Very quickly this deposit type became the most important exploration target. This basin is formed in wide depressions with buried channels developed far from the bordering mountains. It is filled with grey molasse sediments. They are flat-lying and mainly consist of fine grained sandstones, siltstones and clays.

The ore bodies are epigenetic and formed in buried channels during and subsequent to late Miocene-Pliocene. There are several ore

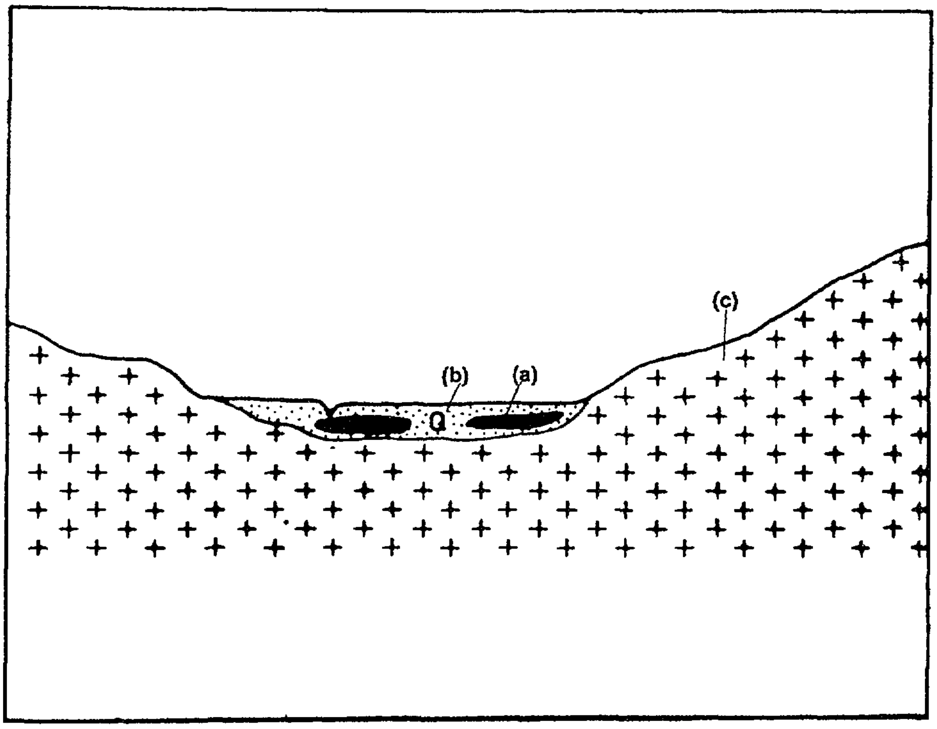

FIG. 5. Section showing surficial type uranium deposit (a) in quaternary valley fill (b) on granite (c) [not to scale].

TABLE 1. CHARACTERISTICS OF SOME GEOLOGICAL PROCESSES FORMING SANDSTONE URANIUM DEPOSITS IN BULGARIA

Genetic type of deposit	Host rock age	Age of mineralization (mill.y.)	Geological processes
Polygenetic	Pliocene	recent	transport of uranium by groundwater
Epigenetic	Pliocene	-	leaching of uranium by by groundwater from the ore bodies and destroying the deposit
Polyphased	Oligocene	3-29	intensive redistribution of uranium; dissolution of one ore body and enrichment of others
Diagenetic	Eocene	18-14	Weak redistribution of uranium

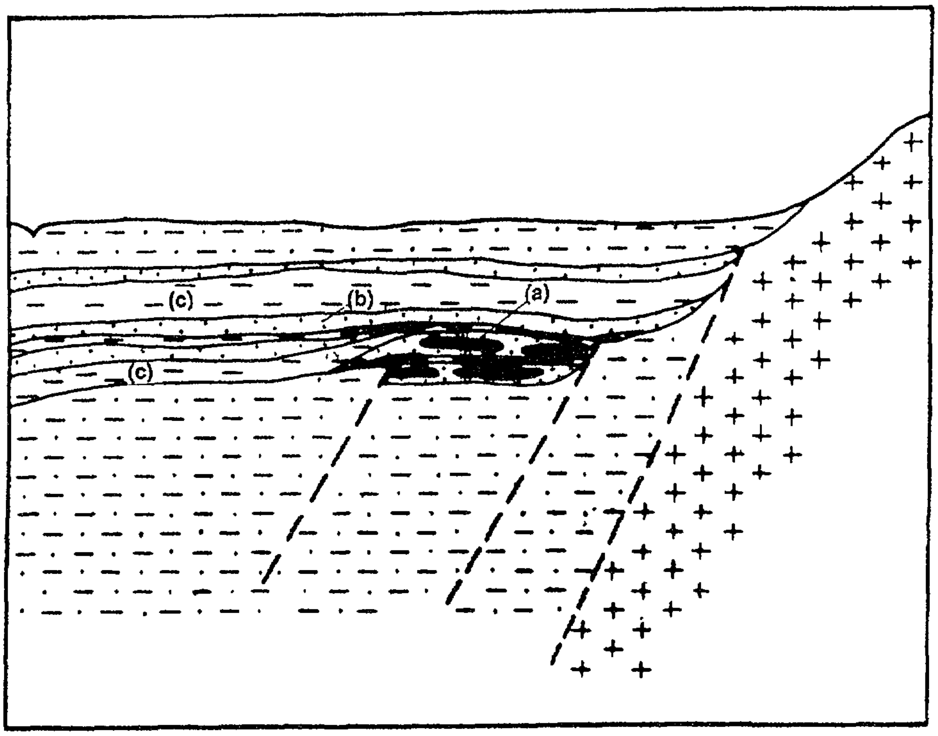

FIG. 6. Section showing uranium ore bodies (a) in Miocene-Oligocene sandstone (b) underlain and overlain by shale (c) [not to scale].

bodies at different levels of the sedimentary pile. The thickness of the productive horizon is 10 m, but the thickness of the actual ore bodies is less. Normally the productive horizon is in sandstones overlain by clay. The host rocks are sometimes oxidized and the ore bodies follow the oxidization-reduction boundary, which indicates in fact a roll-type deposit. The carbon content in the grey sandstones is 0,6%. The ore is medium to low grade but the uranium is easily leachable by in-situ leaching techniques which is why this type of deposit is the most profitable. The main geological features of different young sandstone deposits are given in Table 1. As demonstrated in the table, the deposits "are living", some forming at present and others being dissolved or enriched and therefore, the radioactive equilibrium differs even in the same deposit. It is important to first drill core holes to determine the equilibrium coefficient and to calibrate the logging equipment. Later exploration could be carried out only by non-core drilling. Figure 6 is a cross-section cartoon through a model deposit in Thrace.

Since approximately 1945, 80% of the Bulgarian territory was covered by ground gamma-ray surveys. More than 18.000 km of drilling was completed and 640 km addits driven. More than of 80% of the drill holes are less than 300 m deep and non-cored. Approximately 85% of the drill holes were drilled for sandstone type deposits and most of the tunnels were driven to explore for vein type deposits. As a result, 75% of the uranium resources in Bulgaria are in sandstone deposits and, bearing in mind that 70% of Bulgaria's uranium production is recovered by in-situ leaching, sandstone type deposits are still the main exploration target.

URANIUM PERSPECTIVE IN TANZANIA
(Abstract)

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The uranium exploration activities carried out in Tanzania by Government Agencies in collaboration with foreign companies during the period 1976 to 1982 are described. The uranium occurrences discovered are classified by geological criteria into fix types: sandstone type, unconformity related, intra-intrusive type, in phosphate rocks, associated with carbonatites and surficial type. It is concluded that Tanzania has a high uranium potential, based on the diverse geological environments which host uranium occurrences.

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URANIUM RESOURCES AND RESERVES IN EGYPT

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Abstract

Resources and reserves of radioactive raw materials in Egypt include some conventional-and nonconventional types discovered at some localities in the Eastern Desert, Sinai and the Western Desert. The conventional-type uranium and/or thorium include replacements in granitic rocks, and in alkaline dikes and sills. The nonconventional-types comprise marine phosphorites and black sand concentrations along the Mediterranean. Latent resources include some anomalous areas in carbonaceous shales, clays and phosphatized sandstones in the Western Desert.

Conventional-type replacements in granitic rocks and alkaline dikes and sills sporadically occur in different areas. The economic potentiality of these areas is not yet assessed. However some target areas are by now under development. In one locality some 3,000 tons of ore assayed at 0.108% U are proved through drilling and drifting. Some other areas approximately of the same magnitude are also feasible.

Marine phosphorites represent potential resources for uranium. The economics of extraction of uranium from phosphatic ores are viewed in connection with industrialization to triple superphosphate fertilizers and phosphoric acid. The total estimated reserve and potential reserve of phosphatic rocks in Egypt amounts approximately to 2.5 billion tons. Assuming an average of 100 gm U_3O_8/ton, the above reserve contains as much as 250,000 tons U_3O_8.

The economic potentiality of black sands with respect to uranium and thorium content must be viewed in terms of industrialization of the whole products coming out from black sands. Nevertheless, the estimated reserve of heavy minerals amounts to over 30 million tons in the top meter and over 600 million tons with 27% heavy minerals to a depth of 20 meters in the area of Damietta East, Rosetta East and West. Some other 42.6 million tons grading about 9% heavy minerals are proved to a depth of 20 meters east and west of the Rosetta mouth of the Nile.

Assuming an annual production of 12,000 tons monazite (this amount yields 54 tons U_3O_8, 720 tons ThO_2 7,500 tons RE and 3,360 tons P_2O_5) and marketing of the other products coming out of black sands, it is estimated that the production cost of one pound U_3O_8 amounts to \$ 15 to \$ 30.

INTRODUCTION

Exploration activities for radioactive raw materials in Egypt commenced in 1956. These activities include both airborne-geophysics and geologic follow-up of areas delineating radiometric anomalies. Out of the total area of the country (1 million sequare km.), some 300,000 km^2 are surveyed either by airborne-radiometric, magnetic or spectrometry (Fig. 1). A great part of the area surveyed by airborne-techniques is geologically investigated either on regional scale or in the most favorable areas on detailed scale.

Geophysical, radiometric and geologic exploration resulted in the discovery of many radioactive anomalies sporadically distributed in different geologic environments in different parts of the country especially in the Red Sea Hills, but occassionally on the younger sedimentary cover in the northern part of the Western Desert, Eastern Desert, and Central Sinai.

Granitic rocks which is the most predominant-type comprising the Precambrian basement is found to be the most favorable host of radio-active anomalies, some of these anomalies are found to be either uranium-bearing or thorium-bearing depending upon the predominance of uranium or thorium minerals. The most ubiquitous radioactive minerals include uraninite (Pitchblende), uranothorite, thorite, thorianite, xenotime, monazite, zircon and a suite of secondary uranium minerals, the most common of which are uranophane, autunite, soddyite,... etc. Some of the anomalous zones in granites are considered of significance and warrant detailed exploration by trenching and exploratory mining. The economic potentiality of these loci is now under assessment.

Another favorable geologic environment for uranium is delineated in the central part of the Eastern Desert where the host rock is alkaline sills and dikes of trachytic composition (bostonites). Uranium is epigenized in the form of atshanite (probably amorphous

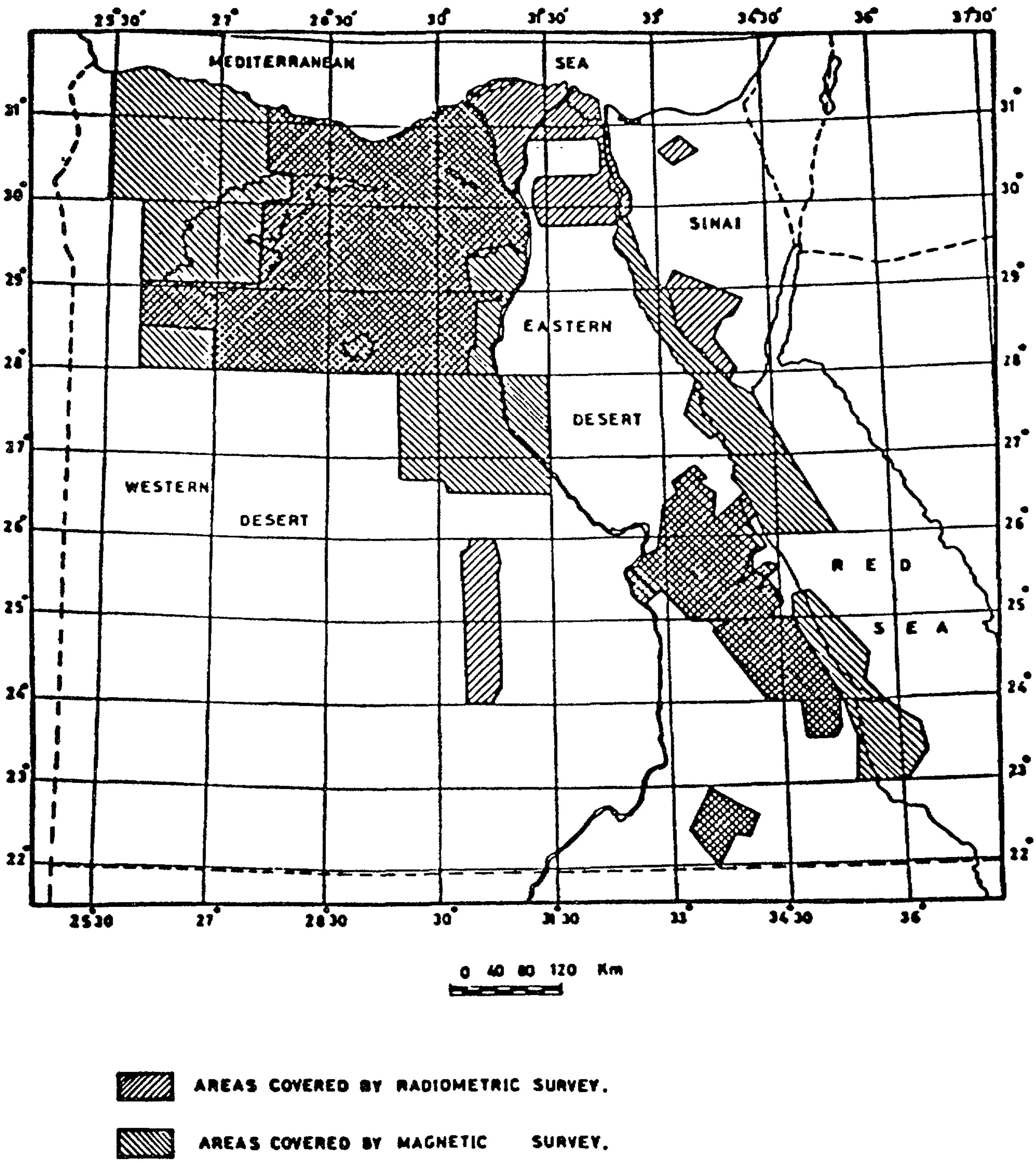

FIG. 1. Areas covered by airborne radiometric and magnetic survey.

clarkeite) and secondary alteration minerals particularly along joint planes and along contact with the enclosing country rocks (Metasediments). Although this type of occurrence is repeated in several places, it represents only small-sized prospects of subeconomic potential.

Radioactive anomalies discovered in the Younger sedimentary cover are represented by anomalies in Carboniferous rocks, in Cretaceous rocks, in Oligocene rocks and in Recent deposits.

Uranium anomalies in Carboniferous rocks (part of Um Bogma Formation) is restricted to Central Sinai and its economic potentiality is not yet assessed.

Anomalies in Cretaceous rocks are related to the exposed section containing phosphates and phosphatic rocks occurring along the Red Sea (between Kosseir and Safaga), along the River Nile (between Idfu and Qena) and in the Western Desert (Oases). Phosphates and phosphatic rocks represent a substantial uranium resource in Egypt.

Anomalies in Oligocene Shales and Sandstones are restricted to the northern part of the Western Desert. The economic potentiality of this type depends largely on the development of appropriate flowsheet for extraction of uranium particularly, if we kept in mind that there is no other by-product that will come out with uranium .

The Recent deposits are represented by the vast resource of black sands containing monazites spreading over along the Mediterranean coast. The economic potentiality of this commodity is viewed in terms of appropriate marketing of the different products coming out of this sand (rutile, zircon, ilmenite, magnetite, ... etc), and the industrialization of large tonnage of monazite-rich concentrate.

RADIOACTIVE OCCURRENCES IN EGYPT

A. CONVENTIONAL TYPES

Results of uranium exploration in areas of different geologic environments revealed the favorability of "Younger granites" as potential targets. Moreover, some other favorable targets are related to subalkaline bostonite dikes and sills that are sporadically distributed in the Central part of the

Eastern Desert. In both cases, uranium is displayed mostly as secondary minerals, but in few instances spechs of uraninite and/or Pitchblende are recognized.

A more recent discovery of uraniferous zones in carboniferous sedimentary rocks in Sinai warrant detailed investigation. In many localities within Abu Zenima district, secondary uranium minerals are found associated with the Middle Unit of the Um Bogma Formation.

The above-mentioned types are provisionally classified as follows:

I- Replacement fissure zones:

A) in granitic rocks:

- Essentially Uranium (subordinate Th) Example:G. Gattar, Eradia and Missikat, Um Ara.
- Essentially Th (subordinate U). Example: Abu Garadi and Um Safi felsite.

B) In Bostonite dikes and sills and contact planes with metasediments. Example: Atshan area.

II- Occurrences in Carboniferous sedimentary rocks associated with Cu and Mn. Example: Abu Zenima Area (Central Sinai).

I- REPLACEMENT FISSURE ZONES

Several zones having radioactivity of above normal values were located in several places in the Eastern Desert. These radioactive zones are not restricted to one type of a host rock nor restricted to specific strike direction. Some of these areas are known to contain discrete uranium and/or thorium minerals, while some others with no identified minerals, but with higher radioactivity which is in a number of instances has been attributed to the presence of accessory zircon,

TABLE 1. CHARACTERISTICS OF RADIOACTIVE OCCURRENCES GENETICALLY RELATED TO I-TYPE GRANITES

Features / Area	Missikat	Eradia	Gattar	Um Ara
Country rock	metamorphosed volcano-sedimentary rocks.	Basic metavolcanics	Basic metavolcanics	Metamorphosed volcano-sedimentary rocks.
Acid Magmatism	Orthoclase-granite	Orthoclase-granite	Orthoclase-granite	Orthoclase granite
Primary minerals	Uraninite Pitchblende?	Uraninite Pitchblende?	Uraninite	Uraninite thorite
Secondary minerals	Uranophane	Uranophane, Soddyite, renardite	Uranophane Carnotite, clarkeite, umohoite, kasolite, zippeite, soddyite.	Uranophane curite.
Wall rock alteration	Silicification Brecciation hematitization fluorite	Silicification Brecciation hematitization fluorite	Silicification Argillic alteration hematitization fluorite	Silicification microclinization Albitization hematitization fluorite.
Associated sulfides	molybdenite galena chalcopyrite sphalerite, pyrite	molybdenite galena, chalcopyrite sphalerite pyrite	molybdenite	———
Structural elements	ENE trending shear zones	N to NE trending shear zone	NE trending fissure zone	NE trending fissure in the north, uranium dissemination due south.
References	Bakhit, 1978 Hussein and others, 1986	El Kassas, 1974	Abdel Monem and Salman, 1988 Sayyah and others (in press)	Abdel Maguid, 1986 Hussein and others, 1986.

(After Hussein et al., 1989).

monazite, etc... or otherwise to the absorption of uranium ions on hematite during hematitization which is a common postmagmatic alteration feature in all of these fissure zones.

Tables 1 and 2 give the main characteristics of the above mentioned types (Hussein et al, 1989) and a brief description of each follows:

<u>Fissure zones in Gabal Gattar granites</u>:

Gabal Gattar is located some 35km. to the West of Hurghada (Fig. 2) on the Red Sea Coast. The area for a long time is known of several occurrences of molybdenite-bearing quartz veins cutting through granites (Hume, 1935, Ghobrial and Lotfy 1967). Granite rocks of this area represent a type locality of Late Precambrian granite intrusives refered to as "Gattarian Granite" which is synonemous to the currently used term "Younger Granite" describing collectively the Postorogenic Pink or red granites which in this particular area, Barthoux (1922) described it as granite rose a l'allanite on account of the occassional presence of allanite.

The newly discovered radioactive zones in this area (Salman et al. 1987) strike in a NNE-SSW and NW-SE direction and is epigenized with a suite of secondary uranium minerals (uranophane, carnotite, clarkeite, uranothorite, kasolite, zippeite and soddyite) associated with fluorite and smoky quartz.

<u>Fissure Zone in El-Eradia and Missikat Granite</u>:

The area is located to the South of Qena-Safaga Road in the Central Eastern Desert (Fig. 2). In these areas, uranium mineralization was discovered in fracture zones within two granitic plutons about 45 km apart (El Kassas 1974, Bakhit 1978).

TABLE 2. CHARACTERISTICS OF RADIOACTIVE OCCURRENCES GENETICALLY RELATED TO S-TYPE GRANITES

Features / Area	Abu Garadi	Um Safi	Wadi El Gemal
Country rock	metamorphosed volcano sedimentary rocks.	metamorphosed volcano sedimentary rocks.	metamorphosed basic volcanic rocks.
Acid magmatism	Granite	Felsite	Psammitic gneiss
Primary minerals	Uranothorite xenotime columbite zircon Thorianite Thorite Uraninite	Uranothorite xenotime columbite zircon	Uranothorite columbite zircon
Secondary minerals	Uranophane Clarkeite autunite, soddyite delorenzite.	———	Kasolite ?
Structural control	Contact between granite and metamorphosed country rocks Along NW-SE, ENE-WSW trending faults.	ENE-WSW trending zones in felsite.	ENE-WSW in metasomatically altered psammitic gneiss.
References	Khawasik, 1968 Attawiya, 1978	El Ghawaby, 1966	Hassan, 1964 Hussein, unpublished

(After Hussein et al., 1989).

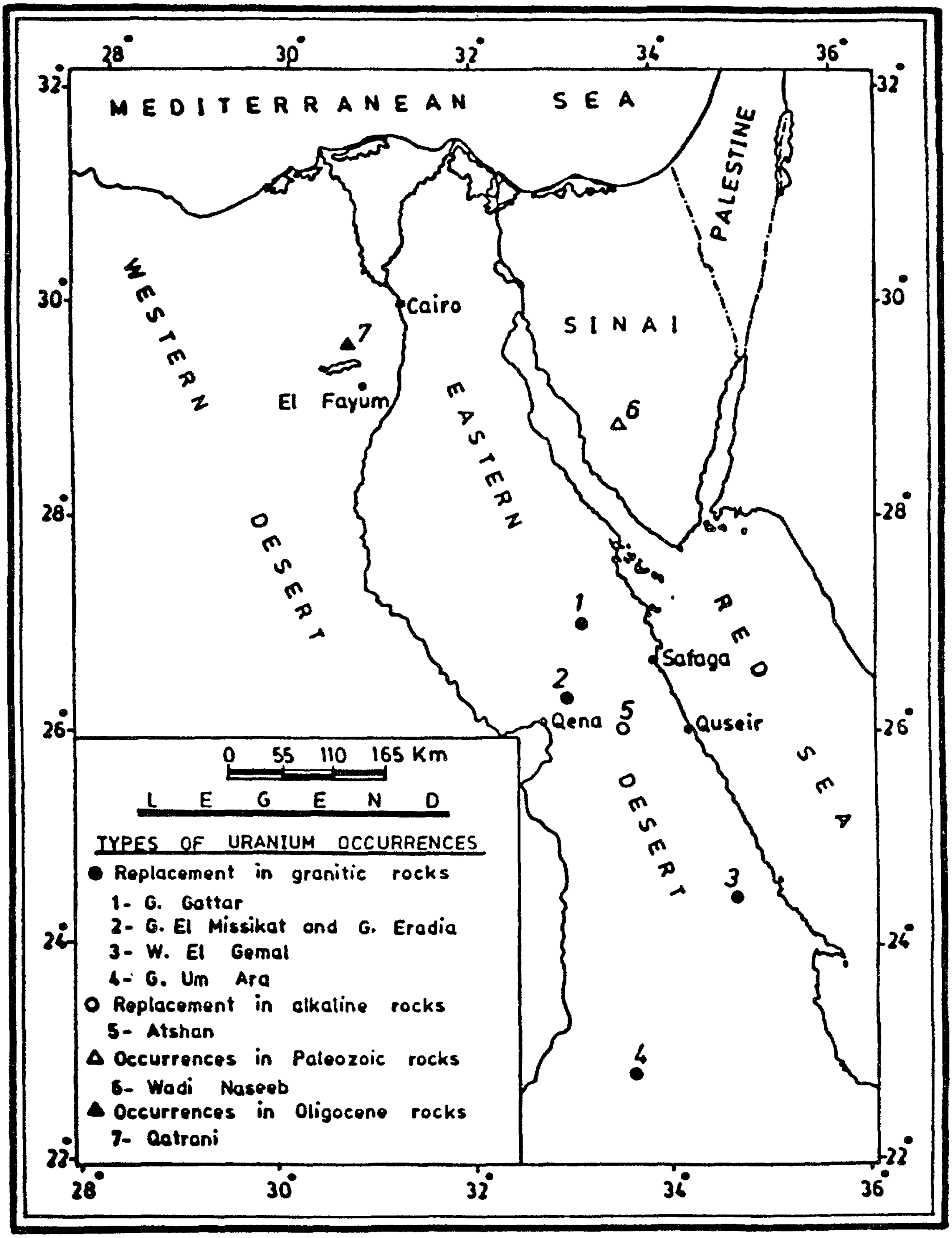

FIG. 2. Map showing localities of uranium occurrences in Egypt.

On the surface dissiminated secondary uranium minerals (uranophane, soddyite, renardite in Eradia and uranophane in El Missikat) occur in jasperoid, quartz and chalcedony veinlets associated with fluorite and minor amounts of pyrite, galena and molybdenite. Exploratory tunnels were dug into these granites where dissiminated and massive Pitchblende were found in local zones. In general, the uranium mineralization is structurally controlled in north-easterly trending fractures or shear zones in the granites. It is believed that oxidation and leaching of uranium in the oxidation zone is the main cause of the erratic distribution, and enrichment of uranium could be expected below the oxidation zone. An exploratory system of adits (drifts and crosscuts) is currently under development for the economic appraisal of the area.

Fissure Zones in Abu Garadi Granite:

The area is located in the Central Eastern Desert (Fig. 2) and is made up of metamorphosed sedimentary and volcanic rocks intruded by pink granite mass and some pegmatite dikes, aplites and quartz veins. The general bedding and foliation of the metasediments and metavolcanics is west-northwesterly and dipping south-southwesterly. The granite mass is intensively jointed in a north-south, northwest-southeast directions. Faulting in the area falls in four groups arranged from oldest to youngest as follows ENE-WSW, E-W, WNW-ESE, and N-S which is the most predominant (Khawasik, 1968).

Anomalous radioactive zones are described in places along the contact between the granite and the metasediments as well as along fault zones trending NW-SE and ENE-WSW and their intersections. Primary uraniferous minerals include uranothorite, thorite, thorianite, zircon, xenotime and columbite. Secondary uranium encrustations of uranophane, autunite, clarkeite and soddyite are noticed lining fractures.

Fissure Zones in Um Ara Granite:

The area is located in the southern part of the Eastern Desert (Fig. 2) and is made up of metasedimentary and metavolcanics intruded by pink granite mass constituting Gabal Um Ara. Major faults and fissure zones in granites are trending in a north-easterly and northwesterly directions. Secondary uranium minerals are identified along fractures and is generally associated with fluorite (purple and green varieties) as well as microclinization of the granites. Abdel Maguid (1986) described uraninite specks disseminated in some parts of the intrusion. The area will be assessed through a number of deep trenches in the mineralized part of the granitic mass.

Fissure zones in bostonite:

Several anomalous radioactive areas are located along the contact between dike bodies and sills of trachytic composition and metasediments. This type of occurrence is restricted in space to the central part of the Eastern Desert around Kosseir on the Red Sea Coast.

Among the most important localities, mention is made to that of Atshan, Wadi Gir, Owershy, Nasb El Qash, Farkha Wadi Kareim, Um Shaghir, Um Huyut, Kab El Abiad, Wadi Rahia, and Kab El Warrada. The most important of these is the occurrence described at Atshan where secondary uranium mineralization at the surface promoted detailed geologic work, diamond drilling and mining works.

The locality of Atshan (Fig. 2) is some 40 km Southwest of Kosseir and the rocks of the area include a thick succession of geosynclinal metasediments intruded by bostonite sills and dikes. The general bedding of the area is northeasterly and dip moderately northwesterly. Faults of the area are mostly northwesterly and northeasterly, but less commonly east-west and north-south. Detailed geologic investigation revealed that high radioactivity is localized along contact zones with the metasediments as well as along fractures and fault zones that are epigenized with secondary uranium minerals. The most radioactive zone in the bostonite sill at Atshan area extends along its upper contact with the metasediments and runs in a N55W direction nearly perpendicular to the strike of the sill. Uranium minerals include; pitchblende, atshanite (probably amorphous clarkeite), bequerelite, schoepite, uranophane, kasolite, soddyite, uranopilite, zippeite and dakeite Abdel Gawad (1964). Some 3,000 tons of ore assayed at 0.108% U are outlinedfrom this prospect Pejatovic (1968).

Fissure zones in felsite:

The area is located in the Central Eastern Desert (Fig. 2) and is made up of metamorphosed sediments and volcanics with general bedding and foliation trending in a northwest-southeast direction. These rocks are emplaced by felsite body and some associated quartz veins and aplites trending NNE-SSW, or ENE-WSW in the felsite mass and N-S or NNW-SSE in the country rocks. The felsite body is striking northwesterly concordant with the regional structure. Some minor radioactive zones in the felsite body follow the ENE-WSW direction. The anomalous radioactive zones contain uranothorite, zircon, xenotime and columbite very similar in this respect to the type described from Abu Garadi area.

II- OCCURRENCES IN PALEOZOIC ROCKS

A more recent discovery of prospective area of anomalous zones with secondary uranium minerals is stratigraphically related to the Carboniferous and lithologically controlled by a succession of sandstones, claystones and silty beds. This occurrences is repeated in a number of places around Abu Zenima (Central Sinai). This occurrence is represented by dispersed secondary minerals in siltstone, shale and sandstone constituting the Lower Carboniferous sequence. Primary minerals identified include xenotime, zircon, monazite and a secondary suite of zippeite, metatorbernile, metaautunite, metazuenerite, carnotite, Rb-carnotite, uranophane and uvanite.

B. NONCONVENTIONAL TYPES

The nonconventional uraniferous occurrences in Egypt include the marine phosphorites of cretaceous age, the carbonaceous clay and shales of Oligocene age and the beach placers of the black sands on the Mediterranean of Recent age.

Marine Phosphorites:

The Egyptian phosphate deposits occurring along the Red Sea coast between Safaga and Kosseir, along the Nile Valley between Idfu and Qena, and in the Dakhla, and Kharga Oases are considered with their huge reserve as a potential submarginal resource of uranium.

The uranium content of phosphate rocks generally increases with the increase of phosphorous content, but deposits rich in phosphate does not necessarily imply they are richest in uranium. The richest uraniferous samples of about 0.005% U from Permian Phosphoria Formation of Western United States are not the most phosphatic. Also, the uranium content of phosphate rocks decreases with weathering due to leaching of uranium sometimes with the development of secondary enriched zones. The intensily weathered phosphate rocks of Florida, Senegal and Nigeria consist of quartz sand and fine materials formed of wavellite crandallite (aluminum-bearing phosphate minerals) which contain locally as much as 0.1% uranium or even more.

Carbonaceous shales:

The Oligocene carbonaceous shale of Qatrani area is uraniferous. The range of uranium content is from 0.003 to 0.065% with an average estimated by Pejatovic (1968) as 0.01 percent. The uraniferous bed extends below basaltic sheet for a distance of about 15 km with thickness varying between 0.1 and 1.0 m and averages 0.4 m. The mineralogical composition of the shale calculated from chemical analysis of one sample selected for leaching experiment is given by El Shazly et al. (1971) as follows:

	%		%
montmorillonite	20.15	iron oxides	9.31
Quartz	2.53	humic organic matter	1.23
dolomite	25.76	soluble salts	9.23
calcite	9.26	sulfur & phosphate traces	
gypsum	22.02		

Beach Sands:

Tremendous reserves of black sands containing monazite besides magnetite, ilmenite, zircon, rutile and garnet are present along the Mediterranean Coast. Concentration plants for the separation of various minerals and required treatments to prepare acceptable shipments in the world market will promote benefication of monazite in making utilization of the extracted uranium, thorium and the rare earths.

RESERVES AND RESOURCES

Egypt's reserves and resources of the fissionable raw materials include the outlined conventional type uranium mineralizations discovered mainly at the localities of G. Gattar, Eradia and Missikat, Atshan, Abu Garadi, Um Safi and Um Ara in the Eastern Desert and, the newly discovered occurrence in Central Sinai, as well as the nonconventional resources included in the marine phosphorites, carbonaceous shale and black sands.

The marine phosphorites represent potential ore resource for uranium. The economics of extraction of uranium from phosphatic ores are viewed in connection with the industrialization to triple superphosphate fertilizers and phosphoric acid.

The phosphate deposits of Egypt occur in the Campanian-Maestrichtian age (Cretaceous) in horizons of different thickness and P_2O_5 content along the Red Sea coast, Nile Valley, and Oases. The total estimated reserve and potential reserve of Egypt amounts approximately to 2.5 billion tons distributed as follows:

Red Sea area	200-250	million tons.
Nile Valley area		
Mahamid	237	million tons.
East & North Mahamid	1.1	billion tons.
Wadi Seraya, Abu Had and Wadi Hamama	400	million tons.
Western Desert		
Dakhla and Kharga oases	700	million tons.

Assuming an average of 100 gm U_3O_8/tons, the above reserve contains as much as 250,000 tons U_3O_8. This amount, however, may be reduced by a factor of two depending upon the percent recovery and variation in the uranium content in phosphorites in different areas.

The uraniferous carbonaceous shales and clay of Qatrani area, Western Desert extends from east to west for a distance of about 15 km. with a thickness that varies between 0.1 and 1.0 m and average of 0.4 m. The uranium concentration along its strike varies between 0.002 and 0.06% U_3O_8 with an average of 0.01 percent Pejatovic (1968) estimated a total reserve of about 1,200 tons. This area, however, should be viewed in connection with the fact that no other product shall come out with uranium.

The economic potentiality of the black sands with respect to its uranium and thorium content as well as the other composing mineral constituents is reviewed in the report presented by Cameron (1966) who advised not to rely on the beach sands as a source of uranium. The estimated reserve of the heavy minerals amounts to over 30 million tons in the top meter and over 600 million tons of a 27% heavy minerals to a depth of 20 m in the area of Damietta East, Rosetta East and West. Some other 42.6 million tons were proved to a depth of 20 m. east and west of the Rosetta mouth of the Nile grading about 9% heavy minerals (EBASCO).

Unless industrialization of the whole products coming out from black sands, Cameron (1966) estimated the cost of one pound of U_3O_8 to be in the range of \$ 100-150 which is very high for the foreseable future requirement.

Assuming an annual production of 12,000 tons monazite (and marketing of other products) some 54 tons U_3O_8 can be achieved at an estimated cost of \$ 15 to 30 per pound U_3O_8 (Cameron, 1966).

In a more recent studies the economics of industrialization of black sands as a source of uranium is based on a minimum annual production of 6,000 tons of monazite.

Moreover, some 3,000 tons of ore assayed at 0.108% U are outlined from Atshan area through intensive drilling program and some exploratory mining operations.

In summary the resources and reserves of fissionable raw materials in Egypt are given in the following table.

RESOURCES AND RESERVES of Fissionable Materials in Egypt.

(1) Conventional - Types

* Fissure Zones in Granites: 4 Localities with Potential shows currently under assessment.
* Fissure Zones in alkaline dikes and sills (Bostonites).
  * Several localities with anomalous value.
  * In one area 3,000 tons of ore assayed at 0.108% U is delineated.
* Occurrences in Paleozoic sandstone under assessment.

(2) Nonconventional - Types

* Phosphatic Rocks (Cretaceous)
  Potential resource of about 250,000 tons U_3O_8.
* Carbonaceous Shale (Oligocene)
  Anomalous zone with some 1,200 tons of ore.
* Beach Sands (Recent)
  Possible annual production of some 50 tons U_3O_8.

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EVALUATION OF THE ECONOMIC POTENTIAL OF URANIFEROUS POLYMETALLIC MINERAL ORES IN MAKHTESH RAMON, SOUTHERN ISRAEL

(Summary)

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Jerusalem

Israel

A systematic airborne radiometric survey over Israel (Aviv & Vulkan 1982), led to the discovery of a uraniferous polymetallic vein-type mineralization (Itamar et al. , 1984) in the Gevanim Valley of Makhtesh Ramon. This is an erosional cirque located in the Negev Desert in Southern Israel (Fig. 1).

The mineralization has been shown to be connected to the quartz syenite bodies intruded, in the Early Cretaceous ,into Triassic and Jurassic sediments. The magmatic rocks are exposed as several isolated outcrops. They measure from tens to thousands of square meters in area. The largest of these are located in the Gevanim Valley to the east and at Shen Ramon to the west.

The ore veins, exposed primarily at the surface, contain a rich variety of metals such as Ag, U, Zn, Pb, Ni, Cu, Mo, Cd and Co in concentrations which range from hundreds of ppm to several percent. They contain various primary and secondary minerals including uraninite, metal sulfides, arsenides and oxides as well as sulfates, arsenates, carbonates, etc .

In order to assess the economic viability of this find, a broad range of exploration surveys and investigations were initiated over this mineralized area (Zafrir and Steinitz , 1985). The following works have been carried out to date :

1) Geological, structural, mineralogical, geochemical and petrological research (Itamar, 1988). This has led to a conceptual model,which describes the phenomena as a polymetallic hydrothermal vein ore generated during the last stages of Lower-Cretaceous magmatic activity by "sedimentary-magmatic" fluids circulation. Hydrothermal solutions were formed from waters trapped within the sedimentary rocks which were released and then moved down towards the magma through breccia zones. Then, they were heated, enriched in metals and volatiles and subsequently moved upward towards the top of the intrusion where the ore was deposited.

2) A detailed radon alpha-track survey, modified for direct measurement in exposed bed rock of the magmatic outcrops, was carried out in Gevanim Valley (Strull et al.,1987). Radon (thoron eliminated) anomalies (3 times the background or more)

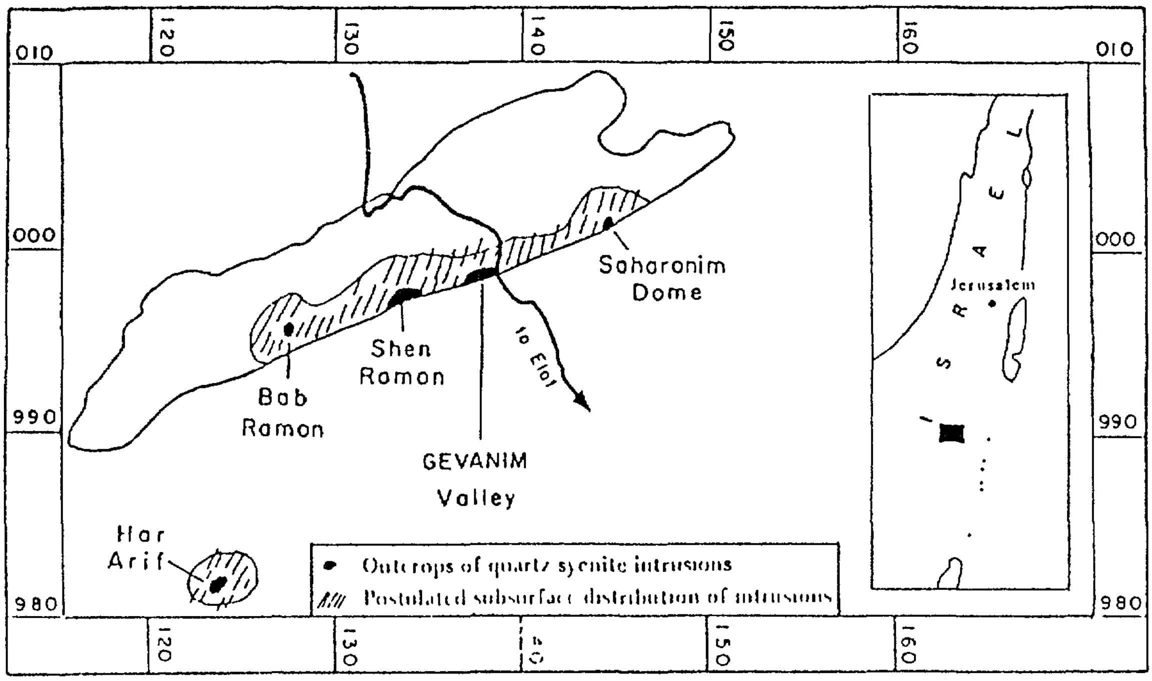

FIG. 1. Location map.

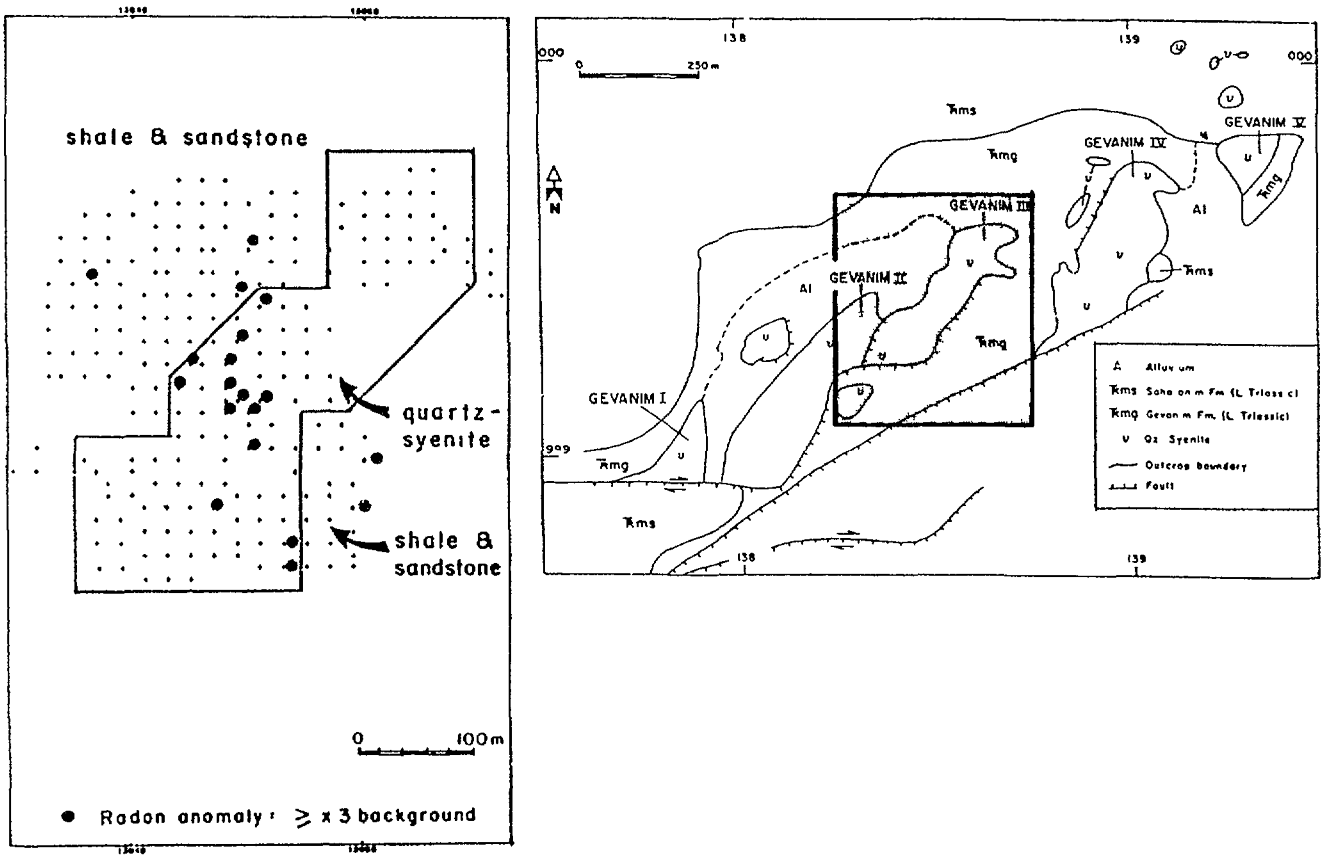

FIG. 2. Radon anomalies in Gevanim III.

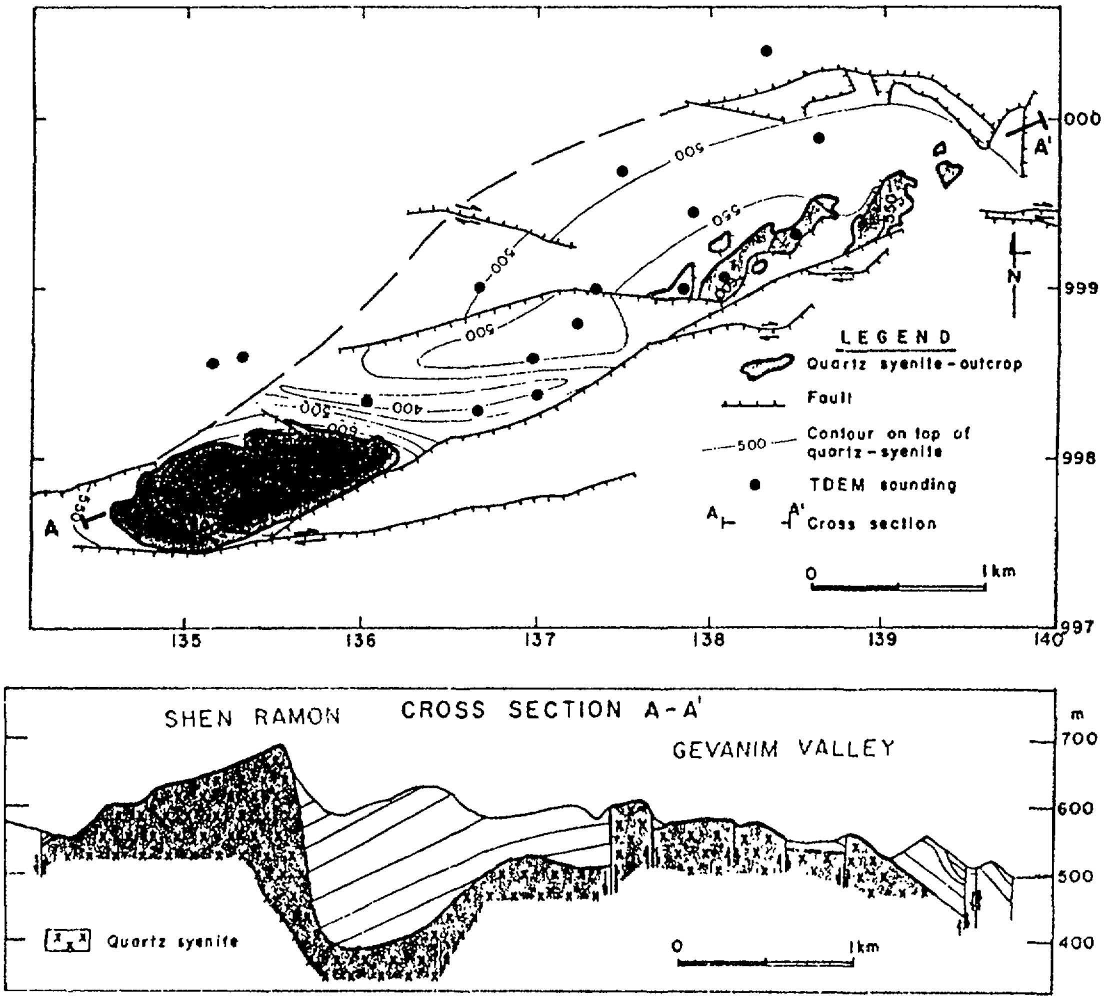

FIG. 3. Location map of TDEM survey and geological cross-section.

which were unaccompanied by a parallel increase in the radium content at the site, extended over an area of few thousand square meters on Gevanim III (Fig. 2). It was considered as an indication of a deep seated uranium source. 18 boreholes drilled to a maximum depth of 100 meters beneath the anomalies, did not reveal a significant uranium mineralization. Another or deeper source must therefore exist for these anomalies.

3) A time domain electromagnetic (TDEM) survey (Goldman et al.,1989) proved the existence of a continuous large quartz-syenitic intrusion in southern Makhtesh Ramon, extending from Shen Ramon to Gevanim Valley thereby expanding the area of the known magmatic intrusion, by a factor of 5 (Fig. 3).

4) A detailed stream sediment survey carried out, over 50 square kilometer centered around the magmatic intrusion of Gevanim Valley and Shen Ramon (Zafrir et al. , 1987). Some 1200 samples were collected, and analyzed for U by delayed neutron activation (DNA), for U,Th and K by gamma-spectroscopy and for Ag,As,Co,Cr,Cu,Mn,Ni,Pb,V, and Zn by HCl+ HNO_3 hot extraction and atomic absorption (AAS) analysis. The results show geochemical correlation to a few hundreds meter between part of

TABLE 1. LOCATION, EVALUATION OF RESERVES, AND PLANNING OF MINING AND PRODUCTION OF METALLIC ORE OCCURRENCES IN MAKHTESH RAMON

Detailed Activity	Quarters, numbered															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Geologic mapping, 1:5000 scale	→	→	→	→	→											
2. Geochemical survey.	→	→	→	→	→											
3. Radon survey.	→	→	→	→	→											
4. Helicopter geophysical survey.	→	→	→	→	→											
5. Ground-level follow-up of helicopter survey.				→	→											
6. Full geophysical ground survey.	→	→	→	→	→											
7. Summing-up; demarcation of potential ore localities.					→	→										
1. Planning of drilling; geodesic field survey.						→										
2. Shallow and deep drillholes.							→	→	→	→						
3. Geophysical measurements in drillholes.								→	→	→						
4. Analysis of samples; data processing.								→	→	→						
5. Summing-up three dimensional modelling of ore bodies.									→	→						
1. Geological mapping, 1:500 scale.										→	→	→	→	→		
2. Cutting-holes, for reserve evaluation.										→	→	→	→			
3. Coreholes, for reserve evaluation.										→	→	→	→			
4. Evaluation of reserves and planning of mining.													→	→		
1. Experimental quarrying.															→	→
2. Mine planning.															→	→

TABLE 2. SUMMARY — BUDGET HIGHLIGHTS ($ 1000)

Year / STAGE*	I	II	III	IV	TOTAL
Stage A - Delineation of Ore Bodies by Surface Prospecting					
Total	2921.0	439.0			3360.0
1. Geologicl mapping on 1:5000 scale.	316.3	29.3			345.6
2. Geochemical survey.	298.6	34.9			333.5
3. Radon survey.	236.6	36.6			267.2
4. Helicopter geophysical survey. (radiometric and magnetic)	196.5	24.0			220.5
5. Ground-level follow-up of helicopter survey.	68.5	55.7			124.2
6. Ground-level geophysical survey. (electromagnetic, magnetic and gravimetric).	497.5	137.5			635.0
7. Data analysis.		127.0			127.0
8. Analytical and geophysical equipment.	1307.0				1307.0
Stage B - Location and spacial demarcation of subsurface ore bodies.					
Total		2909.1	1398.4		4307.5
1. Geodetic and field planning.		201.5			201.5
2. Shallow and deep prospection drilling, data processing and ore modelling.		2527.6	1398.4		3826.0
3. Geophysical measurement equipment.		180.0			180.0
Stage C - Estimation of minable reserves in the ore bodies. Total			2589.5	548.7	3138.2
1. Detailed geologic mapping, 1:1500.			182.0	103.2	385.2
2. Cutting holes.			1573.5	105.0	1678.5
3. Coreholes.			834.0	27.5	861.5
4. Evaluation of reserves and mine planning.				313.0	313.0
General - Operations management and logistics.	400.0	** 400.0	*** 400.0	200.0	1400.0
TOTAL****	3321.0	3748.1	4387.0	748.7	12205.7
Cumlative total -		7069.1	11457.0	12205.7	
Manpower (included in budget)					
1. Academics/scientists	7	7	7	6	
2. Technicians	11	11	11	8	

Notes:

* Timetable based on immediately continuous work schedule: Stage A, approximately 18 months during Years I-II; Stage B, approximately 15 months during Years II-III; Stage C, approximately 15 months during Years III-IV.

** $52,000 allocated to Stage A and $348,000 to Stage B.

*** $140,000 allocated to Stage B and $260,000 to Stage C.

**** Stage A, $3,874,700; Stage B, $4,706,500; Stage C, $3,624,500.

the anomalies and the known vein type mineralization, while other independent anomalies could designate other potential sites.

In order to delineate, evaluate and exploit the ore, a complete program has been outlined, including the activities previously described (Table 1). It will be implemented in four stages each to be initiated in the event of positive results of its predecessor. Budget estimates - on an annual basis - are presented in Table 2 .

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THOUGHTS ON FUTURE PROSPECTS FOR URANIUM IN SOUTH AFRICA

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Abstract

This paper reviews the historical production and market trends of uranium and looks at the future prospects for the metal in South Africa. Estimates of future electricity demand based on economic considerations and population growth, lead to the prediction of a sustained growth rate in the region of 5% per annum for the Republic of South Africa. At this growth rate the RSA's known extractable coal reserves will be depleted by the year 2035 necessitating the use of alternative means of generating electricity to sustain the the growth rate. At present nuclear energy is the only proven alternative to coal.

The major portion of the RSA's uranium resources are associated with quartz-pebble conglomerates from which it has been mined as a by-product of gold since 1953. According to reliable estimates, the production of gold will decline to negligible levels by the decade 2030-2040, coinciding with the time of maximum uranium demand for nuclear power generation, using current light water reactor technology. Cognisance is also taken of developments relating to enrichment and breeder technology.

The effect of the current uranium production rate, at levels of 3 800 tU/annum, on the resources (<$130/kg U) available in 2030 will be deleterious but not serious. Approximately 30% of the RSA's current resources in the same cost category, will have been consumed by then. A positive factor will be that a substantial proportion of the Witwatersrand uranium resources will have been mined out for gold, but not treated for uranium. These will be available on surface in tailings dumps, constituting a low cost resource, always bearing in mind a potential loss to back-fill and dilution. Other resources within or outside the Witwatersrand Basin will then have to be mined as a primary product and the cost of extracting this uranium will profoundly affect the cost of electricity. The geological flexibility of the South African uranium deposits to supply market requirements and the degree to which local producers will be able to meet the projected demand is addressed.

The abovementioned scenario is viewed against the background of growing concern about environmental phenomena such as the greenhouse effect, air pollution and acid rain related to electricity generation from coal.

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1 Introduction

As this meeting is one on uranium resources I have to mention something about the RSA's resources, but much rather I would like to tell you what we plan to do with them. Energy scenarios as a means to strategic planning enjoy much attention in the RSA as in any other country, however, predictions are subject to many uncertainties and are so hard to make. In contrast to the first law of geology which states that the present is the key to the past, here the law applies that the past is the key to the future. It has been stated by the French futurist Jouvenel in 1967 that the past is that domain of time of which we know the facts, but which we cannot change and the future is that domain of time of which we have no facts, but which we must shape (to some extent at least).

This paper examines the history of uranium and coal production and their roles in the generation of electricity, and discusses the criteria for a reliable estimate of the future growth in electricity demand. Scenarios for the growth in electricity demand and the way in which it can be met by these resources are presented. Only coal and uranium are considered as source materials for electricity generation. Finally factors which may influence the scenarios are addressed.

2 Electricity Generation in South Africa

In the RSA the major sources for electricity generation are coal, nuclear power, pump storage, hydro power and gas turbines in order of importance. The most significant is coal which contributed 87,6% from 21 stations to the total installed electrical capacity of 31 261 MW in 1987, while one nuclear power station and one pump storage station contributed 6,2% and 3,2% respectively. Two hydro power stations and three gas turbine stations contributed 1,7% and 1,2% respectively.

Coal is the resource with the longest history on which future electricity demand predictions can be based. In 1987 the portion of coal sales for electricity generation amounted to 39% (Fig.1). The coal resources currently available for electricity generation amount to 18 660 million tons and considering a conversion factor of 4 161 tons/MW-year, this represents a thermal equivalent (electrical) of 4 484 500 MW-year or a supply of 112 112 MW for 40 years. The increase of coal consumption for power generation is shown in Figure 2 and the total power station output of electricity, ignoring the small nuclear contribution, matches this trend closely (Figure 3). Although the graphs show an increasing trend the actual percentage growth has been declining since 1973 following the 1973 oil crisis (Fig. 4).

Although South Africa is not dependent upon oil for electricity generation, the effects of the 1973 oil price shock had several secondary influences on the supply of electricity in the RSA.

1 Because Eskom, the national power generating utility, imports a large fraction of its development equipment abroad, higher capital costs per installed MW for new power stations had to be paid to countries abroad, which were subjected to rising production costs and inflation in the wake of the oil crisis;

2. The high inflation rate in the RSA and a lowering in the rand exchange rate towards other currencies as well as increased interest rates resulted in higher financing costs for Eskom's projects;

3. The continued high growth rate in load demand required high capital expenditure in a period during which capital became more expensive;

4. Local high inflation coupled with high wage increases contributed to increased operational costs.

These factors contributed to the fact that the capital costs per installed MW in the decade 1972 to 1982 increased by a factor 3, compared to the same increase over the foregoing 44 years since 1928. This tremendous capital expenditure and its resultant drain on the available capital in the country necessitates the prediction of the electicity demand growth rate as accurately as possible.

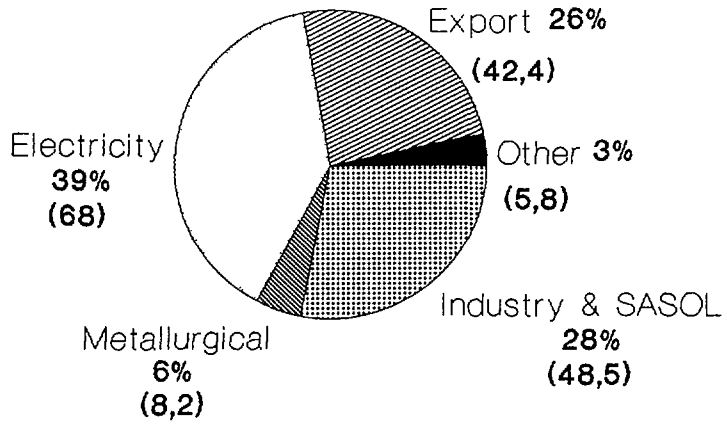

FIG. 1. South African coal sales in 1987 (million tons).

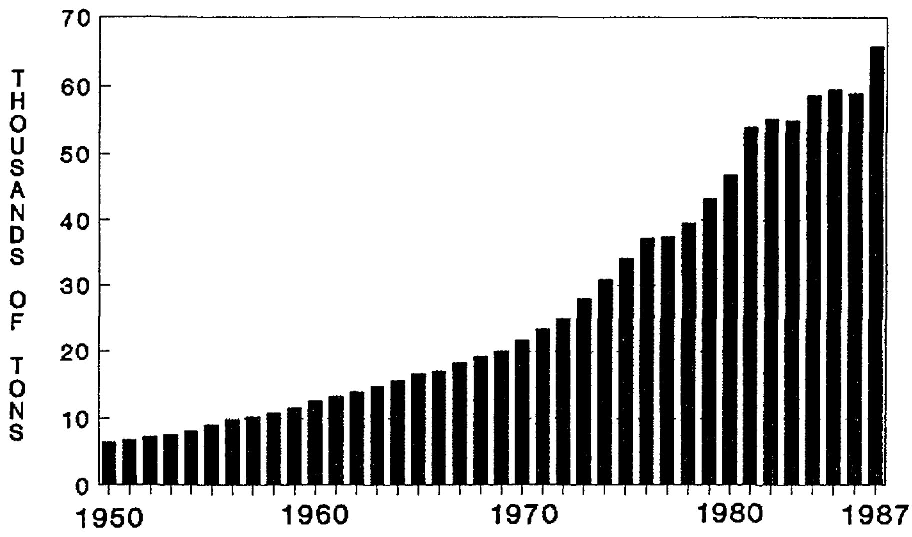

FIG. 2. Coal used for power generation.

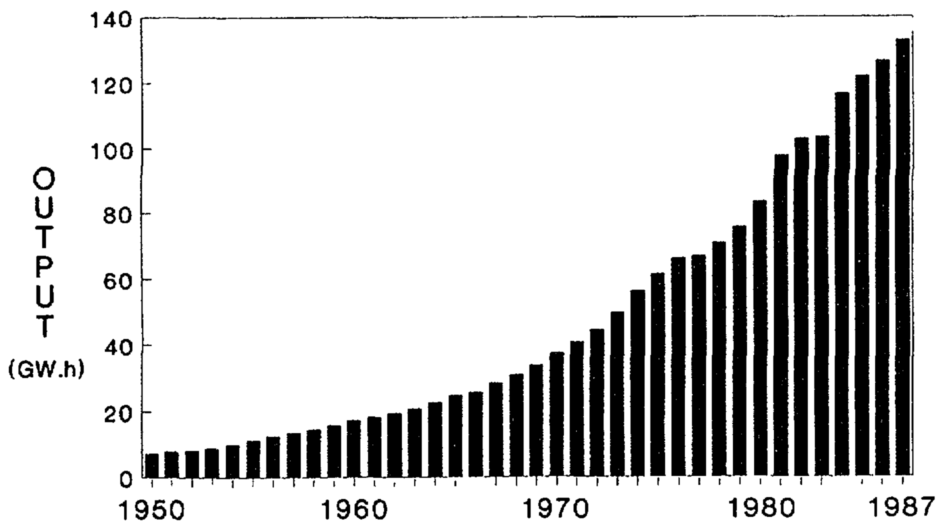

FIG. 3. RSA total power station output.

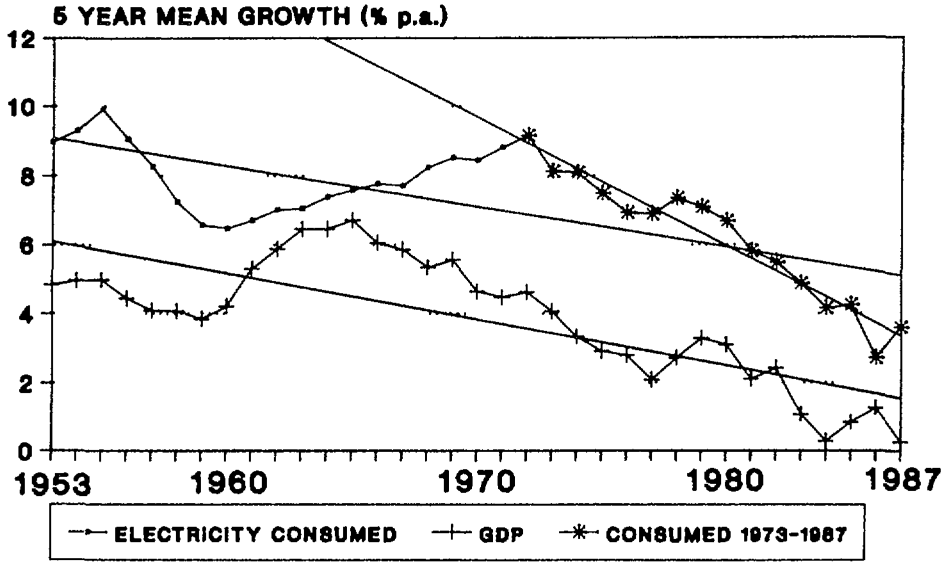

FIG. 4. RSA electricity consumption and real GDP.

The world wide economic recession especially following the 1979 oil price shock obviously also affected the South African economy. One of the consequences was that the Eskom electricity sales growth rate declined in 1982 to 2,4% per annum and in 1983 to 2,2% per annum, the lowest in Eskom's history.

Estimation of future growth rate in electricity demand

So far the factors which influenced past electricity demand have been examined, but what about the future demand. The lead time from the decision to install a new power station to final operation is at least ten years. It is therefore neccesary to accurately predict the demand 10 years ahead and short term fluctuations must therefore be largely ignored.

Prognosis of future electricity consumption relies on econometric methods whereby historical relationships between the growth rate of the economy and the total growth rate of net energy consumption are utilised to estimate future growth rates. It may well be that the availability of electricity at cheap rates will stimulate industrial growth, as the case has been in the seventies, but if tariffs rise to levels comparable to that in other countries, it may be doubtful whether this stimulation will persist. The assumption here is rather that the economic growth rate, coupled with factors such as population growth and an improved standard of living and the increased consumption of electricity over other forms of energy will stimulate the demand more than any other factor.

Consideration of the effects of population growth on electricity consumption can lead to a few qualitative indicators of electricity demand:

> The population growth within the RSA's borders is currently 2,8% p.a. Given the restrictions of water and food supplies, the total South African population could hardly exceed 80 million in the year 2080 and taken the current electricity consumption of 4 MW per annum per capita, this represents an electricity demand growth of 2% on average. Assuming an increase in the standard of living, this consumption could steadily increase to 8 MW per capita per annum by 2080 and an average increase of 5% appears to be very highly probable.

In Figure 4 the trends of five year moving averages of the percentage growth in electricity demand and the gross domestic product (GDP) in South Africa are shown for the period 1950 to 1987. The graphs show that the regression line of the GDP moving average indicates a steady lowering of the GDP over the past 20 years and has not exceeded the figure of 4,5% since 1973, although short term rates have exceeded this level. Although the regression line for electricity demand since 1953 shows a widening tendency with respect to the GDP regression line, the regression line shows a narrowing gap since 1973. During the period 1979 to 1982 the electricity consumption growth rate was on average 3,4% higher than the GDP growth rate. This indicates a growth rate in electricity demand of between 5 and 6% p.a. A determined effort to save electricity could result in this figure decreasing to approximately 5% p.a. The tendency is, however, a decreasing one and this is a factor that will have to be considered in any energy scenario.

An Energy Scenario for South Africa

In Figure 5 the year of installation of the last coal power station is shown as a function of growth rate in coal consumption for various coal resource figures. The most realistic figure of 2/3 of the available coal resources should be used since the current consumption is 40% and with Eskom allowing 50% above the reserve for the life of a power station i.e. (a total of 60%). The graph shows that the last coal power station is to be installed in 2035 at a 5% growth rate and a slightly less pessimistic scenario is evident if the full coal resource is to be utilised. This

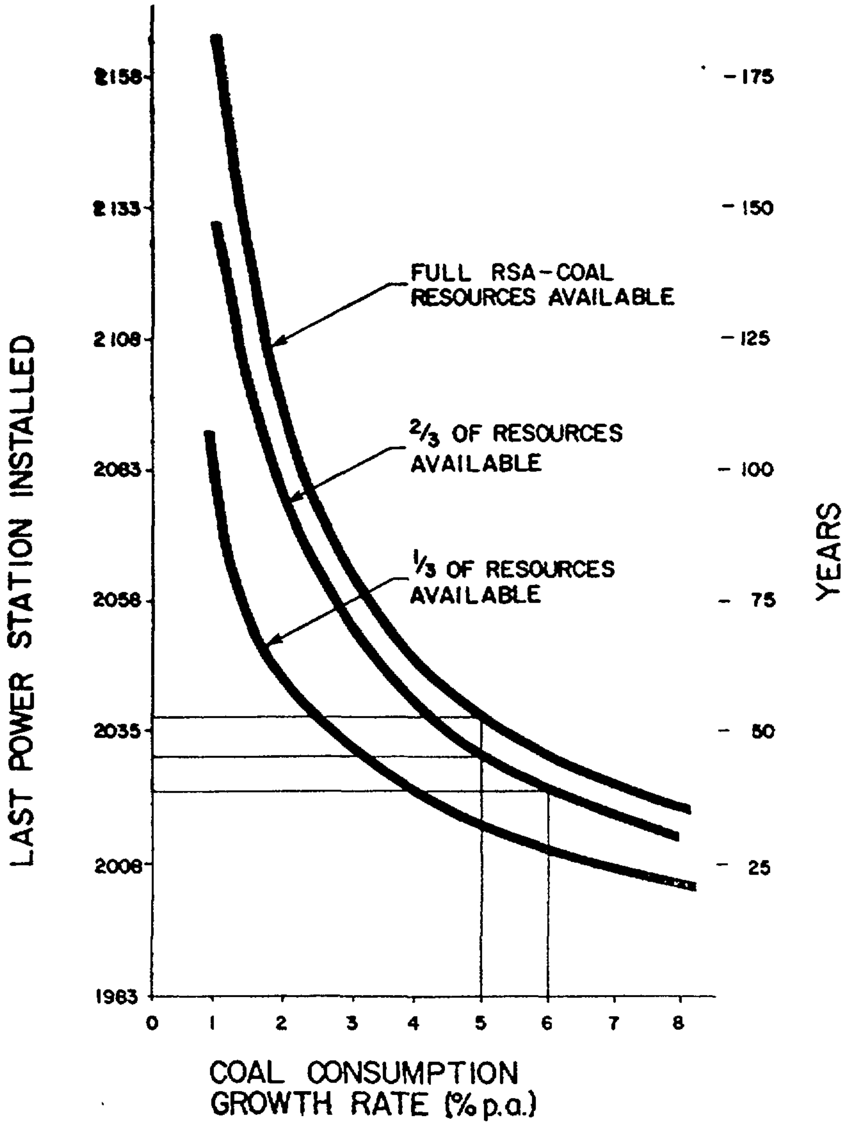

FIG. 5.

necessitates the phasing in of an alternative energy source long before 2030.

The only proven alternative energy source available in the RSA is nuclear power. The current RSA uranium resources in the cost category <\$130/kg U are 536 600 tons U from sources as shown in Figure 6. The thermal equivalent of this uranium when used in LWR's such as Koeberg, is approximately equal to 7 650 Mt of coal which would not make a considerable impact on the coal resources shown in Figure 5. However, in breeder reactors these uranium resources could be the thermal equivalent of 900 000 Mt of coal in which instance energy supply problems will probably not arise for centuries to come.

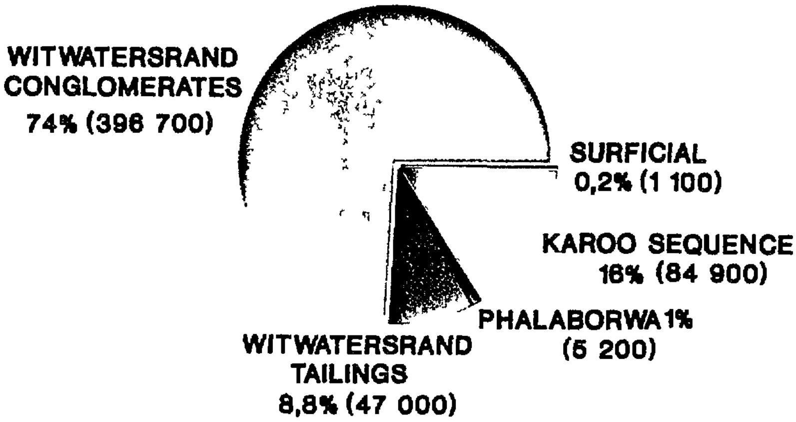

FIG 6. RSA uranium resources, January 1987 (metric tons U)

Considering then some of the abovementioned criteria for future energy growth, an energy scenario can be formulated for South Africa. The assumptions adopted for the scenario are as follows:

An energy growth rate of 6% for 1988 is assumed and the rate for 1989 is 5% which decreases linearly to 1% in the year 2050, from which date on it will remain 1%.

Nuclear power stations will be phased in in units of 2*921 MW acording to the LWR concept with a once through fuel cycle.

The total South African uranium resources are 536 600 tU as at 1 January 1988. The current South African uranium production is in the order of 3 800 tU per annum of which the major portion is exported. The effect of this may be deleterious on the uranium resources available for power generation, but probably not serious, because the uranium industry will promptly respond to a growing demand, should this arise. For the first scenario a decrease of 20% of the uranium resources, due to exports, will be assumed and for the second scenario the total present resources will be available for nuclear power generation.

Coal power stations will be phased in in units of 6*850 MW (5100 MW).

The total current coal resource for power generation is assumed to be 18 660 Mt.

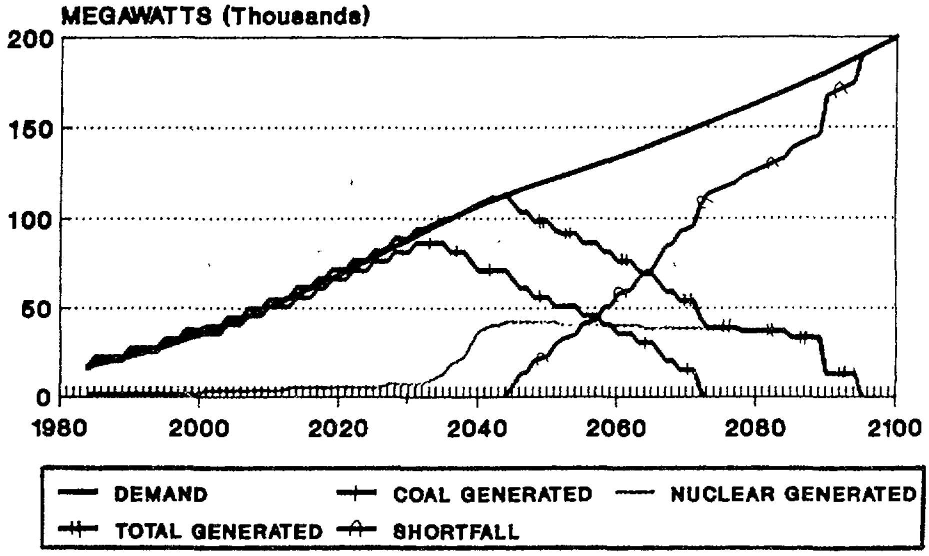

FIG. 7. Projected energy supply and demand in South Africa (1984–2100).

Considering the first scenario in Figure 7, the last coal power station will be installed into the network by 2032 and the last PWR by 2044, from which point onwards alternative energy sources wil have to be provided at a considerable rate. Even in a more optimistic scenario (Fig. 8), where it is assumed that the total uranium resources are available for power generation, this date is postponed by only 20 years. However, a fast initial phasing in of PWR's as in the first scenario will require a vast capital layout, which in the present economic climate is hardly conceivable.

Whichever scenario is chosen, the focus of interest is the decade 2030 to 2040, during which the local demand for uranium will increase dramatically. This period of maximum demand coincides with the time during which the gold production from South African mines reaches negligible levels according to a scenario put forward by the celebrated geostatistician Prof D Krige (Fig. 9).

This means that the uranium associated with gold reefs in the Witwatersrand will have been mined out, but not necessarily recovered. In addition 17% of current resources, constituting 91 200 tU, are located outside the Witwatersrand Basin. The cost of recovering this uranium will therefore have a profound influence on the cost of electricity. Many reefs exist where the uranium content is high, but gold grades are currently uneconomic to exploit. Mining of these reefs primarily for their uranium content and with gold as a by-product could therefore

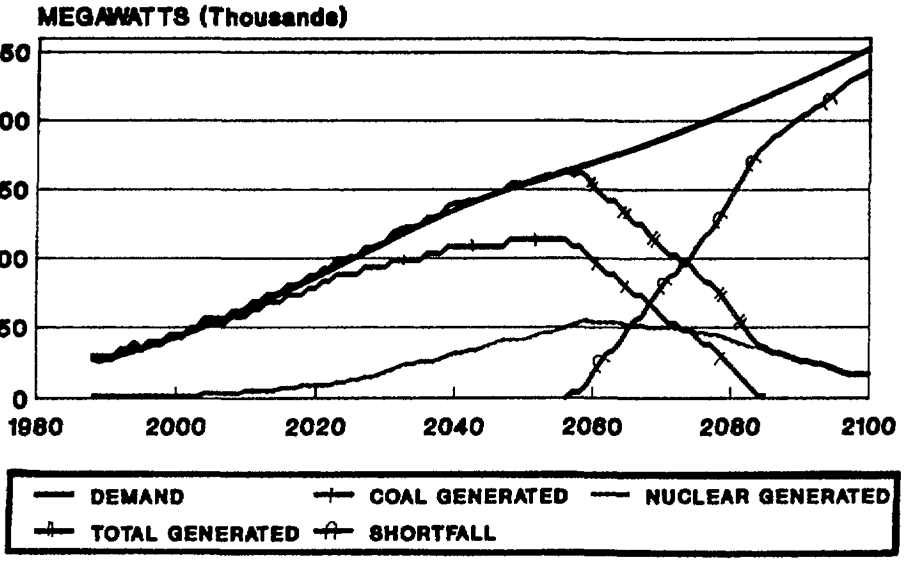

FIG. 8. Projected energy supply and demand in South Africa (1988–2100).

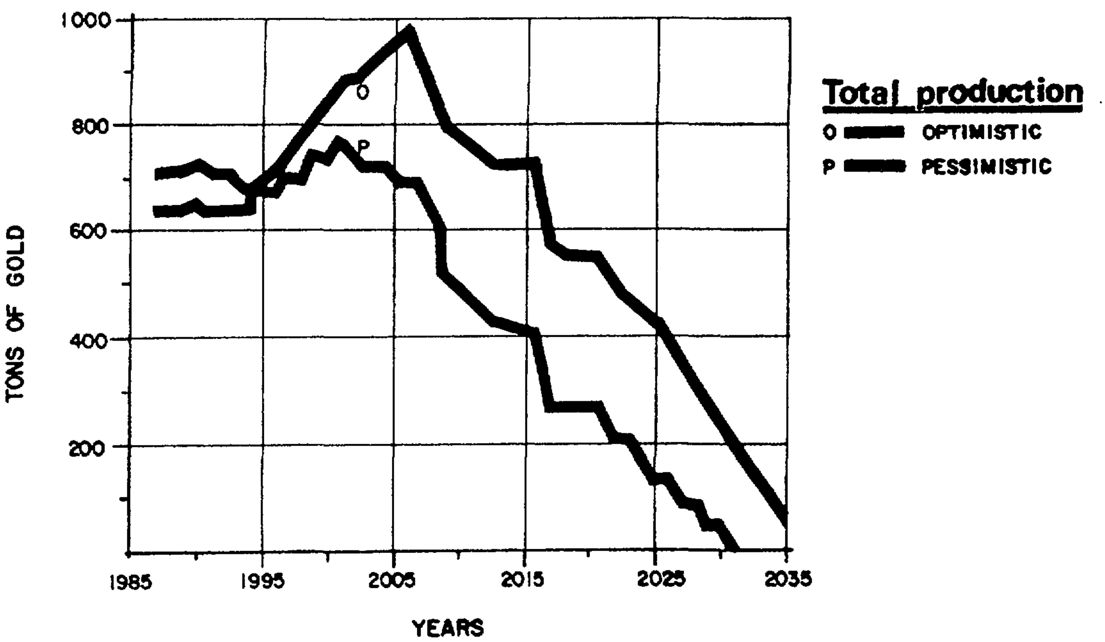

FIG. 9. Forecast of future RSA gold production.

increase the life of many mines e.g. Beisa in the Orange Free State Goldfields.

Will South African uranium producers be able to respond to the predicted demand? The answer is clear if the history of uranium production in the RSA is considered (Fig. 10). The South African mining industry responded promptly when called in 1945 by Field Marshall J C Smuts, then Prime Minister, to assist in acquiring uranium for the "Manhattan Project" as

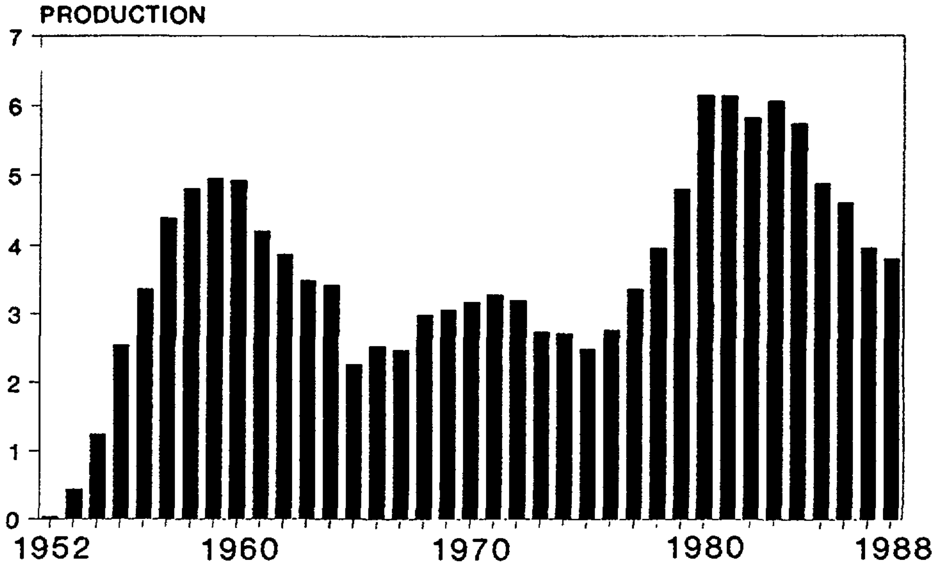

FIG. 10. RSA historical uranium production (metric tons U x 1000).

it was called. The mining industry moved quickly to erect uranium plants and in October 1952 the first uranium plant was opened at West Rand Consolidated Mines. By March 1955 sixteen mines had been authorised to produce uranium. By 1980 the uranium production of South Africa, reached a peak of 6 143 tU. The subsequent history of uranium production followed global trends and the major events which affected the world uranium market were also playing its role in the South African uranium market. The years since 1980 have seen a marked decline in uranium production which could be mainly ascribed to economic factors which are operating world wide, and is not a phenomenon unique to the political situation in the RSA.

Because most of South Africa's uranium is produced as a by-product from the Witwatersrand gold mines (Fig. 11) and a small portion as a by-product of copper at the Phalaborwa mine, the level of production is not entirely dependent upon uranium market forces as is the case for primary uranium producers. This, coupled with the fact that the major portion of production is committed to long-term contracts, leaves the South African uranium industry relatively free from short-term fluctuations in the uranium market.

Factors Influencing the Energy Scenario

There are several factors which could influence the scenarios pictured above:

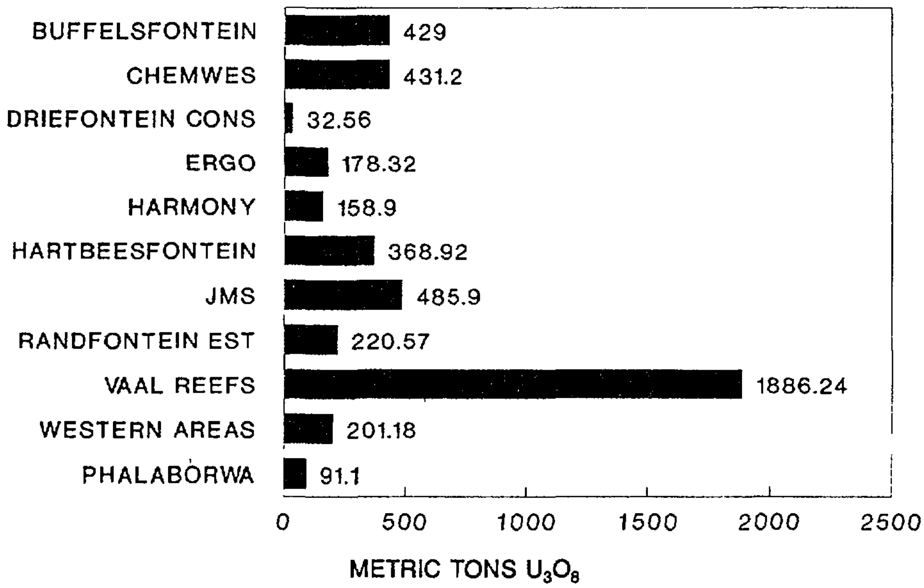

FIG. 11. South African uranium producers (1988).

Costs: Nuclear versus Coal

The cost of electricity from nuclear power, compared to electricity from coal, plus transmission costs, will be the deciding factor in the utilisation of our uranium for power generation. For the short term (<15 years) a coal power station in South Africa has a decided cost advantage over a nuclear power station, contrary to the situation in France, where the unit cost of electricity from a nuclear power station is considerably cheaper than the unit cost of electricity generated by coal, even at a load factor as low as 45,6%. However, if total costs over the life time of a station are considered, the point at which the unit cost of electricity of a nuclear power station at the coast in South Africa is cheaper than its coal counterpart, is already reached after 15 years, if upgrading is neglected, and after 20 years with upgrading. It is expected that scrubbing in a coal station, to decrease pollution, will add 30% to the capital cost, in which case this crossing point could be brought forward by another five years.

Environmental Concerns

Environmental concerns in South Africa as elsewhere in the world are playing an increasing role.

The Eastern Transvaal Highveld where 80% of the country's power is generated in an area of 30 000 square kilometres, is the area where more pollutants are liberated than in any other area in the world of comparable surface area. During 1984 these stations pumped 313 946 tons of solid particles into the air comprising 84% of all solid releases into the air. Power stations in addition released 90% or 937 492 tons of sulphur dioxide, nitrogen oxide and carbon-dioxide in the area. As an intermediate solution the use of 275 m stacks were implemented to release the pollutants to higher altitudes with higher wind speed to disperse the pollution to areas above the inversion level, which tends to trap the pollution to the land surface. In the late seventies, however, the implementation of scrubbers in the stacks were required by legislation for new stations. The fitting of scrubbers to decrease SO_2 exhaust could increase the capital cost of coal power stations by up to 30%. The high cost of fitting scrubbers, coupled with the scarcity of water in the interior, led to the decision by Eskom to build an air-cooled coal power station, Lethabo, near Ellisras in the north western Transvaal.

In the RSA the availability of cooling water in the interior will become a serious consideration in the location of coal power stations.

This is viewed against the shortage of suitable sites for the location of nuclear power stations at the coast, which presumably will be the only suitable location, where sufficient cooling water is available (Fig. 12).

Transmission costs due to the long distances involved in transmitting electricity from the interior to the coast may contribute considerably to the unit operating cost of electricity.

The debate over the greenhouse effect is continuing and the effect of this phenomenon remains an undetermined factor. Recent findings by the Biosphere group indicates that the amount of CO_2 in the ocean remains as yet an unknown variable in the greenhouse equation.

Solutions

A promising process based on coal gassification is in a stage of development in the RSA, which converts coal to gas, which can drive gas turbines for electricity generation. The waste heat of the turbines will heat water to steam driving steam turbines for electricity generation. The technology is by no means new and has not been proven on a commercial scale. The process is believed to efffect a 15% lower coal

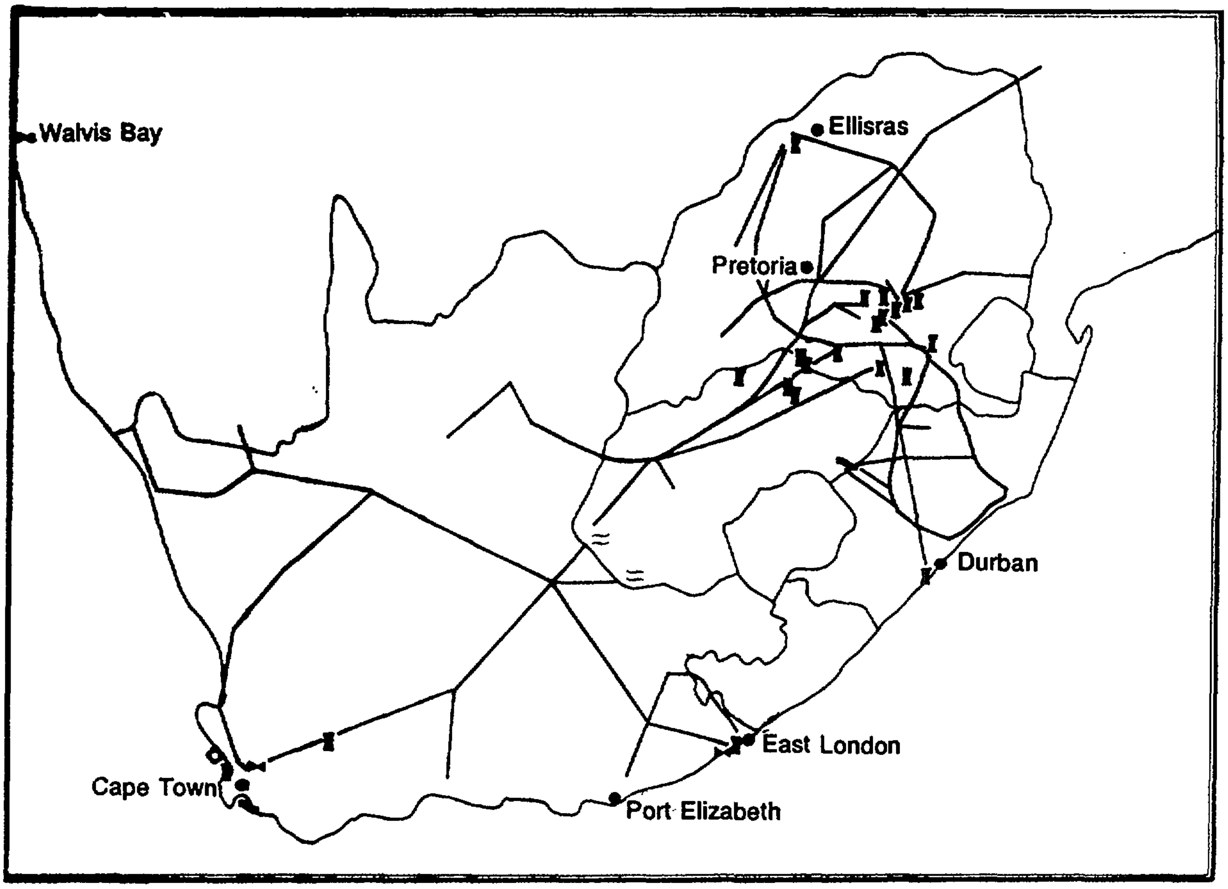

FIG. 12.

consumption, release lower sulphur levels, and consume less oxygen for combustion. In addition it will use less cooling water and will use coal which is currently unsuitable for burning.

Before committment to a large scale nuclear programme, the possibility to purchase from African neighbouring states will require attention. Hydroelectric power from the Cabora Bassa Scheme in Mozambique, the Lesotho Highlands Water Project, the Zaïre- and Zambezi rivers in Zaïre and Zimbabwe respectively are among the options which could be considered.

It was announced in parliament earlier this year, although somewhat obscured by the political scene at the time, that the RSA has developed the ability to manufacture fuel elements for its Koeberg Nuclear Power Station. However, this event places the RSA in the group of 15 countries with that ability and will make South Africa independent with respect to nuclear fuel. The draw back of the plant is that it is approximately one fiftieth of the size required to benefit from the economy of scale and production to supply in the current Koeberg fuel needs utilises only 60% of its design capacity.

Cold fusion from seawater is regarded with scepticism in scientific circles, and even hot fusion as a means of electricity generation appears to be a remote proposition.

Solar and wind power could be viable substitutes for coal and nuclear power, but the scales required to meet the national needs are also at present inconceivable.

URANIUM EXPLORATION AND RESOURCES IN CHINA

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Abstract

Since 1955 China has made tremendous efforts to explore its vast territory, which hosts a large variety of geological environments. About 30% of its land surface have been covered by ground radiometrics and nearly 20% have been surveyed by airborne methods.

Within the period 1955 to the present, there have been a number of changes in uranium exploration methodology. Each period characterised by a certain approach, has resulted in the discovery of uranium deposits.

The uranium resources in China show a distinct space-time relationship. Most deposits are located in the eastern and southern parts of China, where a Mesozoic age of the deposits predominates. The deposits discovered so far, belong to four genetic types (granite hosted, volcanic, sandstone, carbonaceous-siliceous-pelitic). Typical deposits belonging to these four types are described. They contain about 51 000 t U of defined reserves, approximately equivalent to the sum of RAR and EAR-I without any cost category. In addition, Speculative Resources are estimated at 1.77 million t U. Future discoveries are expected in other parts of China in a number of environments.

Uranium exploration in China commenced in 1955 under the direction of the Bureau of Geology of the then Ministry of Nuclear Industry (now the China National Nuclear Corporation). All necessary funds are provided by the Government. The Bureau of Geology maintains a countrywide infrastructure including six regional branches supervising over 50 geological teams. The total staff amounts to more than 50 000. Seven research institutes, eight equipment factories, a college of geology, seven geology and technical schools, as well as an airborne remote sensing centre provide services and support.

Since 1955, nearly 3 000 000 km^2 equalling 31% of the total Chinese territory have been covered by surface gamma-ray surveys and 1 834 000 km^2 have been surveyed by airborne methods. Total drilling, including some tunnelling, amounts to 25 765 km.

The uranium exploration activities can be divided into three periods, from the mid-1950s to the mid-1960s, from the mid-1960s to the mid-1970s and from the mid-1970s to the present time.

From mid-1950 through the mid-1960s, the main objective was the discovery of outcropping uranium deposits. As a result of this phase some sandstone type deposits including Daladi and Mengqiguer, were discovered in Jurassic coal bearing strata in the Jlli intramontane basin (Xinjiang Autonomous Region) in 1955. Subsequent discoveries in 1956 included the sandstone deposit Pukuitang of Cretaceous-Tertiary age, near Hengyang (Hunan Province), as well as the deposit of Baiyanghe (Xinjiang Autonomous Region) in upper Paleozoic volcanics. In 1957, the Xiwang deposit, the first discovery in granitic rocks, was found in a silicified fracture zone in the Guidong granite massif. In the same year, the Xiangshan district was found in a volcanic environment.

In the second period, from the mid-1960 to the mid-1970s, a combination of metallogenetic research and geological field work was applied both in areas with known mineralization and in unexplored regions. Exploration in this second period lead to a number of discoveries including:

- the Chanziping deposit (Guangxi Autonomous Region) in carbonaceous-siliceous-pelitic rocks,
- the Quinlong deposit (Hebei Province) in sandstone,
- the Jianchang deposit (Liaoning Province) in sandstone,
- additional new deposits in siliceous limestone of Silurian age in northwestern China,
- deposits in volcanic and granitic environments in southeastern China (Jiangxi and Guangdong Provinces), which made this part of the country an important uranium district, and
- several deposits in coal and sandstone conglomerates of late Tertiary age in western Yunnan Province.

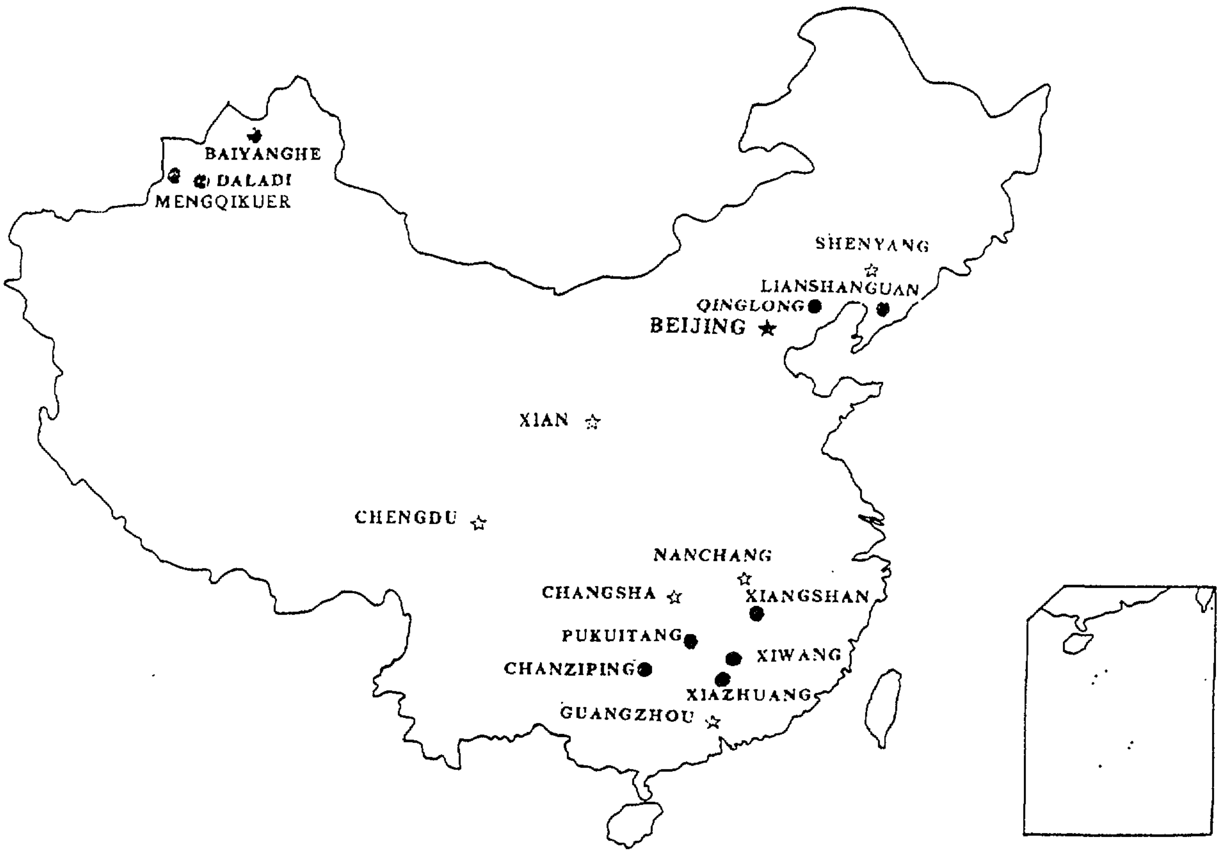
From the mid-1970s through the present, modern exploration methods, including soil gas surveys, small diameter diamond drilling, estimation of undiscovered resources as well as computerized geological data integration techniques have been used. Exploration efforts concentrated on new prospective areas and new deposit models in the North China platform and resulted in the discovery of additional resources in volcanic and sandstone deposit types in the Yanliao metallogenetic belt. The definition of a potential to discover new deposits in northeastern China was also a consequence of these efforts. In addition, significant success was achieved in the search for new deposits in known districts in southern China.

Plans have been made to continue and intensify uranium exploration in China with the primary objective of locating world class deposits which should become the future source of uranium both for export and domestic requirements.

URANIUM RESOURCES

Uranium resources in China show distinct features as regards space-time relationship. The most significant characteristics are as follows:

1. Known uranium deposits are geographically widely distributed, but show regional differences. Although there are known uranium deposits in most provinces and/or autonomous regions, the bulk of the resources is concentrated in the central and eastern parts of the country.



Principal uranium deposits in China

2. The age of the known uranium mineralization is relatively young. Uranium occurs in all stratigraphic ages except the Ordovician. The majority of uranium deposits were formed in upper Mesozoic; some are Tertiary in age.

3. Uranium deposits tend to occur in clusters. A district can host more than ten deposits. Typical ore grades vary from 0.1 to 0.5% U.

4. The majority of uranium deposits belong to the four deposit types, hosting the indicated percentage of known Chinese uranium resources:

Granite hosted	41%
Volcanic hosted	20%
Sandstone hosted	21%
Carbonaceous-siliceous-pelitic rock hosted	13%.

In addition, it is estimated that the remaining 5% of the resources is distributed among the following deposit types; uraniferous coals, carbonate hosted, quartzite hosted, alkaline rock hosted, phosphorites and pegmatitic granite hosted.

Typical deposits of the four major types are described as follows:

The Xiazhuang district occurs in the Guidong granitic massif of the Yanshan period (isotopic age 142.3 - 183.3 Ma). The uranium mineralization is controlled by the intersection of silicified fracture zones and lamprophyre dikes and has been dated as 59.5 - 86 Ma. There are two mineralogical associations: pitchblende-albite-hematite and pitchblende-microquartz.

The Xiangshan district is located in the Ganhang volcanic hosted metallogenetic belt at the contact between the southern China Caledonian fold belt and the Yangzi paraplatform. The volcanic sequence is of upper Jurassic age and overlies low grade metamorphics of Sinian age, as well as a sedimentary sequence of lower upper Jurassic. Uranium mineralization occurs in a collapse-type volcanic caldera and, more specifically, in a major shear fault zone. The host rocks include subvolcanic granite-porphyry, rhyolites and dacites and are affected by hematitization, hydromicazation, chloritization, fluoritization, etc. The uranium minerals are pitchblende, coffinite, uranothorite and brannerite.

The Quinlong uranium district is located in a small down faulted basin between the Shanhaiguan paleo uplift and the Yanliao graben. The basement of the basin is composed mainly of early Proterozoic granites and Archean gneisses. The basin fill is made up of continental clastic sediments, volcanoclastic sediments as well as lavas of middle Jurassic age. The uranium mineralization is located in the basal granite derived conglomerate and in carbonaceous tuffaceous sandstone conglomerates and is associated with pyrite and organic matter. Its age ranges between 76 - 134 Ma.

The Chanziping deposit, hosted in carbonaceous-siliceous-pelitic rocks, is located in a Caledonian syncline between two granitic massifs. The ore bearing horizon is underlain by Sinian sediments (sandstone, dolomite, siliceous mudstone) and overlain by Cretaceous red beds (sandstone, conglomerates). The mineralized strata are of lower Cambrian age and include carbonaceous mudstone (with 46% of the uranium resources), siliceous mudstone (with 24%), spotted slate (with 19%) and argillaceous slate (with 11% of the uranium resources).

URANIUM RESOURCES - AS OF 1ST JANUARY 1989
(Tonnes U)[1)]

Principal deposits or districts [2)]	Defined reserves[3)]
Xiazhuang district	12 000
Xiangshan district	26 000
Qinlong district	8 000
Chanziping deposit	5 000

1 No information on recoverability is available
2 Typical examples for different deposit types
3 Approximately equivalent to the sum of RAR and EAR-I; unassigned cost category.

In addition to the resources listed above, there is good potential for the discovery of further resources. An estimation of undiscovered uranium resources made in 1987 with the crustal abundance model resulted in the quantification of 1.77 million t U as Speculative Resources, of which 1 million t U are concentrated in the western part of China.

On the basis of the exploration experience in China and abroad, the strategies of future exploration will be to search for new deposits of the types known in China and to intensify the exploration for those types not yet found in China, such as the unconformity related , the Cu-U breccia complex deposit and the surficial deposit types.

In addition it is expected that new resources will be discovered in granitic, volcanic and carbonaceous-siliceous-pelitic environments in southeastern China. Prospective areas are the Taoshan-Zhuguan metallogenic belt, with granitic rocks of Indo-China to Yanshan rocks, the Ganhang and Wyuishan belts of late Jurassic to Cretacous age, as well as the Xuefengshan belt and the South Guangxi area underlain by Sinian-Cambrian mudstones.

In northern and northeastern China, prospective areas are those covered by Proterozoic and Mesozoic-Cenozoic basins. Targets are environments similar to those of the Lianshanguan deposit which occurs above the unconformity between the migmatic granitic basement and the lower Proterozoic as they are found along the northern margin of the North China platform.

In addition, the Henan and Shanxi provinces located at the southern rim of the platform are considered to have potential for unconformity related and Cu-U breccia complex deposit types. Mesozoic-Cenozoic basins in northern and northeastern China are areas with favourable prospects. In recent years a number of new deposits have been found in Jurassic basins in the Yanliao belt, which is becoming a new district. Also new and unique sandstone deposits have been discovered in similar basins in Inner Mongolia.

Western China's potential is based on the presence of Mesozoic-Cenozoic sedimentary basins, covering nearly 50% of the outcropping rocks. Apart from the early discoveries of the Daladi and Mengqiguer deposits, there is a potential for additional sandstone type deposits in Tianshan, Longshonshan. northern Qinling and western Yunnan. Further potential exist in the Ordos, Tarim, Junggar and Erlian basins, etc. The Kandian nucleus in southwestern China is considered a potential host for unconformity-related and Cu-U breccia complex deposit types.

NATIONAL POLICIES

China is willing to enhance co-operation with foreign parties in uranium exploration, on the basis of equality and mutual benefit.

Recent technical co-operation agreements have been concluded with some Asian countries. These agreements provided for technical services by Chinese uranium specialists.

The Bureau of Geology of the China National Nuclear Corporation is willing to strengthen continually technical co-operation with all countries in the field of uranium raw materials. This co-operation could also include the supply of instruments, equipment and services.

LONG TERM URANIUM SUPPLY FOR KEPCO

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Abstract

The industrial development of the Republic of Korea lead to strong growth in energy demand. To decrease the dependence on imported oil supplies, the Korea Electric Power Corporation (KEPCO) invested in nuclear power plants, thermal power plants fired with coal and LNG as well as hydroelectric plants. Subsequently, the electrical, generating capacity by coal-fired power plants, has decreased from 72% in 1975 to 24% in 1988. In the same year, the share of the nuclear generating capacity reached 33.4%.

The nuclear power programme in the Republic of Korea started in 1978, when the first nuclear power plant, KORI Unit 1, a 587 MW(e)-PWR went into commercial operation. In April 1989, there were a total of eight nuclear power plants with a continued capacity of 6666 MW(e) in operation. One additional plant with 550 MW(e) capacity is nearing completion. Two further NPP are in earlier stages of construction. It is planned that by 1996, these two reactors will be completed and that the total nuclear electricity generating capacity will reach 9616 MW(e) supplying about 47% of the total electricity of the country. Through the end of the century two more NPP with 1000 MW(e) are planned.

The uranium requirements for the nuclear programme of the Republic of Korea will increase from over 1220 t U in 1989 to about 2150 t in 2005. As there are no indigenous mineable uranium resources in the country, supplies have to be secured from outside sources, both through short and long term purchase contracts and through investments in uranium projects. At present, there are about 50% of the requirements through 2000 covered by long term contracts, while the remainder is planned to be secured from production centres at which KEPCO holds equities as in Dawn Lake, Cigar Lane and Crow Butte, and through spot market purchases.

THE ENERGY SITUATION IN THE REPUBLIC OF KOREA

Agriculture was the mainstay of the country's economy in the 1950's when firewood was the principal energy source. With the commencement of the five year Economic Development Plan at the beginning of the 1960's, the demand for energy and mineral resources in the industrial sector increased on a large scale. As the Republic of Korea is poorly endowed with mineral resources, the dependence on energy supply from overseas sources has grown intensified, increasing the vulnerability of the economy to external shocks.

Consequently, The Government was implementing an energy conservation policy, which included the reduction of the oil consumption, when the first oil crisis broke out. With these domestic efforts, together with huge Middle East construction and export booms, the Republic of Korea managed to overcome the first oil crisis without too many problems. It was not until the second oil crisis that the Government initiated the general substantive energy policy. The second oil shock left the country's economy with many difficulties, such as the drop of GNP, price hike and imbalance of international payment. During this period, the main purpose of the energy policy centred around the assurance of a stable supply of crude oil with emphasis on the effective absorption of the oil shock on the national economy.

As the economy was recovering from the negative growth in 1980 and oil prices stabilized with the year 1982 as a turning point, the energy policy was implemented on a firm basis with an adequate assessment of the world energy situation. Energy conservation was recognized as a supreme target in every policy task. At the same time, the expansion of bituminous coal and LNG use in both the industrial sector and residential areas were encouraged. With a view to securing a stable supply source, investments have been made in overseas resources development, particularly as regards crude oil, coal and uranium.

ENERGY DEMAND PROJECTIONS

The economy of the Republic of Korea is projected to expand at an average annual rate of 7.3% during the sixth, Five Year Economic Plan (1987-1991). Despite continous energy conservation efforts, based on this projection, energy demand will increase steadily from 61.1 million TOE in 1986 to 79.1 million TOE in 1991. Accordingly, the dependence on overseas energy resources will also increase to 82.6% by 1991. In the meantime, high quality energy sources such as LNG and electricity will be the preferred options as the level of living standards is increasing.

ELECTRICITY DEMAND PROSPECT

As the national economy shows a continuing robust growth, a steady increase in the electricity demand of 10.3% per year through 1991 is projected as a short term estimate, and thereafter an annual growth rate of 5-6% is expected.

TABLE 1 POWER GENERATION BY SOURCES

UNIT: GWh

YEAR	1986	1988	1991	1996	2001
HYDRO	4,019	3,070	3,598	3,686	3,686
FOSSIL	32,625	37,941	69,733	69,733	90,820
NUCLEAR	28,311	40,302	65,142	65,142	83,894
TOTAL	64,695	81,313	138,561	138,561	178,400

LONG-TERM POWER DEVELOPMENT PLAN OF THE KOREAN ELECTRIC POWER CORPORATION (KEPCO)

As a result of the continuing effort to develop non-oil power plants since the oil shock of the 1970's, the ratio of oil-fired plants to other types of plants has dropped from 72% in 1975 to 24% in 1988, whereas the ratio of nuclear power and coal-fired plants have increased to 33.4% and 13.5% respectively.

KEPCO is pursuing a diversity in power generation resources by developing more nuclear and coal-fired plants together with LNG plants and pumped storage facilities.

The total generation capabilities at the end of 2001 will be 35,725 MW(e) with a composition of 34.5% nuclear power [12,316 MW(e)], 35% coal-fired [12,520MW(e)], 10.2% LNG [3,650 MW(e)], and 10.1% hydro power [3,599 MW(e)].

NUCLEAR POWER PROGRAMME

Since Kori Nuclear Unit 1, the first nuclear power plant in the Republic of Korea, went into commercial operation in April 1978, nuclear units with the combined capacity of 6,666 MW(e) have occupied 33.4% of the total installed power capacity as of the end of 1988.

TABLE 2 INSTALLED CAPACITY RATIO BY POWER SOURCES OF KEPCO

UNIT : MWe Gross

PERIOD / ITEM	EXISTING IN '88		6TH PERIOD ('87 ~'91)		7TH PERIOD ('92 ~'96)		8TH PERIOD ('97 ~ 2001)	
	INSTALL-ED CAPA.	%	ACCUMUL-ATED CAPA.	%	ACCUMUL-ATED CAPA.	%	ACCUMUL-ATED CAPA.	%
HYDRO	1,236	6.2	1,499	7.1	1,499	5.3	1,499	4.2
PUMPED-STOR.	1,000	5.0	1,000	4.7	1,600	5.7	2,100	5.9
SUB-TOTAL	2,236	11.2	2,499	11.8	3,099	11.0	3,599	10.1
COAL-FIRED	3,700	18.6	3,700	17.5	8,105	28.9	12,520	35.0
OIL-FIRED	4,792	24.0	4,795	22.6	4,186	14.9	3,640	10.2
GAS-FIRED	2,550	12.8	2,550	12.1	3,100	11.0	3,650	10.2
SUB-TOTAL	11,042	55.4	11,045	52.2	15,391	54.8	19,810	55.4
NUCLEAR	6,666	33.4	7,616	36.0	9,616	34.2	12,316	34.5
TOTAL	19,944	100	21,160	100	28,106	100	35,725	100

Nuclear power generation in 1988 was 40,101 GW.h or 46.9% of the total power generation and played a leading role in the production of electricity in the country. The average capacity factor of the eight nuclear units has been maintained at over 73% consecutively for five years since 1984.

The number of forced outages has also been significantly reduced (1.6 times per reactor in 1988), contributing to the stable supply of electricity. For the first time in the nuclear history of the Republic of Korea, Kori Nuclear Unit 3 made a record of one complete cycle of continuous operation (304 days) from October 1988 without a plant trip. In the same month, Kori Nuclear Unit 2 marked the longest continuous operation of 327 days with its 15 months fuel cycle in the country.

Even though increased and radical anti-nuclear movements exist in the Repulic of Korea, it is believed that nuclear energy is one of the

TABLE 3 NUCLEAR POWER PLANTS OF KEPCO

UNIT		CAPACITY (MWe,GROSS)	TYPE	COD	REMARKS
KORI	UNIT 1	587	PWR	'78.4	TURNKEY
	UNIT 2	650	PWR	'83.7	"
	UNIT 3	950	PWR	'85.9	NON-TURNKE
	UNIT 4	950	PWR	'86.4	"
WOLSONG	UNIT 1	678.7	PHWR	'83.4	TURNKEY
	UNIT 2	678.7		'97.6	PLANNING
YONGGWANG	UNIT 1	950	PWR	'86.8	NON-TURNKEY
	UNIT 2	950	PWR	'87.6	"
	UNIT 3	1,000	PWR	'95.3	"
	UNIT 4	1,000	PWR	'96.3	"
ULJIN	UNIT 1	950	PWR	'88.9	"
	UNIT 2	950	PWR	'89.9	"
	UNIT 3	1,000	PWR	'98.6	planning
	UNIT 4	1,000	PWR	'99.6	"

most reliable alternate energy resources, and that nuclear power must be continuously promoted to support the growth of the national economy. Furthermore, if nuclear fuel cycle technology is localized, nuclear energy will make the country self-reliant in energy resources.

NUCLEAR POWER PLANTS AND CONSTRUCTION SCHEDULE

The nuclear programme in the Republic of Korea was initiated in the early 1960's and the construction of the first nuclear power plant, Kori Unit 1 commenced in 1970 and went into commercial operation in 1978. Since 1987 the proportion of nuclear power generation in the total electricity generation has been over 50%.

Eight nuclear power plants are in commercial operation and one is near completion stage. Two more reactors are under design and three are in the planning stage. As shown in Table 3, Kori Units 1,2,3,4 and Yonggwang Units 1 & 2 are PWR with their NSSS supplied by Westinghouse. Uljin Units 1 & 2 and Yonggwang Unit 3 & 4 are also PWR, whose NSSS vendors were Framatom and Combustion Engineering, respectively. Wolsong 1, whose NSSS was supplied by AECL, is a CANDU PHWR.

TABLE 4 YEARLY INSTALLED CAPACITY TO URANIUM REQUIREMENTS

YEAR	INSTALLED CAPACITY (GWe)	REACTOR RELATED REQUIREMENTS (TONNES U308)
1989	7.6	1,227
1990	7.6	1,262
1991	7.6	1,498
1992	7.6	1,733
1993	7.6	1,910
1994	7.6	1,674
1995	8.6	2,216
2000	12.3	2,146
2005	12.3	2,146

The total installed capacity of nuclear power plants will be 7,616 Mw(e) (gross) in 1991 and 9,616 Mw(e) (gross) in 1996, representing 36% and 34.2% of the national installed capacity (Table 2). However, actual power generation by nuclear sources will be about half the total power generation by the turn of this century.

Uljin Nuclear Unit 1, a 950 Mw(e) class PWR declared its commercial operation on September 10, 1988 as the eighth nuclear power plant in the country while Uljin Nuclear 2, with the same capacity, finished fuel loading on January 5, 1989 for commercial operation in September 1989. Both units were supplied by French companies.

Site excavation work for both Yonggwang Nuclear Units 3 & 4 began in May 1987 by domestic main contractors, and construction is due to be completed in March 1995. A high level of domestic construction technology will be obtained through the construction of these two units.

By 1996, the end of the 7th Power Resources Development Plan the nuclear capacity will be increased to 9,616 MW, occupying 34.2% of the total power capacity and the annual nuclear power generation will be 65,142 GW.h, representing 47% of the total electricity production.

NUCLEAR FUEL AND IN-CORE MANAGEMENT

The amount of natural uranium required up to the early 1990's has been secured by long-term contracts. Considering economy and security, KEPCO also participates in the uranium mine development projects in Canada and U.S.A. Long-term contracts are made with the U.S. DOE and the French COGEMA for uranium enrichment services.

A PWR fuel fabrication plant, with an annual capacity of 200 MTU per annum has been in commercial operation since October 1988 and a conversion facility is in the final construction stage scheduled for commercial operation in January 1990. In order to increase the plant capacity factor, in 1987 Kori Nuclear Unit 2 has adopted a 15 month cycle operation rather than the conventional 12 months cycle and this long-term fuel cycle has also been applied to Kori Nuclear Unit 1 since 1989.

URANIUM CONCENTRATES

The current uranium requirement of KEPCO as about 1,500 t U_3O_8 per annum and will increase to over 2,000 t U_3O_8 after the middle of the 1990's.

Since the late 1960's, a government organization has explored domestic uranium resources. Resources of about 20,000 t U_3O_8 in low grade ores were confirmed, but without succeeding in locating mineable resources at current market condition. Therefore, the country's uranium requirement has to rely on overseas sources.

Security of supply is the most important goal of our procurement strategy of the Republic of Korea. Diversification of supply sources as well as maintaining a proper inventory are important objectives.

The required uranium levels in KEPCO is one year of forward reactor consumption and the current stock is below the required level. However, by the year 1991, stocks are expected to reach the required levels.

The uranium demand of KEPCO will be fulfilled mainly by long-term contracts, together with foreign exploitation joint venture programmes.

About 50% of the uranium requirement up to the year 2000 was secured by long-term contracts with Australian, Canadian and French suppliers. KEPCO will leave minimal provision for purchasing uranium from the spot market.

The first uranium concentrates were supplied to KEPCO by the reactor vendor Westinghouse. Uranium concentrates required for reloads and initial core for subsequent reactors were purchased by KEPCO. To secure uranium requirement, an invitation to bid for a long-term contract was issued in 1976 but this met with no response. Therefore, KEPCO had to rely on the spot market for its uranium requirements until 1979. As market conditions made it necessary to seek a safe alternative uranium supply method, KEPCO participated in an overseas uranium exploration programme, as did numerous utilities in the 1970's. Two overseas uranium exploration programmes were selected, one in Paraguay with Anschutz Corporation (USA) and another one in Gabon with COGEMA. After several years of exploration the joint ventures failed to find mineable resources. These experiences led KEPCO to the decision not to take part in any joint uranium exploration programmes.

As the uranium marked changed from a strict seller's market to a more balanced one, long-term uranium requirements which were calculated based on its current nuclear power plants, were delayed and this caused a build-up of stockpiles of uranium concentrates. Although the spot market uranium price has been decreasing since 1979, the actual requirement of KEPCO were fulfilled mainly by long-term contracts and by its own inventories and therefore did not enter into the spot market.

Fortunately, this uranium inventory procured at high costs was recently exhausted. Now KEPCO has a flexible way of seeking uranium by long-term contracts and/or at the spot market.

However, as the Republic of Korea has no proven mineable uranium resources to support its nuclear power programme at current uranium prices KEPCO decided to participate in an overseas exploitation projects. Currently the company is involved in joint ventures in the Cigar Lake and Dawn Lake Projects located in Saskatchewan, Canada and in Crow Butte, Nebraska as detailed in Table 5.

TABLE 5 INVOLVEMENT IN URANIUM PROJECTS

COUNTRY	PROJECT NAME	CO-PARTNERS	REMARKS
CANADA	DAWN LAKE 4.32%	CAMECO COGEMA	EXPLORATION
		PNC CEGB	
	CIGAR LAKE 2%	CAMECO COGEMA	UNDER CONSTRUCTION
		IDEMITSU CORONA	
	HENDAY LAKE 20%	CAMECO COGEMA	EXPLORATION
		PNC CEGB	
U.S.A.	CROW BUTTE 10%	FERRET GEOMEX	PLANNED,START-UP
		FIRST URANERZ	1989/1990
GABON	NORD LEYOU	COGEMA	DEFERRED

For the time being, the uranium spot market is expected to remain soft. However, this market is not believed to be a reliable one and long-term market price forecasting is adopted for calculation of fuel cycle costs.

Since 1985 uranium production has not been able to cover the actual uranium demand and the supply and the impact of higher uranium prices is being considered.

Therefore, to ensure the uranium supply for KEPCO's existing and planned nuclear power plants, consideration is being given to a strategy which will meet long-range uranium requirements starting from the early 1990's through overseas development and mining projects. Within this approach the following aspects are considered :

First to take lead times into full consideration
Secondly, to reduce inherent risk as low as is practicable by
- participation in projects with proven ore reserves,
- participation in a favourable investment country, and

Thirdly, to achieve production cost competitive with long-term contract prices.

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URANIUM RESOURCES FOR INDIA'S NUCLEAR POWER PROGRAMME — OVERVIEW

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Abstract

Indian nuclear power programme has been conceived as a three phase programme with the ultimate objective of utilising India's vast reserves of thorium and somewhat modest resources of uranium. Growing demand for electric power in India necessitated a short-term target of 10,000 MWe of nuclear power by the turn of the century. Exploration strategy adopted in the formative years, which consisted of the most direct approach such as known occurrences of uranium minerals and hydrothermal mineralisation, has given place to conceptual geological modelling that takes into account knowledge of geochemistry and the concept of time-bound character of major uranium deposits of the world. The integrated approach has made it possible to identify 64,610 t U at costs less than 1% of the value of the uranium resources and, with about 13 metre of drilling per t U proved, in a country where, during the early 1950s, only a few occurrences of uranium minerals had been reported. The recent discovery of commercially viable sandstone type of deposit in the Mahadeks of Cretaceous age in Meghalaya illustrates the successful application of conceptual model that took into consideration the geological evolution of the basin. Phosphatic limestone hosted uranium deposit identified in the Proterozoic Cuddapah basin, Andhra Pradesh provides another example of uncommon type of mineralisation that has widened the scope for uranium in similar geological environments.

1. INTRODUCTION

The importance of induction of nuclear power into power systems in India was recognised in fifties. The fact that India has about 31 % of world's thorium resources [1] and somewhat modest resources of uranium led Dr.Homi Jehangir Bhabha, the founding father of Indian Nuclear Power Programme, to draw out a nuclear power strategy utilising these resources most effectively. The strategy envisaged installtion of natural uranium fuelled thermal reactors in the first phase, followed by fast-breeder reactors in the second, using plutonium from the first generation reactors with either ^{238}U or thorium in the blanket and eventually by reactors based on the ^{233}U - thorium cycle. The exception for this strategy was the Tarapur Atomic Power Station, purchased from USA on turnkey basis which uses slightly enriched uranium as fuel and light water as moderator and coolant. This deviation was necessary for the early introduction of nuclear power in the country and for giving an opportunity to Indian technical personnel to gain experience in building and operating a nuclear power station in an Indian electrical grid system [2, 3].

Projected growth of electric power in India indicates that the gross additions to the present generation capacity of 55,000 MWe, should be 100,000 to 120,000 MWe by 2000 A.D. The need for more than

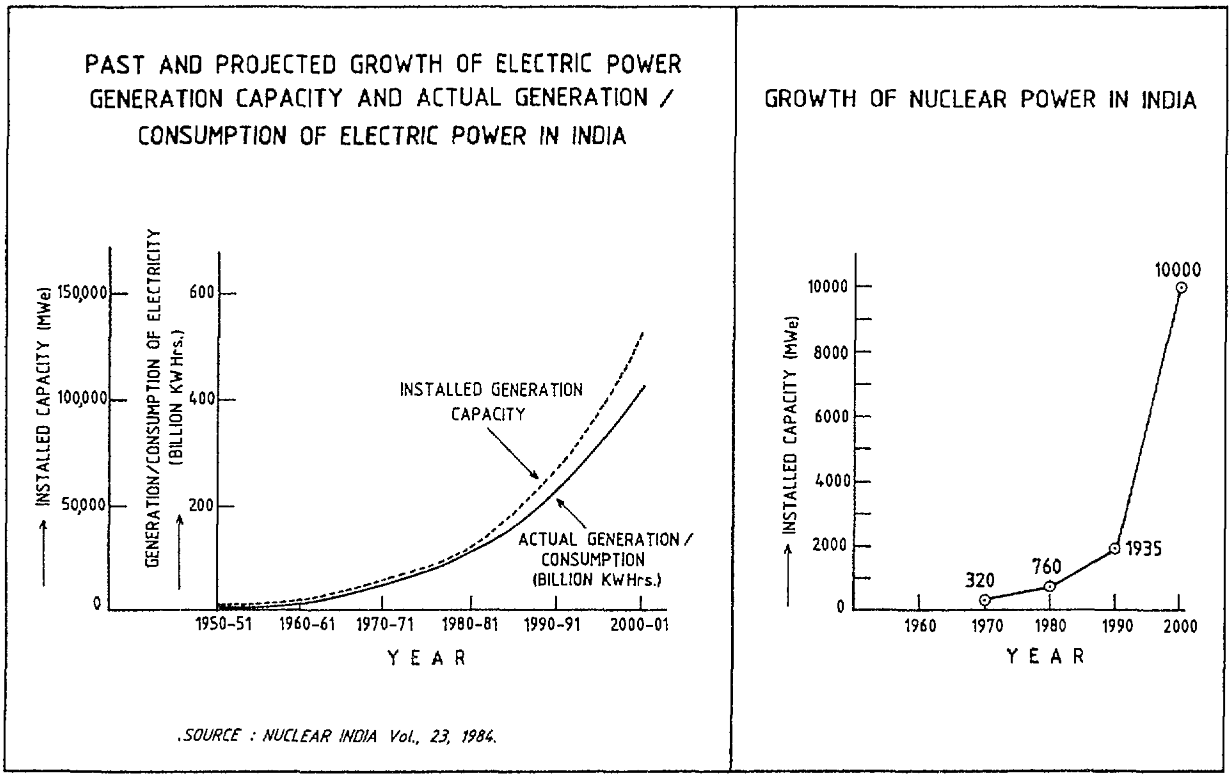

FIG. 1.

doubling the installed electrical generating capacity by the turn of the century necessitated the planners to set a short-term target of 10,000 MWe of nuclear power by then. The target which would be 10% of the total installed power capacity, has been set taking into account, among other things, uranium resources already identified in the country (Fig.1),[3].

The present installed nuclear capacity is about 1465 MWe and a further 1645 MWe is under construction. Another 6940 MWe has been planned that would involve installation of 4 units of 235 MWe and 12 units of 500 MWe. Presented here is a brief review of exploration efforts made and the availability of indigenous uranium resources which is the basic pre-requisite for any sustained nuclear power programme.

2. URANIUM EXPLORATION

Organised exploration for uranium in India was initiated in early 1950s. In the formative years, the task of identifying resources was formidable since India had embarked upon an exploration programme almost simultaneously with the developed nations but without the scientific, technological and industrial backup of the latter. Uranium geology was not formally taught in the Indian Universities.

2.1. Pre 1970 scene

Exploration strategy consisted of the most direct approach such as known occurrences of uranium minerals and hydrothermal mineralisation, especially, of Cu and Pb. Granitoids and the associated rocks and the major structures like shear zones, boundary faults, thrust contacts, etc. were also the target areas. First significant uranium occurrence was discovered in 1950 at Jaduguda in the Singhbhum Thrust Belt [STB] of Bihar where torbernite had been reported in the same belt in the early 1920s by a private prospector and documented in the

Records of Geological Survey of India. Subsequent foot surveys using G.M. counters led to the discovery of uranium deposit at Bhatin, Narwapahar and few others in the STB. Jaduguda deposit was opened in 1956 and has since developed into a mine supporting a mill with a capacity to treat 1,000 tonnes of ore per day. Around the same period, uranium mineralisation was located along the black shale - dolomite contact at Umra and in pegmatites at Bhunas, Rajasthan. Radioactivity predominantly due to thorium was recorded in the Proterozoic conglomerates occurring at the base of Cuddapahs, Andhra Pradesh, and Delhis and Aravallis in Rajasthan [4].

Application of airborne radiometric techniques for narrowing down target areas commenced in 1956 making India one of the earliest countries to adopt this methodology [5]. Development of Singhbhum Province and systematisation of methodology of exploration through stages of detailed mapping, surface trenching, shielded probe logging and sampling and limited drilling integrated with ground magnetic and resistivity surveys were the thrust areas during the period 1950-1970.

2.2. Post 1970 scene

Diversification of exploration efforts, spanning the last two decades, into different areas outside the Singhbhum Thrust Belt resulted in the identification of other areas of mineralisation such as sandstone type mineralisation in Satpura-Gondwana, in the Siwaliks along the Himalayan foothills and in the Cretaceous Mahadeks of Shillong Plateau; numerous zones of mineralisation of vein type in quartizites; disseminated type in metabasic rocks along major shears in the Lesser - Central Himalayan region and Quartz pebble conglomerate type in the Karnataka Craton at the base of the early Proterozoic Dharwar sedimentary metavolcanic iron ore sequence. An interesting strat-abound, phosphatic limestone-hosted uranium mineralisation was also located in the Proterozoic Cuddapah basin in Andhra Pradesh [6-8].

The past four decades also witnessed the development of instrumentation and many field techniques. These efforts have served to provide indigenous capabilities and self-reliance [9].

3. CONCEPTUAL GEOLOGICAL MODELS

The exploration strategy for uranium in India has largely been guided by conceptual models that have evolved over the years. Exploration strategy adopted in the early years which consisted of the most direct approach such as geological favourability has given place to conceptual geological modelling that takes into account knowledge on uranium geochemistry and the concept of time-bound character of major uranium deposits of the world. Major revisions in the chrono-litho stratigraphy of Precambrian rocks of India based on geochronology and detailed geological mapping that were taking place since 1960s also influenced thoughts on uranium exploration. This integrated approach has made possible location in India of all known types of world Uranium occurrences, with the exception of the unconformity related and surficial type (Table-1 Fig.2). The models adopted are discussed in relation to uranium in Precambrian formations and in Phanerozoic sediments (Fig.3) [10, 11].

3.1. Uranium in Precambrian formations

Uranium in Precambrian formations could be assigned to any one of the following types namely : i. the quartz-pebble conglomerate type; ii. the hydrothermal vein and disseminated type, and iii. the recently discovered Proterozoic stratabound (?) phosphatic limestone type.

T A B L E - I

SIGNIFICANT URANIUM DEPOSITS AND/OR OCCURRENCES IN INDIA

Classification	Area
1. Quartz-pebble conglomerate and pebbly arenites	Walkunji*, Yelakki, Arbail, Dhanjori basin, Badampahar, Gangpur basin, Barimata, Beleta.
2. Vein type/disseminated	Singhbhum Thrust Belt (Jaduguda*, Narwapahar*, Bhatin*, Turamdih*, Mohuldih*, Bagjata-I*, Garadih*) Bodal*, Jajawal*, Umra-Udaisagar, Lesser Himalayan occurrences, Palamau.
3. Sandstone	Mahadeks (Gomaghat*, Domiasiat*), Gondwanas (Bhawra), Siwaliks (Astotha, Rajpura, Danaur).
4. Others	Tummalapalle (Vempalle limestone), Cuddapah basin, Kerali, Abujhmar basin.

* Deposits.

3.1.1. Quartz-Pebble Conglomerate type

The recognition of time-bound character of the uraniferous - quartz pebble conglomerates and their deposition below the banded iron formations in South Africa, Canada, Brazil and Australia was the forerunner to the discovery of Bababudan conglomerates (2900 - 2600 Ma), in mid 1970s, occurring below the Bababudan iron formations in Western Karnataka. Following this discovery, similar geological horizon with uraninite and other U-Th minerals was located at the base of Dhanjori meta-volcanics, Bihar and Gorumahisani iron ore series, Orissa. These areas are currently under active exploration. Quartz-Pebble conglomerates associated with the Eparchaean unconformity at the base of Aravallis in Rajasthan and Bijawars in Uttar Pradesh and Madhya Pradesh are also being given increased attention though earlier investigations in the former had resulted in the identification of predominently thoriferous areas [6,12].

3.1.2. Hydrothermal vein and disseminated type

Deposits of this type that fall in the time-band of 1600-1400 Ma are the most important source of Uranium in India and account for nearly 78% of the resources identified. They occur in different geotectonic environments, which include: i) the well known Singhbhum Thrust Belt, Bihar [18]; ii) the shear zones along rhyolite - andesite sequences of Dongargarh Supergroup in Madhya Pradesh; iii) Shear zones in migmatite - amphibolite sequence of the Chotanagpur gneissic complex, Madhya Pradesh; iv) shear zones and tension joints in the quartzite and chlorite schists (e.g. Rampur group) associated with Himalayan thrusts [7]. Recent additions to this category of uranium are those associated with the fault breccias in the basement rocks near Sanipaya - Tsundapalle, Cuddapah district, Andhra Pradesh and the shear controlled felsitic mylonites/migmatite mobilizates in the basement rocks in Mirzapur district, Uttar Pradesh.

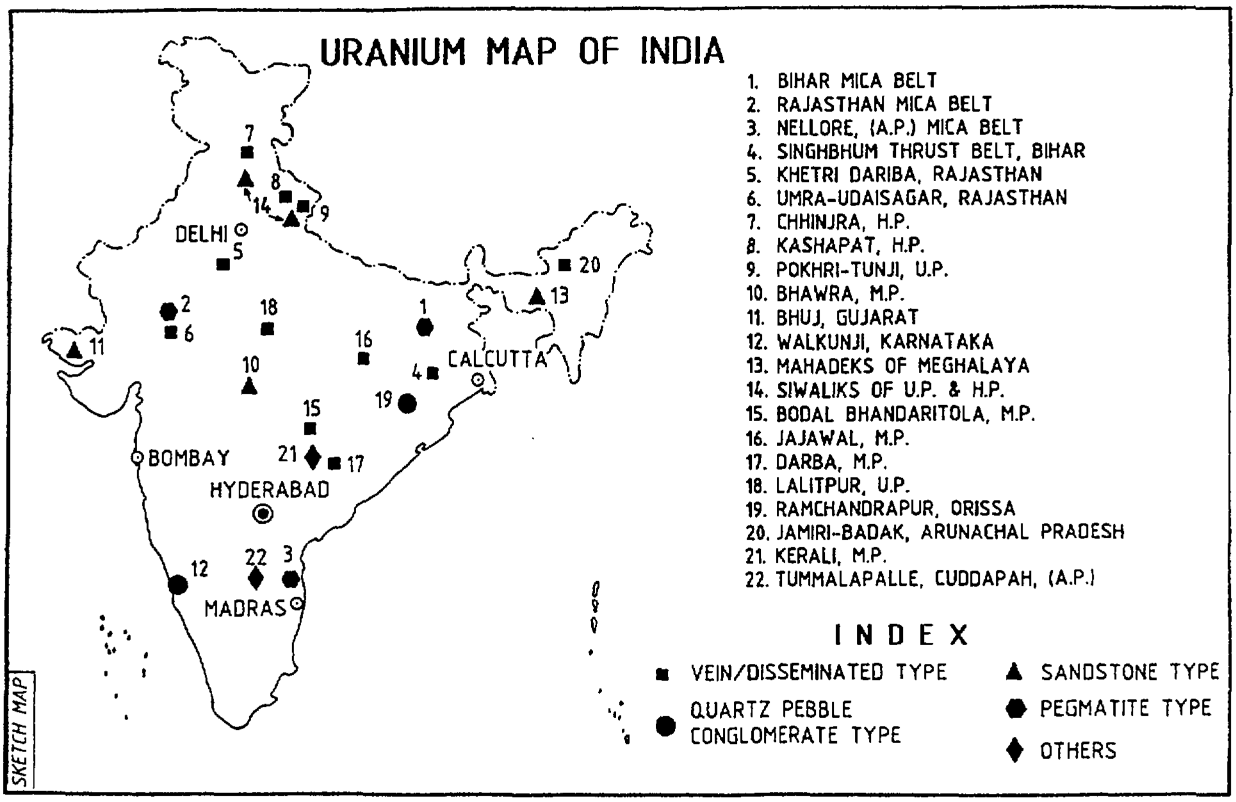

FIG. 2.

3.1.3. Unconformity related type

This class of deposits has not yet been located in India. The extensively developed Proterozoic basins in the peninsular India, namely Cuddapah, Pakhal, Bhima-Penganga, Indravati, Abujhmar, Chattisgarh, Bijawar and the Aravalli and Delhi are being critically evaluated by detailed radiometric and geochemical surveys, geological mapping, stratigraphic drilling and basin evaluation studies. Encouraging surface and sub-surface uranium mineralisation have already been located in the sandstones and quartzites in Kerali area of Abujhmar basin, Madhya Pradesh; in the calcareous sandstone and shales of Bijawars of Uttar Pradesh and along the eastern margin of Cuddapah basin, Andhra Pradesh.

3.1.4. Phosphatic limestone type

The recently identified interesting uranium deposit in the Proterozoic Cuddapah basin (1700-900 Ma) in Andhra Pradesh is hosted by phosphatic limestone that overlies the Gulcheru quartzites. The uraniferous Vempalle limestone has been traced over an arcuate belt of about 63 Km and uranium occurs mainly as pitchblende intimately associated with granular pyrite (biogenic ?). Mineralisation is along the bedding planes, contact of carbonate - phosphate layers and corrugated boundary of microstylolites. The common size range of pitchblende grains is 0.02 to 0.06 mm occasionally going upto 0.08 to 0.1 mm. Preliminary studies on the surface and borehole cores have indicated 69 to 85% leachability via carbonate route in 24 hours contact time. This extensively developed stratabound (?) deposit is a kind of its own and has large potential besides widening the scope for uranium exploration in similar geological settings [13].

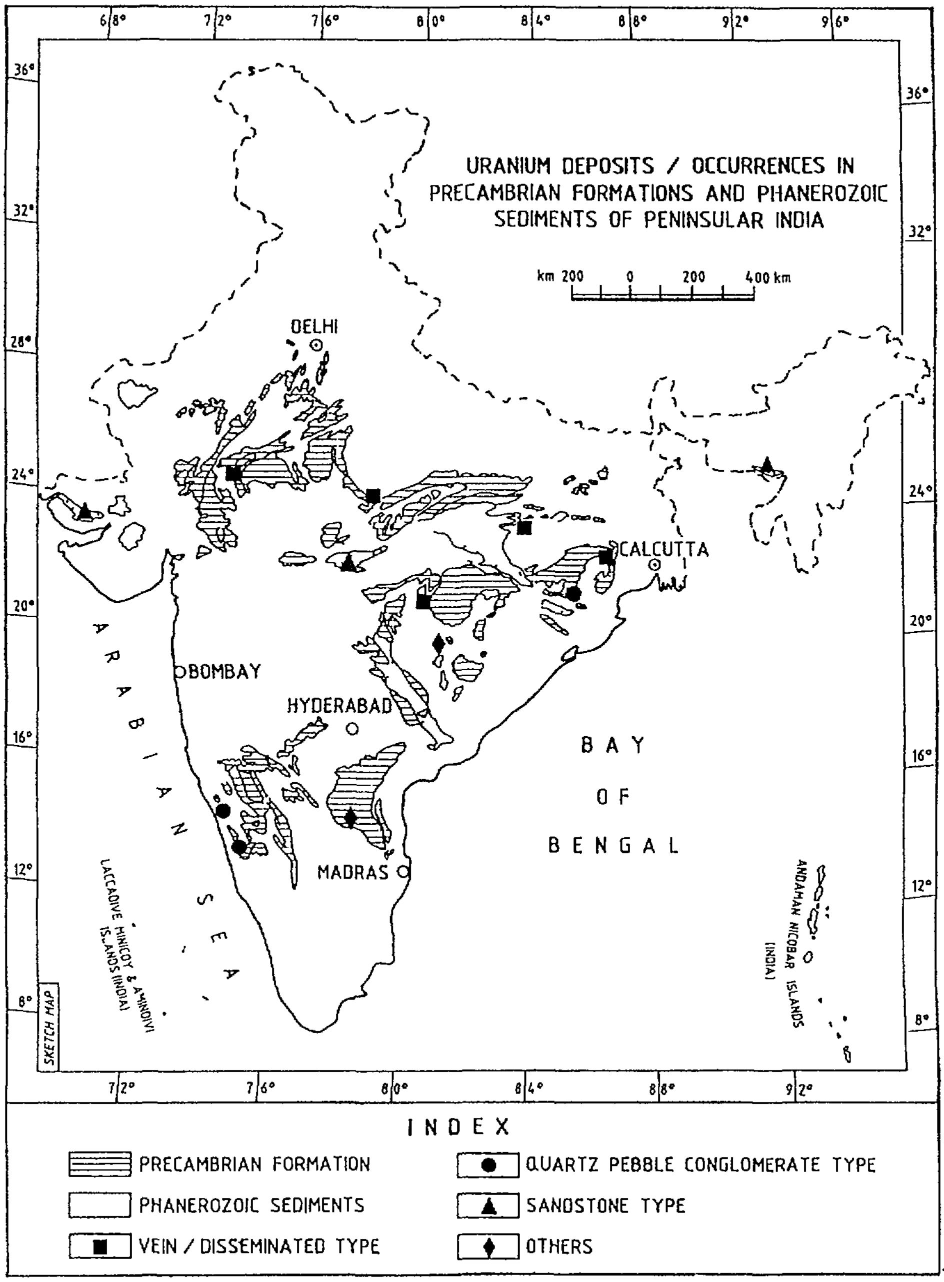

FIG. 3.

3.2. Uranium in Phanerozoic Sediments

The uraniferous Phanerozoic sediments identified in India are: (i) the Motur and Bijori formations of Permian age of the Satpura Gondwana basin in Madhya Pradesh; (ii) the Cretaceous Mahadek beds along the southern slopes of Shillong plateau; and (iii) the Siwalik formations along the northwest Sub-Himalayan foothills. [6, 8, 10, 13-16].

The environments of deposition are fluvial in Moturs and Siwaliks and marginal marine to fluvial in the Mahadeks. These basins, have uranium rich provenance, the speedy tectonic uplift of which gave rise to accumulation of uranium-bearing immature sediments.

The recent discovery of economically viable uranium deposit (Domiasiat) and other uranium occurences in the Cretaceous sediments of Meghalaya in Northeastern India has opened up a promising belt. It is interesting to record that the preliminary surveys, carried out during early 1960s,indicated only dominance of thorium in the sediments. The breakthrough was the find of small patches of uraniferous sandstone completely free from thorium near Dawki and Pung Tung area of Khasi Hills district during the early 1970s that generated renewed interest. The prospect of Mahadek sandstones as a source for uranium was presented at IAEA, Vienna in 1976 and subsequently, IAEA sanctioned a research grant for a period of 4 years which continued upto 1981.It was not until mid-eighties that the discovery of Domiasiat deposit was possible and delineation of Lower Mahadeks into Ghat and plateau domain each with distinct characteristics could be completed.

Plateau domain which proved to be more favourable for uranium mineralisation is represented by uranium occurrences of Domiasiat, Pdengshkap, Tarangblang, Mawkyrwat and Phlangdiloin. It has distinct evidences of fluvial environment which may be related to braided channels and the basement lows. The basic control of uranium mineralisation is the organic reductants and the redox interface. Uranium mineralisation is more consistent in areas where the sandstone facies contain finely disseminated carbonaceous matter in the matrix. Discrete uranium minerals present are uraninite, coffinite, metazeunnerite, and metakahlerite. The uranium mineralisation in the Ghat domain, represented by the Gomaghat occurrence, is confined to the redox interface developed between the top and bottom units of Lower Mahadeks. The environment is fluvio-deltaic. Uranium mineralisation occurs both as discrete minerals pitchblende and coffinite, and as adsorbed uranium in the clays, and organic material [19].

The numerous uranium occurrences identified in the Satpura Gondwanas and the Siwaliks are also more or less confined to specific litho-stratigraphic horizons. The conceptual approach based on which extensive areas of uranium mineralisation could be delineated in all the three basins, comprised tectonic uplifting of the provenance, mobilization of uranium into sediments of the clastic type and subsequent enrichment in zones of reduction through circulating ground waters.

4. URANIUM RESOURCES IN INDIA

During the last four decades uranium resources totalling 64,610 t U (76,200 t U_3O_8) have been identified. These comprise both Reasonably Assured Resources (RAR) and Estimated Additional Resources - I (EAR-I). Fig-4 depicts the growth of uranium resource position. The resources also include uranium recoverable as by-product from copper tailings of Roam - Rakha, Surda and Mosabani copper mines in Singhbhum Thrust Belt and the estimated production of uranium from phosphoric acid.

Most of the resources are from Precambrian formations of the vein or disseminated type and about 69% of the total reserves are confined to Singhbhum Thrust Belt. A major change in uranium resource figures, in the recent years, has been the significant increase in areas outside STB. (Table - 2).

Commercially exploitable uranium deposits identified, besides Jaduguda, are Narwapahar, Bhatin (U-Ni-Mo), Turamdih East, Turamdih West (U-Cu), Mohuldih, Bagjata-I, Turamdih South and Garadih, Singhbhum district, (Bihar); Bodal, Rajnandgaon district and Jajawal, Sarguja district, (Madhya Pradesh); Domiasiat, West Khasi Hills district, (Meghalaya); and environs of Tummalapalle, Cuddapah district (Andhra Pradesh).

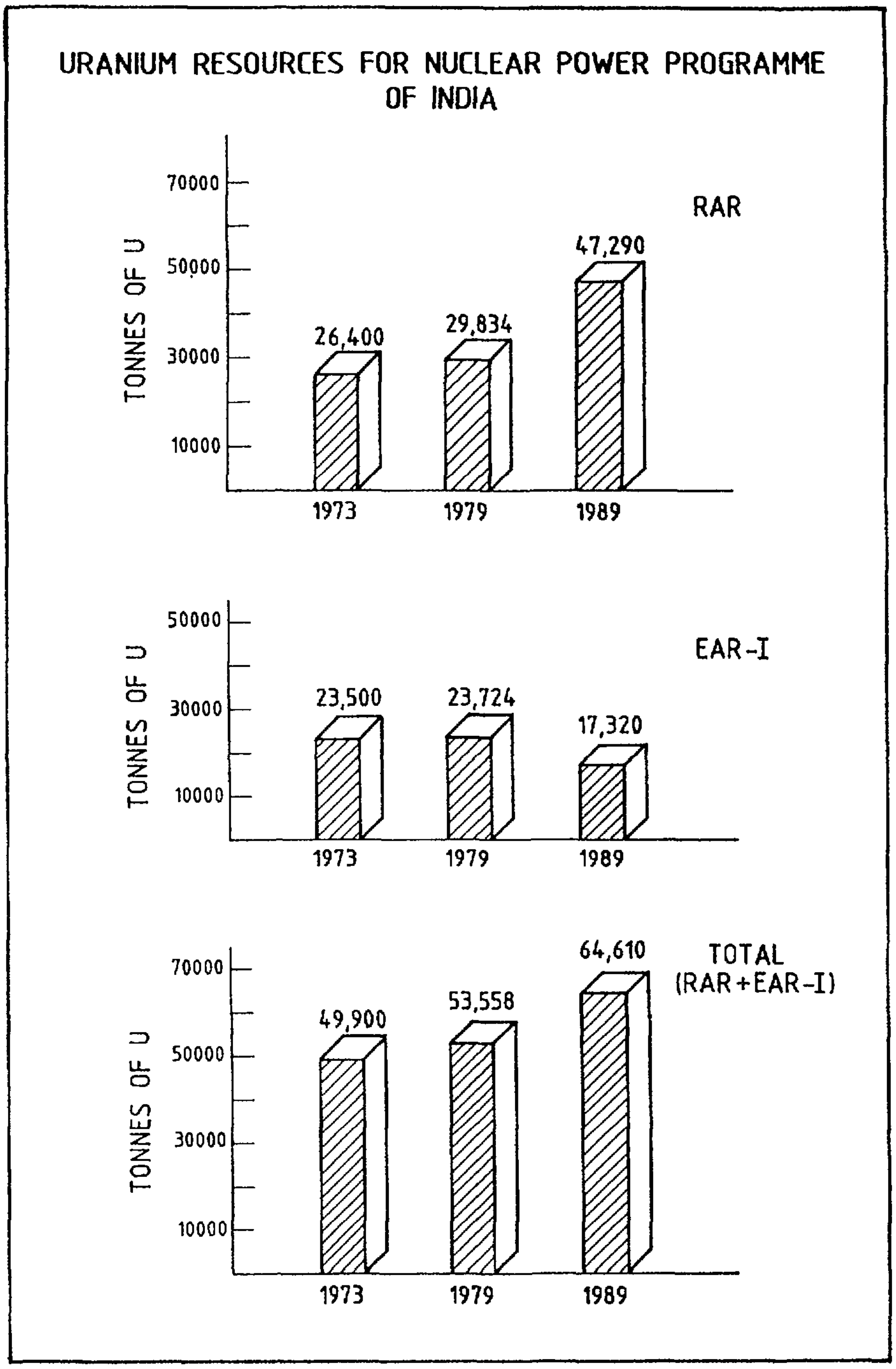

FIG. 4.

It is significant to note that these resources have been identified at an exploration cost of less than 1% of the value of the resources and with about 13 metres of drilling per t U proved [4, 17].

Besides the Jaduguda deposit, which has been under commercial exploitation since 1969, many other deposits have been earmarked for exploitation in a phased manner. A total mining and processing capacity of 1800 tonnes of U3O8 is proposed to be established by the end of the century which will be adequate to meet the requirements of all the nuclear power stations that will be operated by then.

TABLE - 2

URANIUM RESOURCES IN INDIA (in t U as of January.1989)

Principal deposits	Reasonably assured resources (RAR)		Estimated additional resources - I (EAR-I)		Total RAR + EAR-I
	Recoverable at costs*		Recoverable at costs*		
	< $80 -	between $80-130	< $80 -	between $80-130	
STB Bihar	35,400	4,010	3,880	1,400	44,690
Others	5,740	2,140	200	11,840	19,920
Total	41,140	6,150	4,080	13,240	64,610

* US $/Kg U.

5. CONCLUSIONS

The history of uranium exploration in India illustrates how a systematic and integrated approach based on evolving conceptual models has made it possible to identify 64,610 t U, at costs less than 1% of the value of the resources proved, in a country where, during the early 1950s, only a few occurrences of uranium minerals had been reported.

The case history of Domiasiat uranium deposit shows how a sustained effort has led to delineation of a uraniferous belt within a province where only predominance of thorium was reported at the initial stages of exploration.

The discovery of uncommon stratabound uranium mineralisation in the Vempalle phosphatic limestone of Proterozoic Cuddapah basin has widened the scope for uranium exploration in similar geological environments.

In the field of instrumentation, the approach from the beginning was to develop indigenous capabilities for designing and fabricating radiometric instruments. At all stages of development, the emphasis was to learn - it - ourselves rather than opting for easy solutions of importing complete instruments. Beginning with simple G.M. counters, the range of products diversified into a host of other instruments including gamma-ray spectrometers.

Despite meeting the uranium requirements for 10,000 MWe of nuclear power programme by the turn of century, exploration efforts are being intensified as the demand for natural uranium would continue until the arrival of third phase reactors based on thorium by the beginning of the next century. Location of higher grade ores and large deposits is also necessary to minimize the mining costs. The chances of proving such deposits are bright in India where about 2 million sq.km, out of a total area of 3.2 million sq.km, are of interest for uranium exploration in view of their geological favourability.

Substantial inputs into the exploration programme including drilling, in the coming years, have already been planned and it is hoped that it will lead to identification of uranium resources to meet the requirements of the country's future nuclear power programme.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to M.R. Srinivasan, Chairman of Atomic Energy Commission and Secretary in the Department of Atomic Energy, Government of India, for the keen interest and active support for the uranium exploration programme in the country.

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CANADIAN EXPERIENCE IN APPRAISAL OF URANIUM RESOURCES ADDITIONAL TO RESERVES

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Abstract

Since the establishment of the Uranium Resource Appraisal Group (URAG) at the Department of Energy, Mines and Resources (EMR), the Geological Survey of Canada (GSC) has been engaged in periodic, systematic quantitative appraisals of Canadian uranium and thorium resources additional to reserves, i.e. Estimated Additional Resources I (EAR I), Estimated Additional Resources II (EAR II) and Speculative Resources (S), with biennial full, and alternate years interim, reports to URAG.

These appraisals, conducted by the GSC Mineral Resource Appraisal Secretariat (MRAS), include: (a) geological analyses of exploration activities in Canada conducted by industry; (b) assessments of uranium and thorium resources of uranium-bearing domains; and (c) estimates of resources, additional to reserves, in identified uranium deposits. The appraisals are based upon field, laboratory and office research on uranium occurrences, on studies in close liaison with exploration and mining companies, with provincial professionals, universities, and with other EMR agencies.

The uranium resource appraisals are based on continuing studies of mineral deposits and their geological environments, on regional uranium metallogenic studies, and on conceptual genetic models for specific deposit types. The data base consists of delineation and geological definition of metallogenic domains, tonnages and grades of known occurrences, structural and lithological information and data from geophysical and geochemical surveys.

The quantification of the resources is conducted by diverse methods, including geological extrapolation, crustal abundance approach, modified MIMIC (Mining Industry Model for Inventorization and Cost Evaluation) and subjective probability estimations. These quatification methods are described in an Instruction Manual "Methods for the Estimation of Undiscovered Uranium Resources" to be published by the International Atomic Energy Agency (IAEA).

Results of the studies are incorporated in the biennial publication "Uranium in Canada: Assessment of supply and requirements" (EMR Report EP-3), in the Nuclear Energy Agency - Organization for Economic Cooperation and Development/IAEA "Red Book" and in "Fact Sheets", distributed by EMR annually to exploration and mining companies operating in Canada. Findings pertaining to regional and local geology and to conceptual models are published in GSC Current Research and IAEA publications, which provide timely information for the professional public.

Introduction

Since the establishment of the Uranium Resource Appraisal Group (URAG) at the Department of Energy, Mines and Resources (EMR) the Geological Survey of Canada (GSC) has been engaged in periodic, systematic quantitative appraisals of Canadian uranium and thorium resources additional to reserves, i.e. Estimated Additional Resources I (EAR I), Estimated Additional Resources II (EAR II) and Speculative resources (S), with biennial full, and alternate years interim, reports to URAG. Results of the appraisals are incorporated in EMR's biennial reports EP-3: "Uranium in Canada: Assessment of Supply and Requirements" [1].

Organization of the appraisals

In 1974 the Minister of Energy, Mines and Resources (EMR) established a Uranium Resource Appraisal Group (URAG) within EMR to audit regularly Canada's uranium resources [2].

URAG is composed of senior officials of EMR and technical experts in the fields of uranium geology, mining and milling and is chaired by the Director General of the EMR Uranium and Nuclear Energy Branch (UNEB) (see the organizational chart in Fig. 1). Activities of URAG are carried out by three inter-related subcommittees [3]: (i) The subcommittee on Reasonably Assured Resources (RAR); (ii) the subcommittee on Estimated Additional Resources (EAR & S); and (iii) the subcommittee on Economic Co-ordination (CO-ORD).

The subcommittee on RAR is responsible for auditing measured and indicated resources in Canadian uranium deposits and for assessing levels of Canadian uranium production. The work of this subcommittee is conducted by the Mine Evaluation Group located in the Mining Research Laboratories of EMR's Canada Centre for Mineral and Energy Technology (CANMET).

The subcommittee on EAR & S is responsible for geological studies of uranium deposits and regions which have geological environments favourable for the occurrence of uranium, for appraisal of inferred, prognosticated and speculative resources of uranium in Canada and for monitoring exploration activity for uranium in Canada. The work of this subcommittee is conducted by the Mineral Resource Appraisal Secretariat (MRAS) of the Mineral Resources Division of the Geological Survey of Canada (GSC).

The subcommittee on Economic Co-ordination is responsible for relating known resources to domestic requirements and export commitments and for co-ordination of the overall URAG exercise. The activities of this sub-committee are centred in the Uranium and Nuclear Energy Branch (UNEB) of EMR.

Members of URAG co-operate with Canadian regulatory agencies, such as the Atomic Energy Control Board (AECB), with Provincial governments and industry. They use information from other institutions, such as from the Natural Sciences and Engineering Research Council (NSERC)) and from related governmental programs, such as Federal-Provincial Mineral Development Agreements (MDA).

Appraisal Process

Uranium resource appraisals, conducted by the subcommittee on EAR, i.e. by the GSC Mineral Resource Appraisal Secretariat (MRAS), include (Fig. 2): (a) analyses of EMR and AECB records and assessment files submitted by industry, particularly economic geological significance of results of exploration and mining activities, including resource estimates; these records are regularly reviewed (audited) with industry by a URAG Technical Team consisting of members of the URAG subcommittees and provincial representatives; (b) assessments of uranium and thorium resources of uranium-bearing domains, which are based on field, laboratory and literature studies by MRAS members; (c) appraisals of resources, additional to reserves, in identified uranium deposits; these appraisals complement estimates of measured and indicated reserves made by CANMET. In cases, where CANMET estimates of inferred resources, these are either confirmed or modified. A computer-assisted data base contains files for metallogenic domains within the Huronian Supergroup, Athabasca Basin, northwestern part of the Canadian Shield and the remaining parts of Canada.

Concept of the appraisals

A schematic flowchart of the concept is shown in Fig. 3.

The uranium resource appraisals are based on continuing research of mineral deposits and their geological environments, in Canada and worldwide. Special attention is paid to world-class

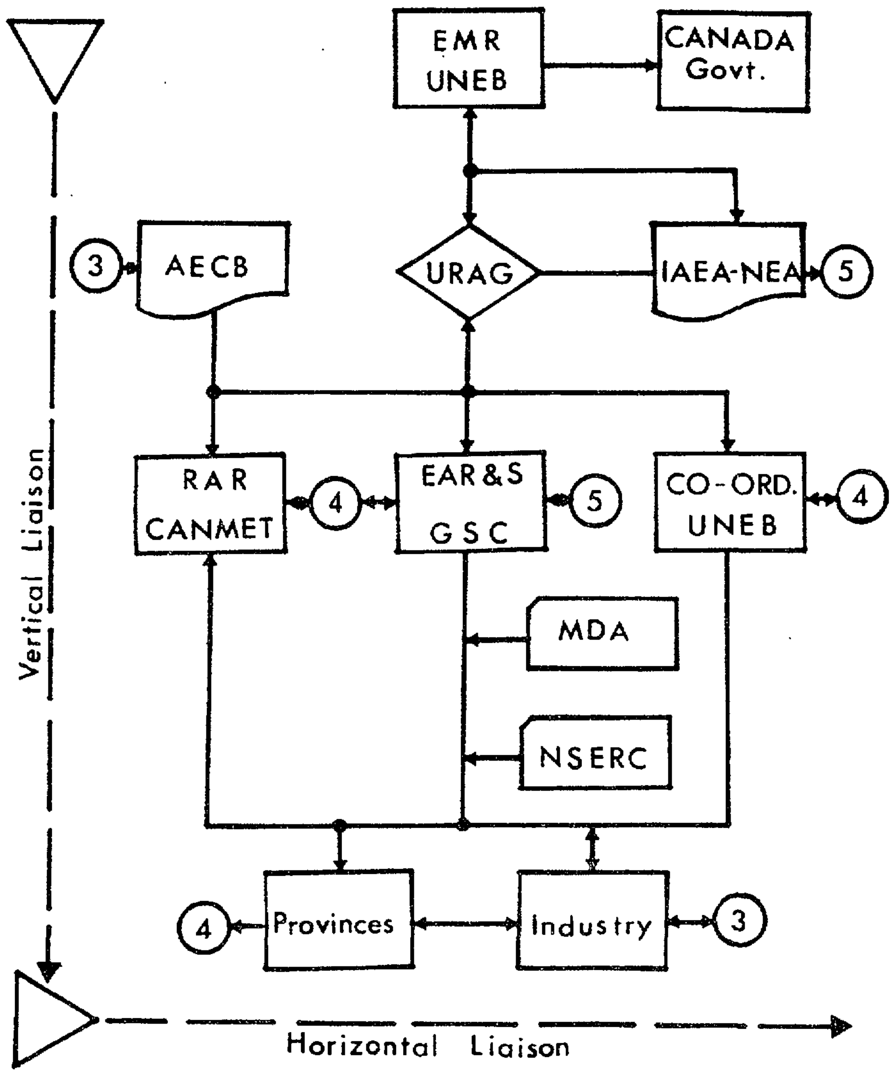

Figure 1: Organisation of uranium resource appraisals in Canada. Abbreviations: EMR = Department of Energy, Mines and Resources; UNEB = Uranium and Nuclear Energy Branch of EMR; CANADA Govt. = Federal Government of Canada; AECB = Atomic Energy Control Board; URAG = Uranium Resource Appraisal Group; IAEA-NEA = International Atomic Energy Agency - Nuclear Energy Agency, Organisation for Economic Cooperation and Development; RAR = Subcommittee on Reasonably Assured Resources of URAG; CANMET = Canada Centre for Mineral and Energy Technology; EAR & S = Subcommittee on Estimated Additional and Speculative Resources of URAG; GSC = Geological Survey of Canada; CO-ORD = Subcommittee on Economic Co-ordination of URAG; MDA = Federal-Provincial Mineral Development Agreement; NSERC = Natural Sciences and Engineering Research Council.

uranium deposits, such as Cigar Lake, Key Lake and Elliot Lake, Canada [4]; Olympic Dam [5] and deposits in the Pine Creek Geosyncline, Australia; deposits in the Grants district, the United States; Witwatersrand Basin, South Africa; Massif Central, France; Erzgebirge, Czechoslovakia and East Germany; Roessing, Namibia; and in the Arlit district, Niger.

Regional uranium metallogenic studies are conducted in the context with metallogenic studies of other commodities and include at present (1989) the Proterozoic intracratonic basins of the Canadian Shield [4], the Great Bear magmatic zone [6; 7] and the Huronian Supergroup [4]. The data base consists of delineation and geological definition of metallogenic domains, tonnages and grades of known occurrences, structural and lithological information and data from geophysical and geochemical surveys.

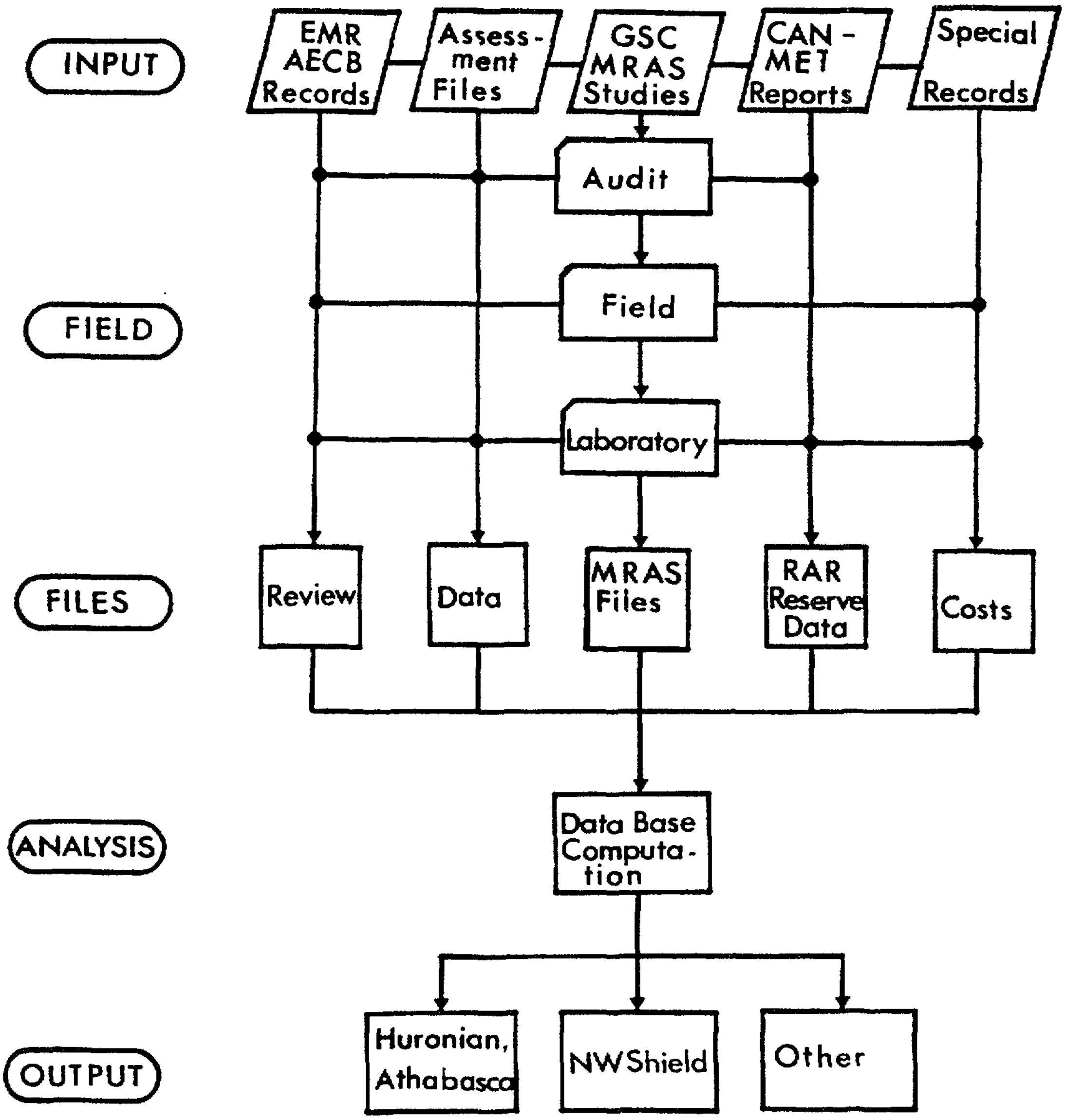

Figure 2: Estimated Additional Resource Appraisal process. Abbreviations: see caption to Fig. 1; MRAS = Mineral Resource Appraisal Secretariat, a Section of Mineral Deposit Subdivision, Mineral Resources Division and Continental Geoscience and Mineral Resources Branch of the GSC; NWShield = Northwestern part of the Canadian Shield.

Conceptual genetic models are important components in the appraisals; they are represented by (a) regional metallogenic models and (b) by deposit models.

Regional metallogenic models represent geological histories of uranium provinces or sub-provinces and include information on magmatic, sedimentary, metamorphic, tectonic and ore-forming processes which were active within a certain time frame. A schematic representation of such a model is, for instance, the flowchart for uranium mineralization in northern Saskatchewan (Fig. 4; [8]). Regional metallogenic models are useful tools for delineation of metallogenic domains and thus for areal definition for regional resource appraisals.

Conceptual deposit models represent genetic aspects of individual deposit types. In Canada, the first conceptual models were established with classification of Canadian uranium deposits by Lang et al. (1962) [9]. A concept for the then world-class uranium deposit models was formulated at the "Symposium on the Formation of Uranium Ore Deposits" organized by the International Atomic Energy Agency and held in Athens, Greece, 6-10 May, 1974 [10]. The

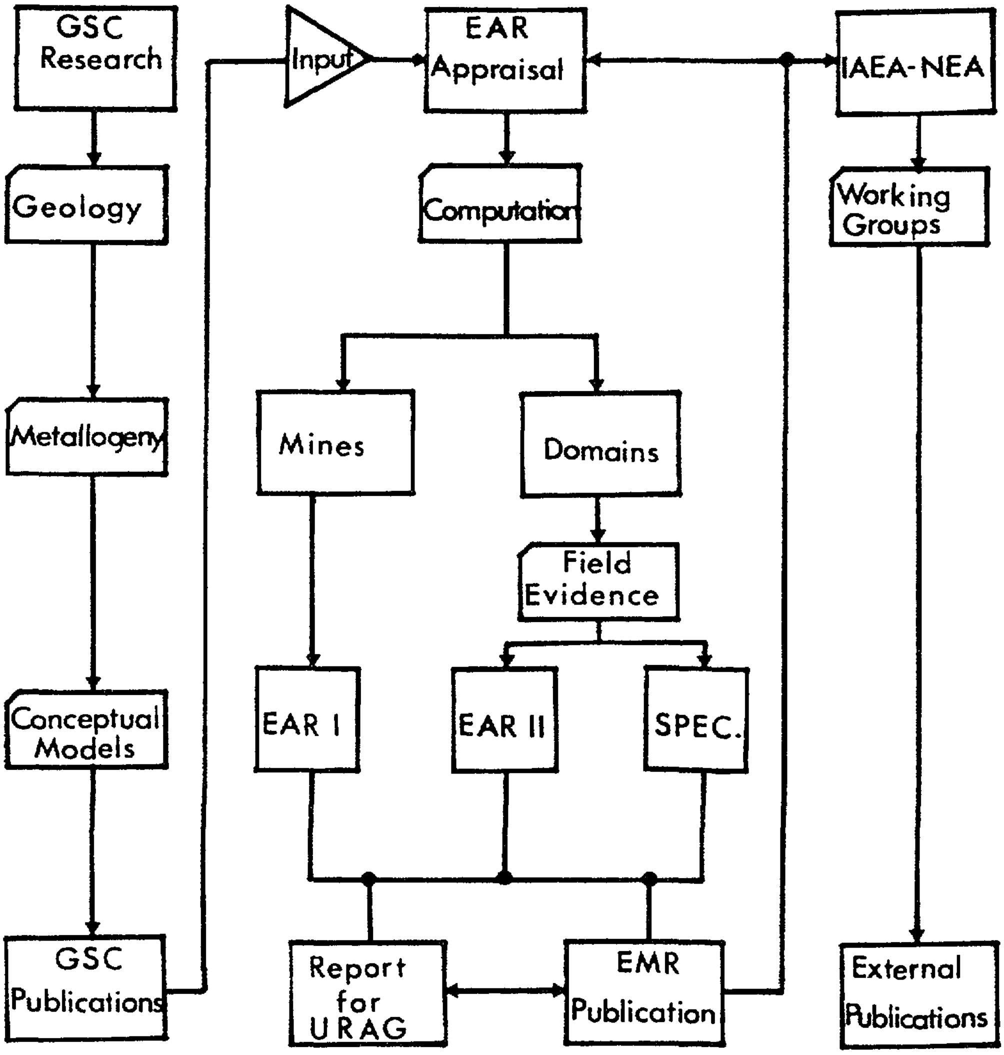

Figure 3: Concept for the appraisal of Estimated Additional and Speculative resources of uranium. Abbreviations: see captions to Figs. 1 and 2; EAR I = Estimated Additional Resources I, i.e. Inferred resources; EAR II = Estimated Additional Resources II, i.e. Prognosticated resources; SPEC. = Speculative resources of uranium.

models included sandstone-type, quartz-pebble conglomerate, vein and similar-type and other uranium deposits.

In the late seventies, conceptual deposit models were applied to appraisal of Canadian uranium resources [11; 12]. This concept is based upon simulation of processes leading to concentration of uranium in the geochemical cycle. The general model postulates: (a) primary concentration of uranium and its geochemical availability; (b) mechanism of transport of uranium from the site of origin or preconcentration to the site of redeposition; this can involve mechanical and/or chemical processes; (c) reconcentration and redeposition of uranium, which can occur in structural and lithological traps; (d) modification of uranium deposits (due to metamorphism, during diagenesis, by oxidation, accretion etc.); (e) preservation of uranium deposits from destruction (retention of sufficient uranium to comprise an exploitable deposit). The application requires quantification or at least estimation of uranium concentration in individual phases of the ore-forming processes. A scheme of a conceptual model for uranium deposits associated with unconformities is shown in Fig. 5.

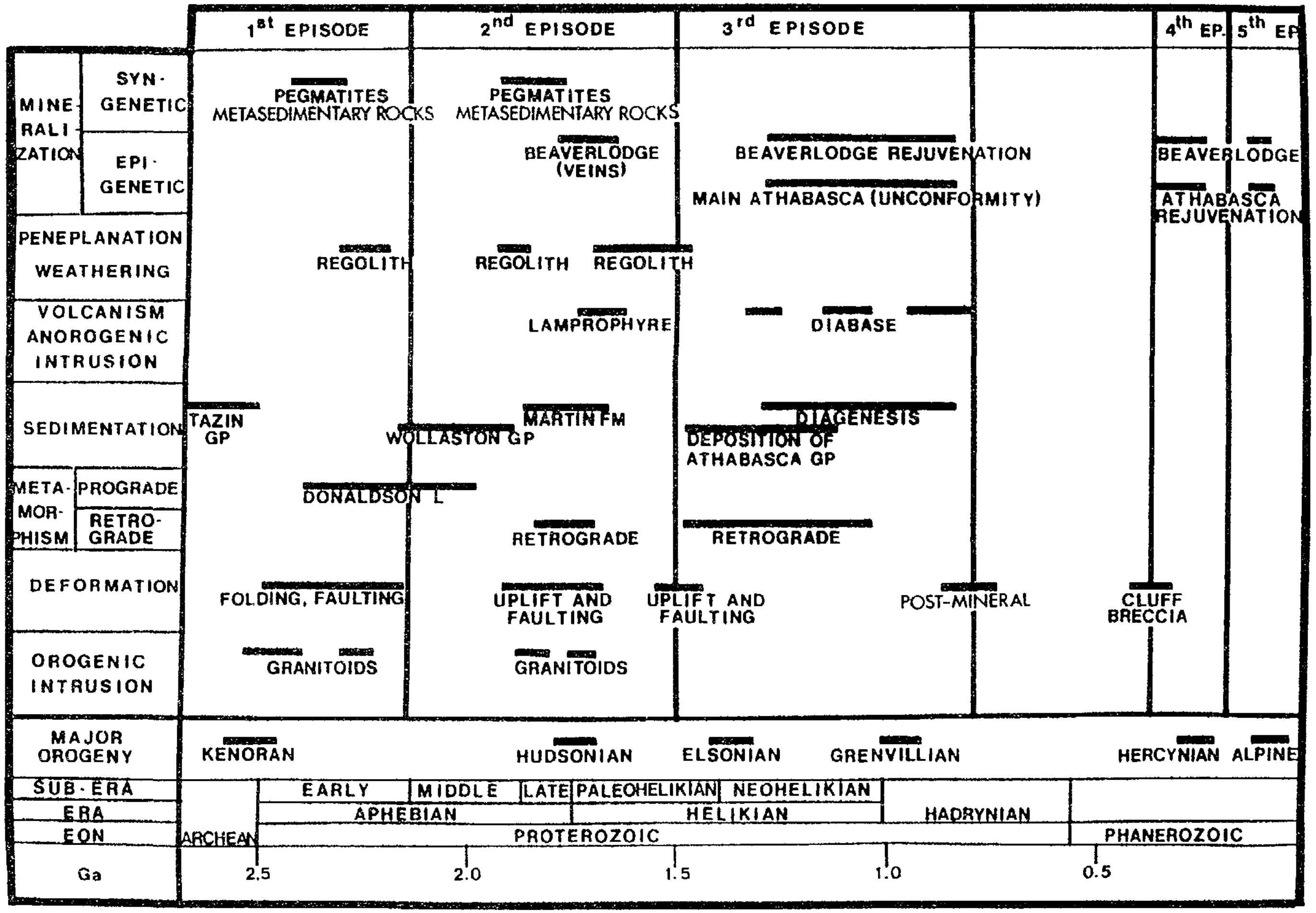

Figure 4: A scheme of a regional conceptual metallogenic model for uranium mineralization in northern Saskatchewan. From RUZICKA and LECHEMINANT [8].

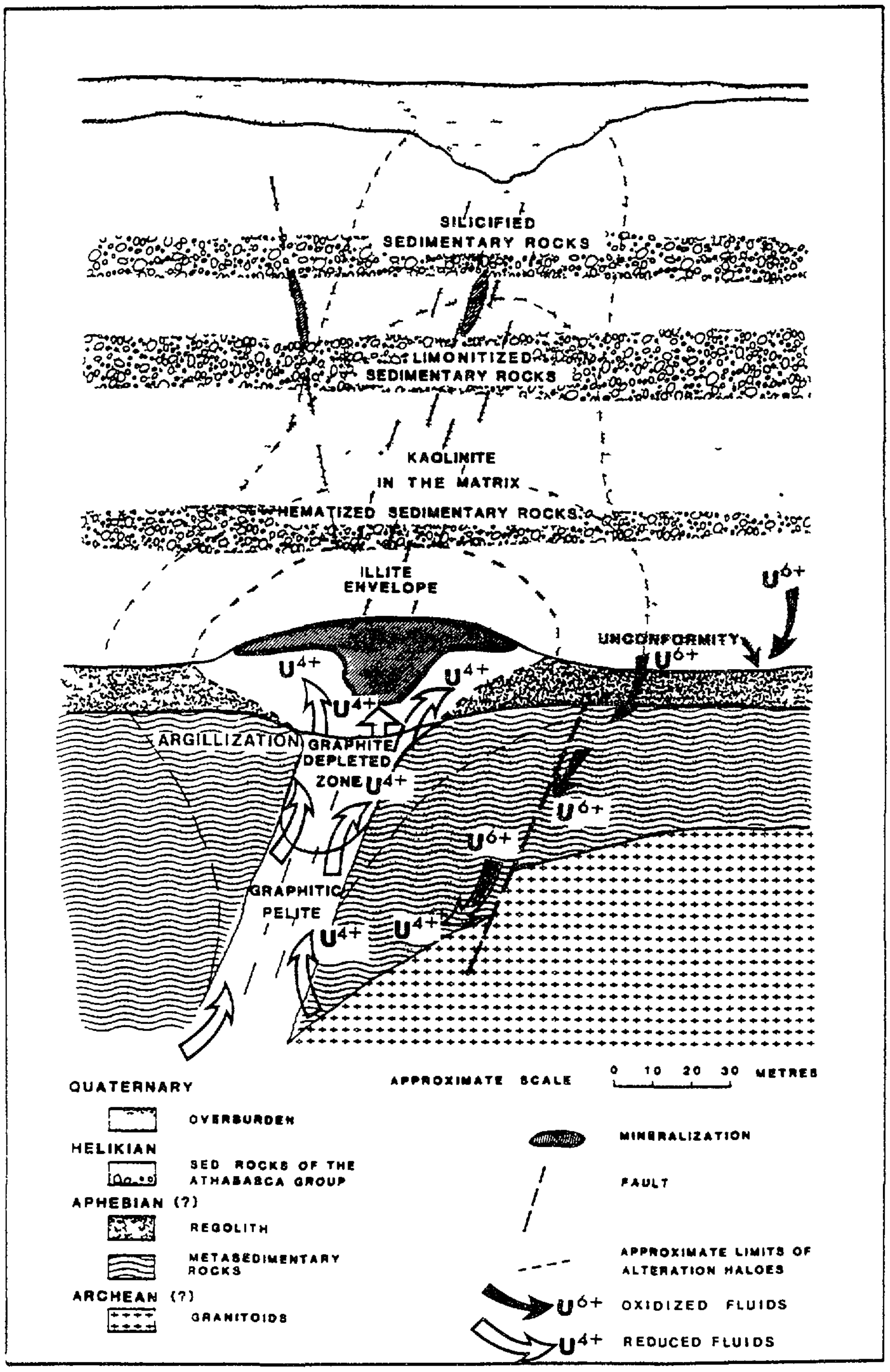

Figure 5: A scheme of a conceptual genetic model for uranium deposits associated with unconformities. Modified after RUZICKA [4].

Classification of resources additional to reserves

Classification of uranium resources additional to reserves is based upon URAG defined criteria, which are compatible with NEA/IAEA definitions [1; 13].

Estimated Additional Resources I (EAR I or Inferred Resources) are estimated for producing mines, deposits under development and for deposits being explored. The resources are spatially located in extensions of Reasonably Assured Resources (RAR), but within the inferred boundaries of the given deposit; or in deposits in which resources have been demonstrated, but are inadequate to be classified as RAR. Quantitative estimates are based largely on the broad knowledge of the geological character of the deposits and on the assumed continuity or repetition of mineralization. Orebodies that are completely concealed, but for which there is some geological evidence, may be included. The report includes a statement of the specific limits within which the resources are estimated.

Estimated Additional Resources II (EAR II or Prognosticated resources) are spatially located beyond the limits of RAR and EAR I, but occur in metallogenic domains within well established geological trends, or in areas with geological environments analogous to those with identified resources elsewhere. The attributes of EAR II are, as a rule, derived by extrapolation from identified deposits or by quantification of geological information.

Speculative Resources are those beyond the limits of RAR, EAR I and EAR II in areas favourable for uranium mineralization. Such resources are determined according to regional conceptual genetic models. Their existence and size are assumed from indirect indications, geological extrapolations and technical and economic considerations.

Data base

The data base contains: (a) delineations, geological definitions and descriptions of uranium metallogenic domains and areas considered favourable for occurrence of uranium deposits; (b) lithological, structural, mineralogical and geotechnical features of identified deposits; (c) quantities of uranium metal, ores, their grades and their spatial distribution; (d) conceptual genetic models for deposit types.

The data base consists of: (a) geological, geophysical, geochemical and topographic maps and aerial photographs; (b) computer records on sampling, quantities of resources and their attributes; (c) computer records on uranium occurrences in Canada; (d) records of and reports on uranium exploration in Canada; (e) annual summary reports for URAG on appraisals of RAR, EAR I, EAR II and S resources; (f) records of field observations by members of the Mineral Resource Appraisal Secretariat.

Quantification of resources

Depending upon the geological nature of deposits and areas studied and data available, two or more methods are used for quantification of resources in order to analyse and reconcile differences in the estimates. A detailed description of these methods is incorporated in the IAEA Instruction Manual "Methods for the estimation and economic evaluation of undiscovered uranium resources" by W.I. Finch, D.P. Harris, V. Ruzicka and E. Mueller-Kahle to be published in the near future. Some of the methods are briefly described, as follows:

(i) The basic quantification method used by MRAS is based on extrapolation of information on identified resources within a well explored (control) area and deposits to target areas, having analogous geological features as the control area. This method is commonly known as 'Geological method'. It is similar to the method, which was used for estimation of undiscovered uranium resources in the United States National Uranium Resource Evaluation (NURE) program [14]. In the above mentioned IAEA Instruction Manual this method is explained under the heading 'Mineralized-rock density methods'.

The basic equation is as follows:

$$R = N * T * F * P$$

where:

R = quantity of undiscovered uranium resources in tonnes U
N = area of the target area in square kilometres
T = tonnes of U metal per square kilometre within the control area
F = favourability factor, a number between 0.0 and 1.0, rarely >1.0
P = probability factor, expressed as a number between 0.0 - 1.0

If the grade of mineralized rocks in the control area can be established, then the variable T is replaced by the weight of the rock (W) in tonnes in the control area and its average grade (G) in per cent U in decimal fraction form, i.e.:

$$T = W * G / 100$$

Favourability (F) and probability (P) factors have to be determined by a geological expert or a group of experts familiar with the geology of the area.

(ii) For the Athabasca Basin region and some of its parts Deposit-size-frequency method (DSF) was used. This was applied in its PC computer version TENDOWG developed by the U.S. Geological Survey [15].

The general equation for the DSF method is:

$$U = A * \{\sum_{i=1}^{k} (\frac{n_{ic}}{A_c}) T_i\} * G * L$$

where:

U = unconditional uranium endowment in tonnes of U above a cutoff of 0.01 percent U

A = favourable area in square kilometres

k = number of deposit-size classes
n_{ic}/A_c = spatial density of deposits of size T_i in the ith deposit-size class within a control area A_c
G = average grade in decimal fraction form
L = optional scaling factor

(iii) For the estimation of global Canadian uranium resources, a crustal abundance method developed by Agterberg and Divi [16] was used. This model is based upon the assumption that the parent distribution of grades of uranium in the Earth's crust is lognormal when taking into account the average value for the distribution equal to their clarkes. However, the cummulative frequencies of the highest values of the metal in the identified deposits exhibit different lognormal distributions. The differences are then determined by calculating standard deviations for various cutoff grades.

(iv) The probability density for crustal grade in relationship to metal endowment was applied by Brinck [17] to appraisal of mineral resources of selected large regions in his MIMIC ('Mining Industry Model for Inventorization and Cost Evaluation') model.

The basic MIMIC formula is as follows:

$$M = R * X = \sum_{k=0}^{\alpha} \frac{\binom{\alpha}{k}}{2^{\alpha}} * R * X\,(1+Q)^{\alpha-k} * (1-Q)^{k}$$

where:

M = total resource of uranium
R = size of the environment in tonnes of rock
X = average initial concentration of uranium

Q = capacity of rock mass to contain uranium mineralization ('mineralizability')
α= order of sorting (separation, subdivision) of the environment
k = an integer from 0 to α

Ruzicka and Garrett [18; 19; 20] applied this model to Elliot Lake area. The model application considers that a certain volume of source rocks contains a fixed amount of uranium. The volume is repeatedly halved and uranium is divided between the halves according to a binomial rule that results in concentration in one half and depletion in the other. The maximum concentration of uranium in the principal ore-forming mineral (uraninite), i.e. 84.7 percent U, is considered a barrier concentration. A computer program simulating this process was developed by Garrett[19], who also applied this method for some other metals. The Ruzicka-Garrett application of the MIMIC method employs a conceptual genetic model for determination of variables, which are difficult to measure directly, namely the specific "mineralizability" and order of sorting of the environment.

(v) A quadrangle-cell method was used by R.T. Bell of MRAS for estimation of undiscovered uranium resources of south-central British Columbia. The area contains several uranium ocurrences of the sediment-hosted basal-channel uranium deposit type. As a base for estimation, one by two degree map sheets have been used. The maps contain information on distribution of uranium occurrences, on distribution of geological units prior to deposition of plateau basalts and on distribution of plateau basalts in the context with distribution of uranium occurrences of the basal-type. The area to be evaluated has been statistically correlated with an area in Japan, where deposits of similar type have been thoroughly investigated. A favourability factor has been assigned to each cell. The factors have been based upon a conceptual genetic model for basal-type deposits. The quantification of the resources was made upon assumption that the mineralization gradually decreases to zero at the borders of the favourable area.

Information transfer

Results of various studies are incorporated in the biennial publication "Uranium in Canada: Assessment of supply and requirements" (EMR Report EP-3), in the Nuclear Energy Agency - Organization for Economic Co-operation and Development and International Atomic Energy Agency joint report "Uranium Resources, Production and Demand" ("Red Book") and in "Fact Sheets", distributed annually by EMR to exploration and mining companies operating in Canada. Findings pertaining to regional and local geology and to conceptual models are published in GSC Current Research, in scientific journals and IAEA publications, which provide timely information for the professional public. Findings and conceptual models are also presented at professional public gatherings as talks and/or poster displays. They are not only timely, but provide a vehicle for exchange and refinement of concepts.

Acknowledgement

Critical reading of the manuscript by R.T. Bell of the Geological Survey of Canada is sincerely appreciated.

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METHODS FOR ASSESSMENT OF URANIUM RESOURCES

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Abstract

Four methods for the assessment of undiscovered uranium resources are presented, as they are being applied in the USSR. They include approaches to estimate undiscovered resources of the P1, P2 and P3 categories, equivalent to inferred, hypothetical and speculative resource categories of WOCA* for areas ranging in size from a few km^2 to large regions.

Uranium resources are assessed by various methods. The choice of the method depends on the extent of knowledge of the areas (territories) to be assessed, as the classification of reserves and resources adopted in the USSR considerably differs from that of other countries regarding reliability of the evaluation. Table 1 presents a comparison of the reserve/resource classification systems.

Table 1.

Comparison of classification for reserves and resources adopted in the USSR and abroad

USSR	reserves		resources		
	A + B + C_1	C_1 + C_2	P1	P2	P3
ABROAD	identified (reserves)		undiscovered		
	demonstrated	demonstrated	inferred	hypoth-etical	specu-lative
	measured	indicated	possible		

*"World outside centrally planned economies areas"

It is necessary to point out that the well-studied masses of raw materials, assessed according to categories A, B, C_1 and C_2 are called reserves in the USSR and all the rest - resources.

In practice the following methods of assessment of resources are used (Table 2):

Table 2.

Method of assessment	Used for assessment of resources in categories	Fields for assessment
Secondary residual dispersion haloes,	P_1-P_2	Single sites
Processes of ore formation for infiltrating deposits or "sandstone" type	P_1-P_3	from sites to provinces
Lithochemical dispersion arteries	P_2-P_3	areas, provinces
Mean productivity	P_2-P_3	areas, provinces, territories

ASSESSMENT USING SECONDARY RESIDUAL DISPERSION HALOES

The method is based on the proven ratio stability of productivity of the secondary residual halo (q_h) and the host rock (Q_{rT}) =

$$q_h = S(\bar{c}_x - c_b)\, m \cdot \%,$$

where

S - area of the secondary halo, in m^2;

$\bar{c}_x$ - mean uranium contents in the halo, in %;

c_b - background uranium contents, in %.

Resources up to a depth of H m will be:

$$Q_{rT} = \frac{1}{k} \quad q_h d \cdot H \cdot 10^{-2}\ t,$$

where

k – ratio coefficient of uranium productivities in the halo and host rock deposition; in many cases $k = 1$;

d – volumetric mass of the rocks; for calculations it is taken 2.5 t/m^3, then

$$Q_{rT} = \frac{q_h \cdot H}{40} \cdot t$$

When the gamma-logging data are used, then

$$Q_{rT} = S(\bar{I}_x - I_b) \cdot H \cdot 2.5 \cdot 10^{-6} \ t.$$

where

$\bar{I}_x$ – mean intensity of gamma radiation in the halo;

I_b – background value of gamma radiation.

ASSESSMENT USING A SET OF CONDITIONS FOR ORE FORMATION

The method is based on the evaluation of the uranium amount accumulated in the region of geochemical barrier by ore forming solutions.

The amount of uranium preciptated on the thinning zones of ground oxidation (per unit of the geochemical barrier) equals:

$$Q = (C_{in} - C_{end}) \ V \cdot t$$

where

C_{in}, and C_{end} – uranium contents (g/l, kg/m^3) before and after the geochemical barrier;

v – filtration rate according to Darcy's law equals – $K_f \ I \cdot 365$ m/year;

t – duration of the process;

K_f – filtration coefficient, m/day;

I – value of the piezometric gradient.

The value of the piezometric gradient could be found from paleohydrogeological reconstructions using the methods of mathematic modelling (from paleohydrogeological maps) with an accuracy sufficient for the calculations. The same methods could be used to assess the possibility of altering the hydrochemical situation to a productive aquifer throughout the whole period of ore formation and, as a result, to project the variation of C_{in} and C_{end}.

For the whole area of the geochemical barrier (h-thickness of the permiable bed, 1 - length of the thinning front of the oxidation zones in m) the total resources will be :

$$Q = (C_{in} - C_{end}) K_f I h C \cdot 365 t.$$

As the uranium incompletely precipitates on the geochemical barrier (a part of it settles on the newly formed minerals, a part - in the reduced zone as primary haloes) a correction coefficient is used in some cases. In practice 0.75 is used.

ASSESSMENT USING LITHOCHEMICAL DISPERSION ARTERIES

The method is based on an established interrelation between the uranium productivity in the dispersion artery and the productivity in the dispersion haloes situated on an adequate water catchment area (denudation basin). Productivity of the dispersion artery c_x (m^2%) on the water catchment area at any point of testing is:

$$q_x = S_x (C_x - C_b) m^2\%.$$

where S_x - water catchment area (denudation region) for a point of testing in m^2;
C_x - uranium contents in alluvia at a point of testing in %;
C_b - local uranium background in alluvia in %.

The prognosticated resources are:

$$Q = \frac{H}{40} \sum_{i=1}^{n} \cdot 9i \ t$$

where n - number of contiguous beds.

ASSESSMENT USING MEAN PRODUCTIVITY

While assessing regions, one can be guided by already known deposits typical for certain geological conditions, encountered in other well-studied regions. It is assumed that the sites with similar geological structure could be similarly ore-bearing. Having determined the productivity q for a well-studied region

$$q = \frac{Q}{S}\ t.km^2,$$

one will estimate the resources of the region to be assessed as

$$Q_r = q \cdot S_{rT}.$$

A similar method can be used when assessing such provinces, where the types of deposits to be used as guides for comparison, are different. Depending on the geological structure of the province, possible analoguous situation in other regions are chosen as samples. Every deposit type is assessed as above; the results are aggregated.

In the case of resources assessment of large less known regions of millions of square kilometers, the mean productivity of well-studied territories is first to be determined (e.g. per 10,000km^2).

URANIUM RESOURCES AND COMMENTS ON RESOURCE DATA

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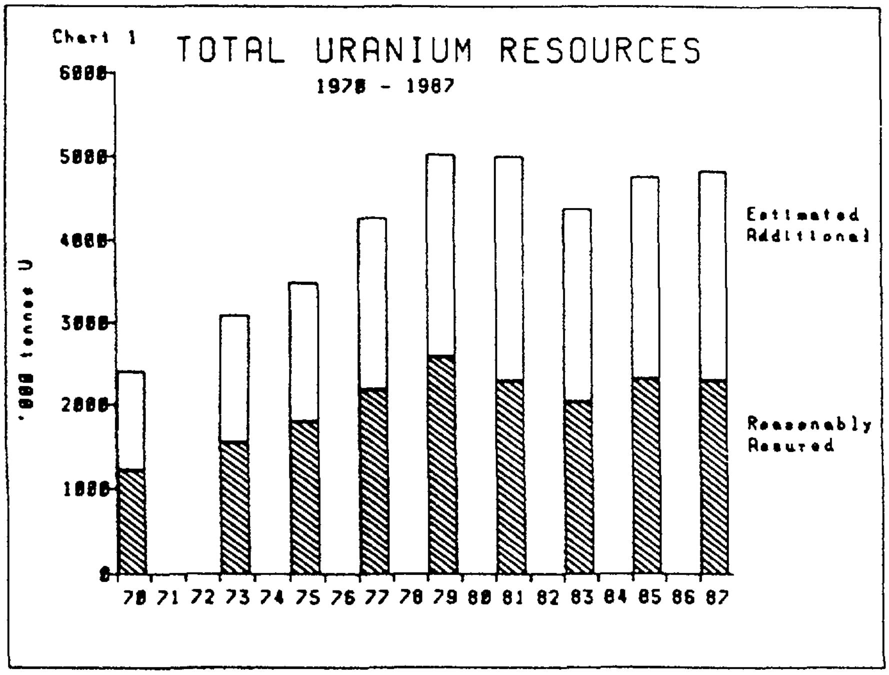
Abstract

The paper correlates past and present data on uranium resources, exploration, expenditure, and Nuexco spot prices (exchange value) and points out that the development of uranium resources over the time 1978 - 1987 is closely related to the exploration expenditures, which again correlate with the uranium spot price development. For the time frame 1970-1987, the changes in the geographical distributions of total uranium resources and RAR are illustrated. It is pointed out, however, that uranium resources are not homogeneous as geology, mining and political factors heavily influence their availability as supply. Finally uranium production, reserves and their relationship with demand are placed into perspective with the relevant data of eight other non-energy minerals.

This brief presentation is based on work done earlier this summer for two other papers on uranium resources. It comprises comment on seven slides for which most of the data is from the OECD/IAEA Reports on Uranium Resources, Production and Demand.

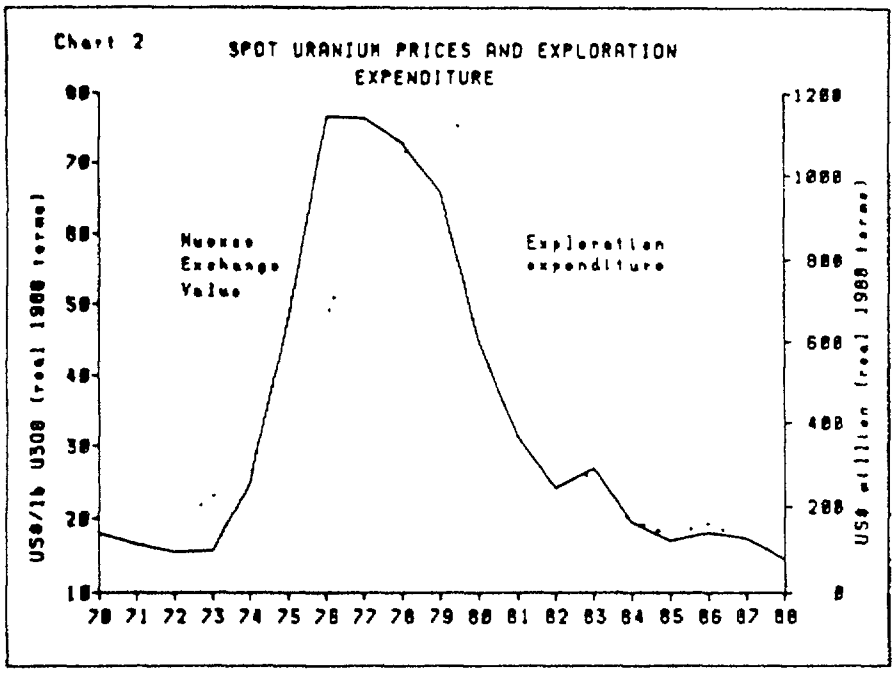
<u>Total Uranium Resources 1970 - 1987</u>



Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

In each year for which the survey of resources is undertaken, two categories are defined on the basis of recoverable cost. There is greater confidence in the lower cost category, or Reasonably Assured Resources and in the early years these were defined as reserves. This first chart simply plots for each year the total resources reported for both these categories. The most recent update of this data has not been included since it is incomplete. The chart shows a steady rise in the earlier part of the period to a peak of around 5 million tonnes in 1979, a level which has not changed very much since then. The level of RAR has remained just above or just below 2 million tonnes across the period.

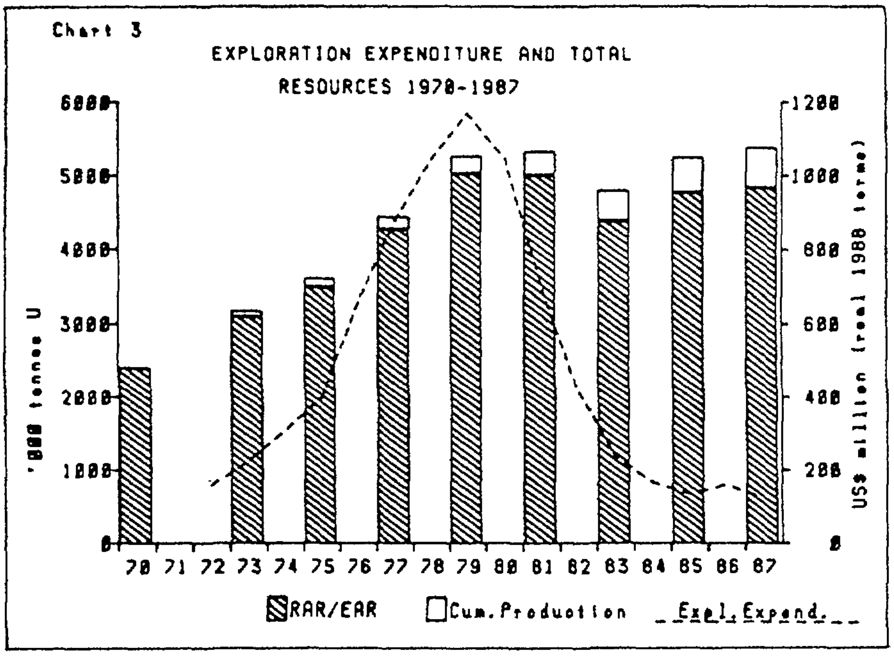
Spot Prices and Exploration Expenditure



Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

An explanation for the trend in the total quantity of resources shown in Chart 1 is given by this second chart which plots exploration expenditure and a measure of spot uranium prices. Both of these have been converted into real 1988 dollars. As you can see the peak in exploration expenditure closely matches the peak in total uranium resources shown in the previous chart and appears to lag the peak in spot prices by about three years. The similarity in the trend between the two is remarkable suggesting that the drop in prices since the mid 1970's has been a contributory factor to the fall in exploration expenditure from its peak in 1979. Changed expectations of growth in installed nuclear generating capacity have also been important.

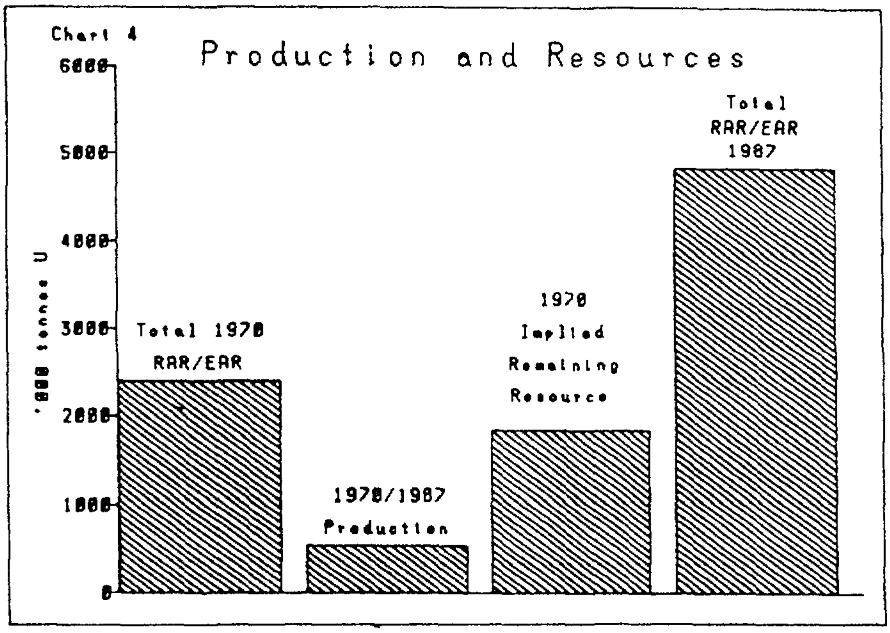
Exploration Expenditure and Total Resources 1970-1987



Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

Chart 3 is similar to the previous two but shows exploration expenditure against perhaps a more correct measure of total resources, that is, with cumulative production over the period added back in. Another way of comparing these resources data with current market conditions is to note that the lower of the cost categories, \$80 per kg U or \$30 per lb U308, is well above the current level of spot prices. The Nuexco Exchange Value has been below \$30 per lb U308 since September 1980. The chart also shows how relatively small is the share of production in total resources.

Production and Resources

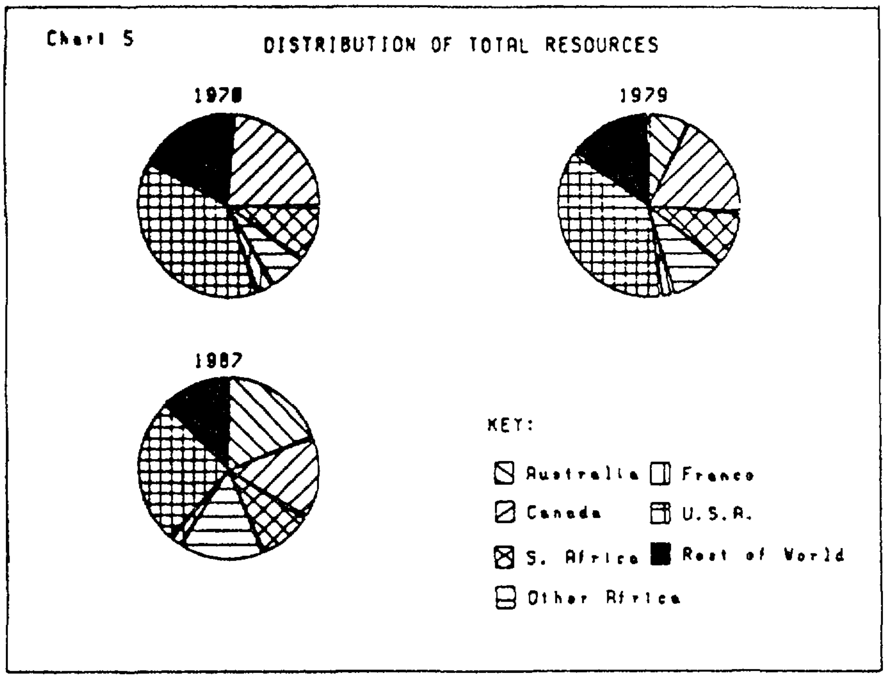


Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

This point is brought out more clearly by the next chart which compares total resources at the beginning and end of the period under review. The first bar shows total RAR and EAR as reported in 1970 and the second cumulative production between 1970 and 1987. Subtracting production from resources gives the implied remaining resource which is the third bar. In fact as you can see the quantity of total RAR and EAR is substantially greater showing that addition to resources has more than kept pace with production.

Distribution of Total Resources

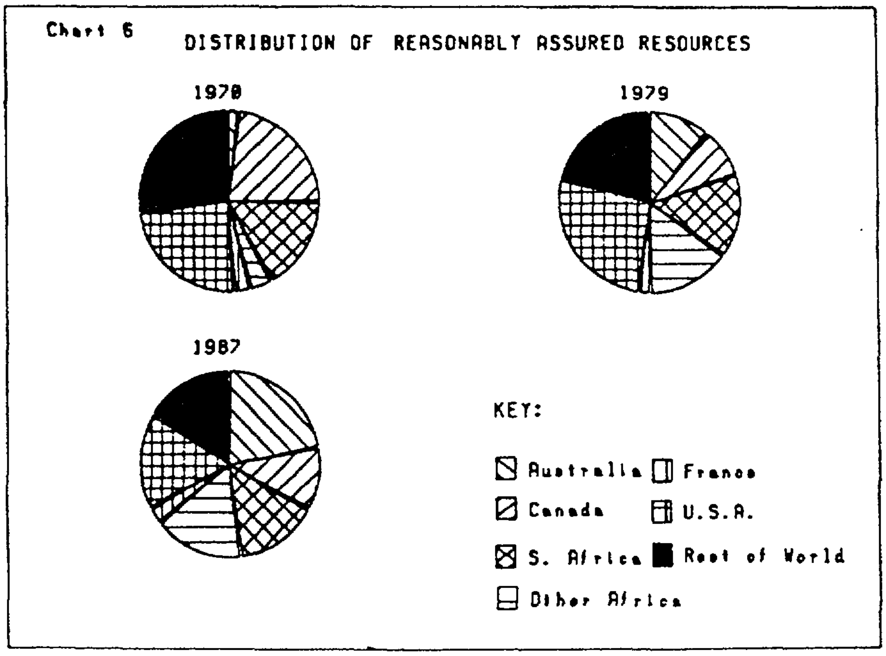
The next two charts are concerned with another aspect of resources, that is, their geographical distribution. Electric utilities quote diversification of sources of supply as an important objective in their purchasing policies.



Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

The three pie charts are for 1970, a year prior to the first oil price rise, 1979 at the time of the second and 1987 the latest year for which complete data is available. The share of North America, that is Canada and the USA, has fallen from 62% in 1970 to 42% in 1987. The most significant change has been for Australia, its share has increased from just 1% in 1970 to a little under 20% in 1987. There has also been an increase in the share of Other Africa which includes Gabon, Namibia and Niger, its share more than doubled between 1970 and 1987. To some extent this must reflect increased investment in exploration in these countries both by national and foreign governments.

Distribution of Reasonably Assured Resources



Source: The Uranium Resource Paper by Sir Alistair Frame to the British Nuclear Forum Conference July 1989.

This chart is on a similar basis but shows the distribution of the narrower definition of resources for the same three years. The overall pattern is similar, with a decline in the share of North America and an increase in that of Australia and Africa, excluding South Africa.

Underlying both these charts is the assumption that resources are homogeneous, which they clearly are not. Variations in grade, just to take one factor, will place resources at different ends of the range within the cost categories. A weak market may result in more resources being extracted from the lower cost categories which could increase the cost of extracting resources in the higher cost categories. In some cases this could result in a permanent loss of resources. Additionally their development may be dependent on production of other metals, such as gold in South Africa. There may also be political restrictions which limit the development of resources, the Three Mine Policy in Australia is a good example.

Production and Reserves for Nine Major Minerals

Table I has been included to place the data on uranium resources into context by comparing it with eight non energy minerals. They have been ranked in descending order of abundance using the measure shown in the first column, that is the Reserve Base[1] for each of the minerals. The main

1. In place demonstrated (measured plus indicated) resource from which reserves are estimated, and including those resources that are currently economic (reserves), marginally economic (marginal reserves) and some of those that are currently subeconomic (subeconomic reserves).

TABLE I. PRODUCTION AND RESERVES FOR NINE MAJOR MINERALS

	A World Reserve Base	B World Production Total 1985/86 Averages	B as a Percentage of A	Static Reserve Life (years)	Ratio of Identified Reserves to Cumulative Primary Demand 1987-2000
	(All in million tonnes)				
Potash	18000	28.6 [2]	0.2	over 300	19
Bauxite (for Aluminium)	5800	22.1	0.4	237	13
Contained Iron	89000	498.0	0.6	132	9
Phosphate	36125	141.6	0.4	very large	5
Uranium RAR 1985	2.3	0.04	1.6	64	3.2
Contained Copper	566	8.4	1.5	40	2.6 [1]
Contained Lead	142	3.4	2.4	28	2.4
Contained Zinc	300	6.9	2.3	25	1.6
Contained Tin	4.3	0.2	4.4	17	1

1. Land Based Only
2. of K_2O

Source: Minerals Handbook 1988-89 P. Crowson

qualification of a table such as this is the comparability of the data. It does however represent at its broadest level the picture of reserves from the perspective of each industry and the ranking is broadly the same across the columns. Of the nine minerals shown phosphate is the only other to have a cost associated with the reserve[2] data.

As the title to the fourth column suggests the reserve data is static. Reserve life assumes that production continues at its 1985/86 level. It is more likely that there is a shift into and out of reserves as the relationship between costs and prices varies over time. The data also excludes above ground stocks, including that in scrap and the possibility of recycle. Similarly the demand forecast cannot take full account of possible developments in technology which may reduce per unit consumption. The uranium market is a good example. Whilst the number of reactors installed worldwide may increase, the trend in demand for uranium may not necessarily increase pro rata due to implementation of Advanced Fuel management schemes for operating reactors and the introduction of new reactor designs.

2. Reserve Base data uses production costs of less than $100/tonne.

HIGHLAND URANIUM PROJECT: A NEW IN SITU URANIUM MINING OPERATION

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Presented by T.C. Pool

Abstract

The development of the Highland ISL uranium project in the southern Powder River Basin by the Everest Minerals Corporation, Wyoming, USA is described. The property had been operated by Exxon between 1972 - 1984 and had produced about 22.9 million lbs U_3O_8 (about 8800 t U), before it was acquired by Everest. After receipt of the required permits, the ISL facility was constructed. It consists of two monitor well rings enclosing 225 production and injection wells on resources of about 2 million lbs U_3O_8 (about 800 t U). Production commenced in January 1988 and was expected to reach one million lbs U_3O_8 in 1989.

In January 1988, Everest Minerals Corporation (EMC) started up the Highland Uranium Project. This is a new large in situ production facility designed to produce up to two million pounds a year.

The project was initiated in July 1982 when Exxon informed EMC that they were interested in selling their Highland Project. EMC had one month to evaluate the project and make an offer. The EMC offer was accepted and the acquisition was concluded in January 1983. At that time, Exxon was operating an open pit mine four hundred feet deep and a conventional acid leach mill, the Highland Uranium Project, and restoring their in situ pilot plant. Exxon operated this facility from 1972 to 1984 producing at rates of up to 2.6 million pounds per year in 1980. During its life the mine produced 22.9 million pounds of U_3O_8.

When EMC acquired the property, they acquired both the remaining unmined reserves which were located outside Exxon's open pit mine and the restoration responsibilities for Exxon's In Situ Pilot Plant. Subsequently, EMC acquired

Exxon's mill building, solvent extraction building, office building, uranium precipitation process equipment, drying and packaging facilities, and associated utilities. They also acquired an abandoned gas well which was cased to a depth of 9800 feet and recompleted this well as a waste disposal well.

In addition, EMC acquired electric well logs for the 17,000 holes that Exxon had drilled on the property. At Highland, EMC controls an area of 15 thousand acres. They acquired the eastern portion from Exxon as the Highland Project, the western portion from Exxon as their West Highland property, and the north central portion from TVA, as their North Morton Ranch property. EMC has reserves in excess of twenty million pounds in this area. The project was initially funded for five years of holding costs to provide time for mine planning, engineering studies, environmental studies, feasibility studies, as well as to obtain permits, sales contracts, and project financing. EMC allowed several years to obtain permits since economic operations were difficult with the type of in situ permits then being issued in Wyoming. Most of the experience in Wyoming with in situ mines had been limited to pilot plants. Consequently, the thinking of the Department of Environmental Quality (DEQ) and Nuclear Regulatory Commission (NRC) needed to reflect what EMC had learned about economic regulation of commercial in situ mines with its Texas operations. During the time EMC was working with the Wyoming DEQ and the NRC they were also restoring Exxon's pilot plant area. EMC asked them to change the way they regulated in situ operations and asked them to consider irrigation and deep well disposal of operational wastes for the first time. In the process, EMC developed the confidence and trust of the NRC and the DEQ. After EMC had their confidence and had explained its concerns, the agencies acted very responsively and professionally. After reaching a philosophical agreement on principles, the permitting went very quickly and EMC obtained the first commercial in situ permit in Wyoming in 9 years. EMC also obtained the first Wyoming permit for disposal of in situ wellfield waste water by irrigation as well as the first Wyoming permit for deep well disposal of in situ waste water.

During the time EMC was waiting on permits it also acquired Tennessee Valley Authority's (TVA) North Morton Ranch Mine. TVA had installed two shafts and some underground haulage at this site, but production had not commenced.

Exxon finished mining at Highland in March 1984, milling operations ceased in June 1984, and in December 1984 they completed the reclamation of the mill area, removed their equipment and turned the mill buildings over to EMC.

On July 20, 1987 EMC began construction of a one million pound per year wellfield/satellite operation and a two million pound a year central plant. By January 1988 two monitor well rings containing 135 monitor wells, and 67 patterns containing 225 production and injection wells had been completed. These rings enclosed a total of approximately two million pounds U_3O_8.

On January 5, 1988, production commenced and by September 1st EMC had produced in excess of 633,000 pounds. The startup was very orderly and on schedule. By the end of February 1988, EMC was recovering uranium at rates about one million pounds a year. In 1989, EMC expects to produce about one million pounds.

Before continuing, a brief review of the in situ process is in order. The in situ uranium mining process, as EMC operates it, is divided into two portions: the satellite process and the central process. These processes are illustrated in Figures 1 and 2. Solutions are injected into the ore by means of a grid of wells drilled into the ore. The grid is designed to efficiently distribute flow through the ore. EMC normally uses a five spot pattern with injection wells at the corners of a square and a production well in the center of the square. Ground water is circulated through the ore zone and through a surface facility which contains ion

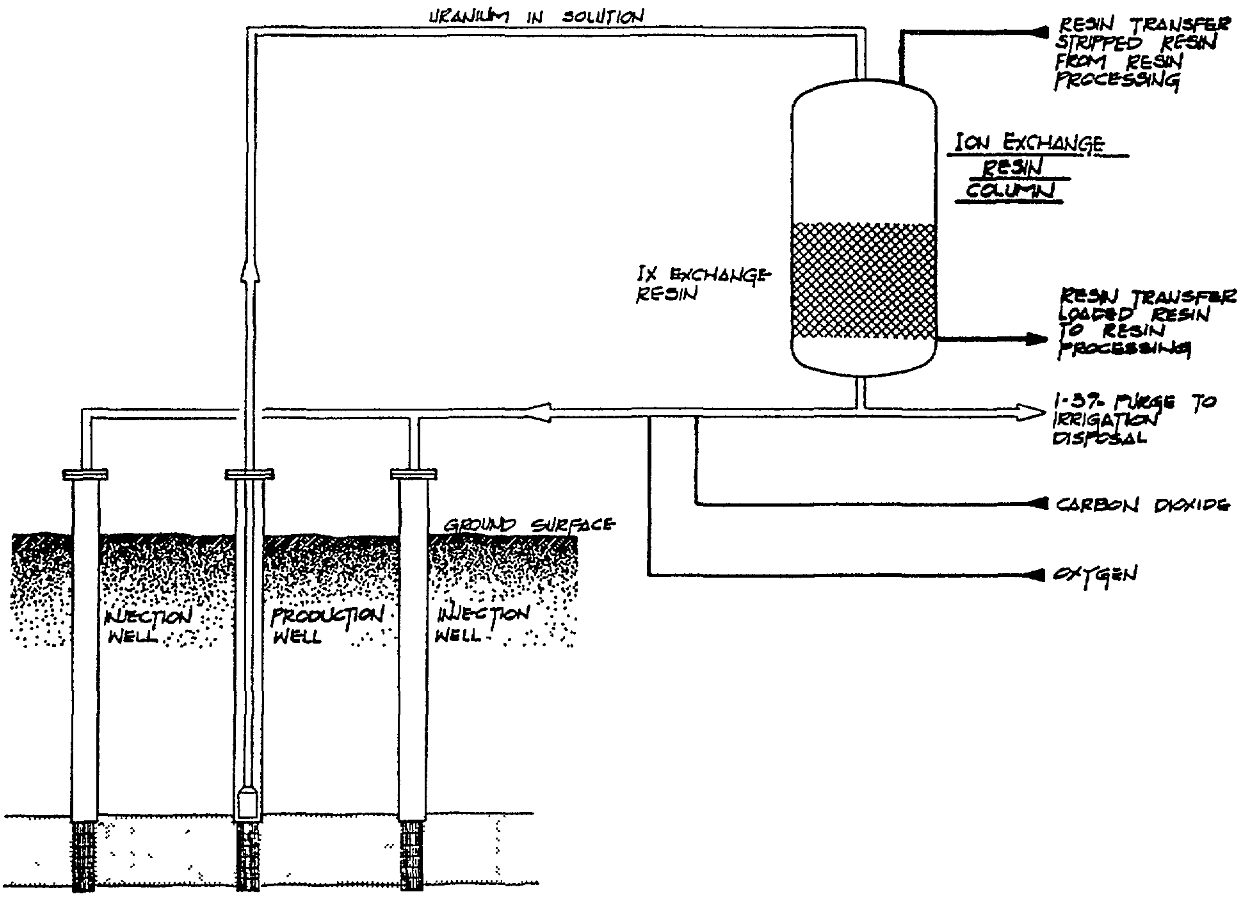

FIG. 1.

exchange columns. These columns are filled with ion exchange resin which is basically small plastic beads. The ground water, with carbon dioxide and oxygen added, flows from the injection wells to the production wells dissolving the uranium as it moves through the ore. The water produced from the production wells contains from 20 to 200 parts per million (ppm) uranium and is pumped from the production wells into the ion exchange columns through the bed of ion exchange resin beads. It is then returned to the wellfield. EMC withdraws one to three percent of the fluid circulated. This withdrawal is called "wellfield purge". It is primarily fresh water containing small quantities of radium and uranium. More water is withdrawn than injected in order to maintain an influx of fresh water into the perimeter of the leach zone. This confines the leach chemicals to the mining zone and prevents any degradation of ground water outside the mine zone. The wellfield purge also controls the increase in sulfate and chloride ions. This buildup

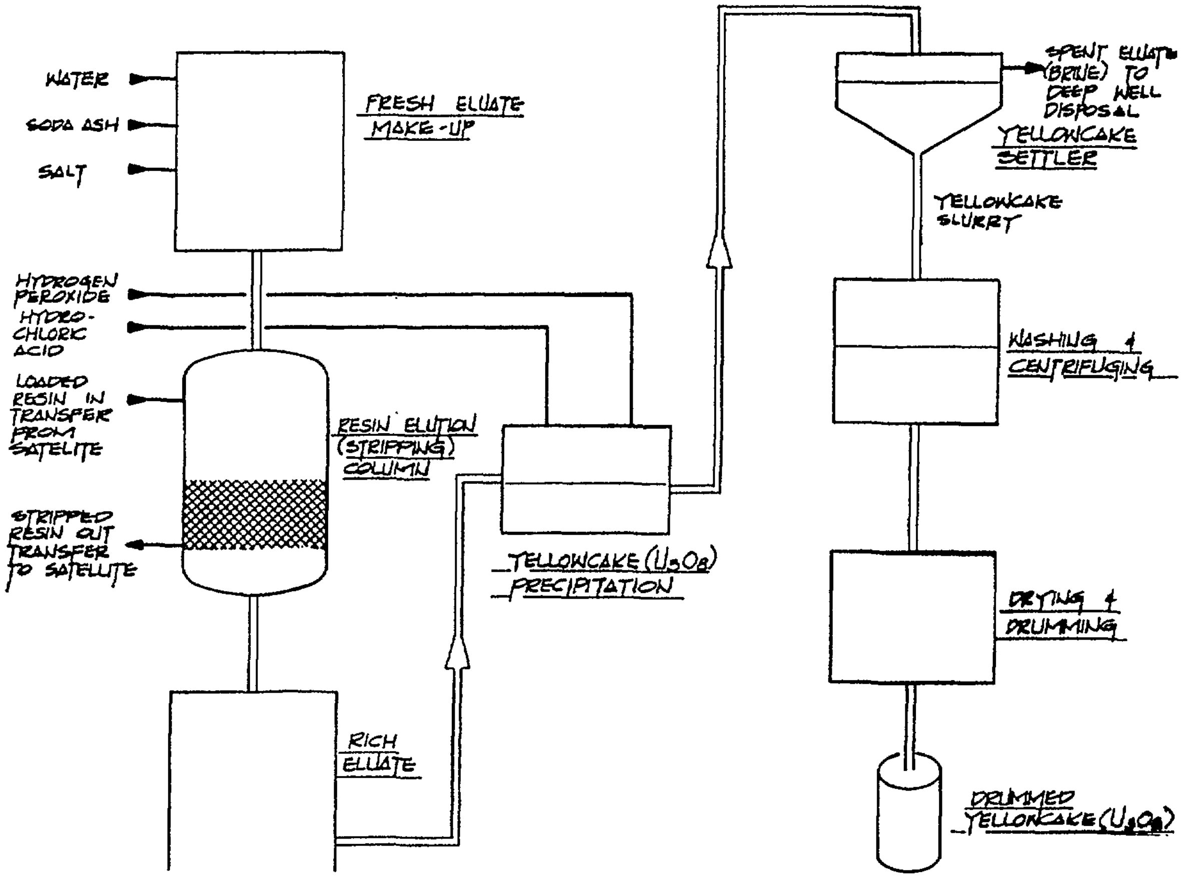

FIG. 2. In situ uranium mining resin processing.

is inherent in the process and is detrimental to the ion exchange recovery rates. Wellfield purge is pumped to a 50-gpm irrigation-type disposal area.

The uranium is recovered on the ion exchange resin beads at the satellite facility. When the beads become loaded with uranium, the resin is removed and trucked to the central resin processing facility. At the central resin processing facility the ion exchange resin beads are placed in an elution column where salt water is passed over the beads. The resin beads contain about two to six pounds of uranium per cubic foot of resin. EMC strips the uranium off the resin beads with the salt water solution which contains about eight percent sodium chloride and two percent sodium carbonate. The brine after contacting the loaded resin contains around twelve thousand parts per million uranium. Therefore, the ion exchange recovery and stripping system has concentrated the uranium from two hundred parts per million in ground water to twelve thousand parts per million in a salt water solution. This salt water solution is called rich eluate. EMC acidifies the rich eluate with either sulfuric acid or hydrochloric acid. This springs out the carbon dioxide enabling the precipitation of uranium. EMC then precipitates uranium as yellowcake either by ammonia precipitation or by hydrogen peroxide precipitation. The choice here is dependent on the molybdenum content of the ore. In those areas where molybdenum is present in the ore it will be produced with the uranium and recovered on the ion exchange resin. In that case EMC uses hydrogen peroxide precipitation since the molybdenum is not co-precipitated with the uranium. With ammonia precipitation, the molybdenum is co-precipitated with the uranium and a subsequent molybdenum removal process is required. At Highland, EMC is able to use ammonia precipitation and in South Texas they use hydrogen peroxide precipitation. After precipitation, the uranium is a finely divided yellow solid about five microns in diameter. EMC settles the yellowcake in a cone bottom tank where it is concentrated to about fifteen percent by weight solids. This slurry is then washed either by counter current decantation at Highland or by batch decantation in South Texas. EMC then either filters or centrifuges the slurry to reduce the water content and this thickened filter sludge or centrifuge solid is pumped to a drying facility. EMC filters at Highland and centrifuges in South Texas with batch drying in South Texas and a rotary hearth dryer at Highland. The uranium is then drummed in fifty-five-gallon drums.

The Highland Project construction was initiated on July 20, 1987 and completed in five and one half months, the operation started on January 5, 1988 in weather that was twenty degrees Fahrenheit below zero. EMC expects to produce about 1,000,000 pounds this year. They are currently constructing another satellite in Section 14 on the reserves acquired from TVA. This will initially be a 1800 GPM satellite to be expanded to 3600 GPM next year. The future production rate for this project will be based on existing contracts. The production will be expanded as EMC acquires additional contracts with favorable terms.

DEVELOPMENT OF AN ECONOMIC SUPPLY CURVE
FOR URANIUM DEPOSITS

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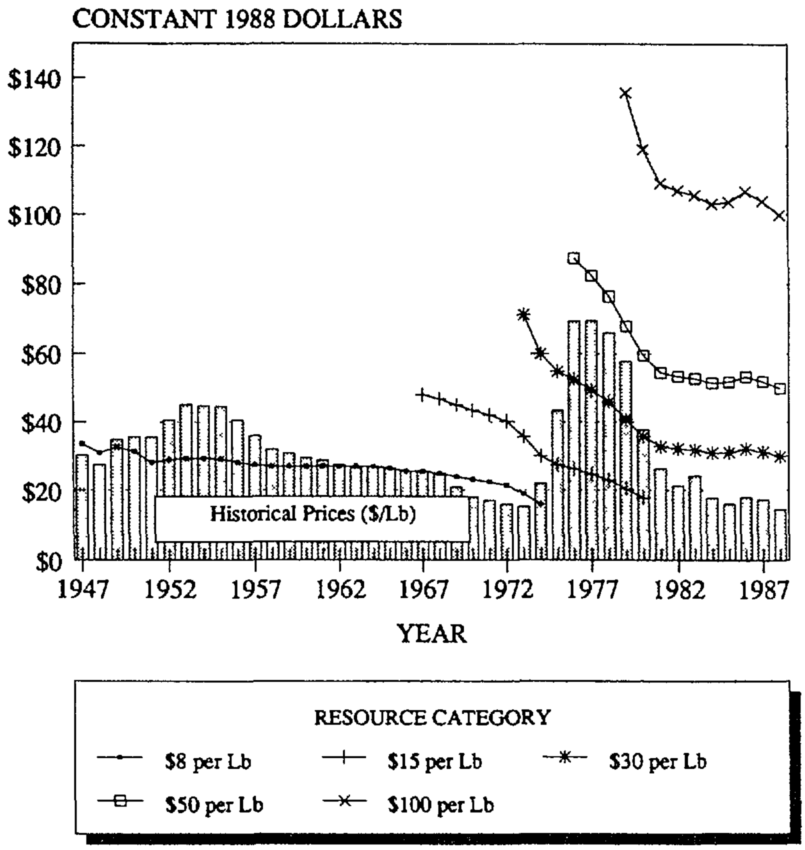
Abstract

The paper presents a system of uranium supply curve development which provides a deposit characterization for a wide range of geological, operational and economic parameters. This concept provides the possibility to determine these parameters both specifically and generically and to use them for a single econometric model. The supply curves generated for individual deposits may by combined into regional, national or ultimately into a worldwide supply curve.

INTRODUCTION

The cost categories in use for uranium resource/reserve classification by various organizations have long been a subject of heated debate between the many interested and involved parties. Controversy of this type was common during the late 1970s when rapidly rising prices and costs made most reserve estimates obsolete within a very short time. The controversy centered upon two factors, the means by which the resources/reserves are calculated and categorized, and the relevance of the categories to the marketplace.

The NEA/IAEA resource/reserve categories have risen from \$5 per pound U_3O_8 in 1965, to the current categories of \$80, \$130 and \$260 per KgU (approximately \$30, \$50 and \$100 per pound U_3O_8). The categorization of US uranium resources/reserves by the U.S. Atomic Energy Commission, the Department of Energy and, most recently, the Energy Information Agency, has followed a similar course. Since 1981, none of these categories have been relevant to prices existing in the marketplace. This disparity, as shown in Figure 1, illustrates the difficulty of correlating point estimates with ever-changing prices.



U.S. AEC, ERDA & EIA Classifications

Figure 1
U.S. URANIUM RESOURCE CATEGORIES
vs HISTORICAL URANIUM PRICES

Those of you who have been involved in resource estimation recognize that single-point values for reserves, production costs and sales prices do not adequately characterize a uranium deposit. Such values do not reflect the spectrum of ore grades available within a deposit. They do not reflect the operational choices of cut-off grade or production rate. And, they certainly do not reflect the potential viability of a deposit at the wide range of product prices likely to be encountered during the mine life.

This paper presents a system of uranium supply curve development which provides a deposit characterization for a broad range of geologic, operational and economic parameters. It offers the opportunity to determine these parameters specifically or generically and to incorporate them into a single econometric model. The supply curves generated for individual deposits may be combined into a regional or, ultimately, a worldwide supply curve.

GEOLOGIC FACTORS

All uranium deposits are unique and each exhibits a diversity of ore grades. Two primary factors influence this diversity: overall average ore grade and homogeneity. In general, one can expect a greater range of ore grades from high-grade deposits simply because they do contain some higher grade material. Secondly, however, the mode of emplacement can have a substantial impact on the distribution of ore grades. Roll-front deposits in Wyoming, for example, tend to be very erratic in the distribution of ore grades while the quartz-pebble conglomerates of Elliot Lake display a more generally-disseminated pattern of ore grades.

The diversity of ore grades within a deposit is a measure of the ability of the deposit to support a changing series of cutoff grades which can be correlated to changing prices. This ability to "high-grade" or "low-grade" the deposit as may be required (or desirable) by high or low metal prices determines the ability of an operation to remain profitable in the face of changing prices. These changes can have a major impact on quantity of resources potentially available at the time of exploitation.

Grade/tonnage curves are a well-established means of assessing the impact of cut-off grade variation on resource grade and quantity. Such curves are readily developed from even the most simplistic computerized data bases. By converting each pair of values on a grade/tonnage curve to pounds U_3O_8, grade/resource curves can be developed. Figures 2 and 3 present a series of grade/resource curves derived from actual drill hole data from uranium deposits in North America. These

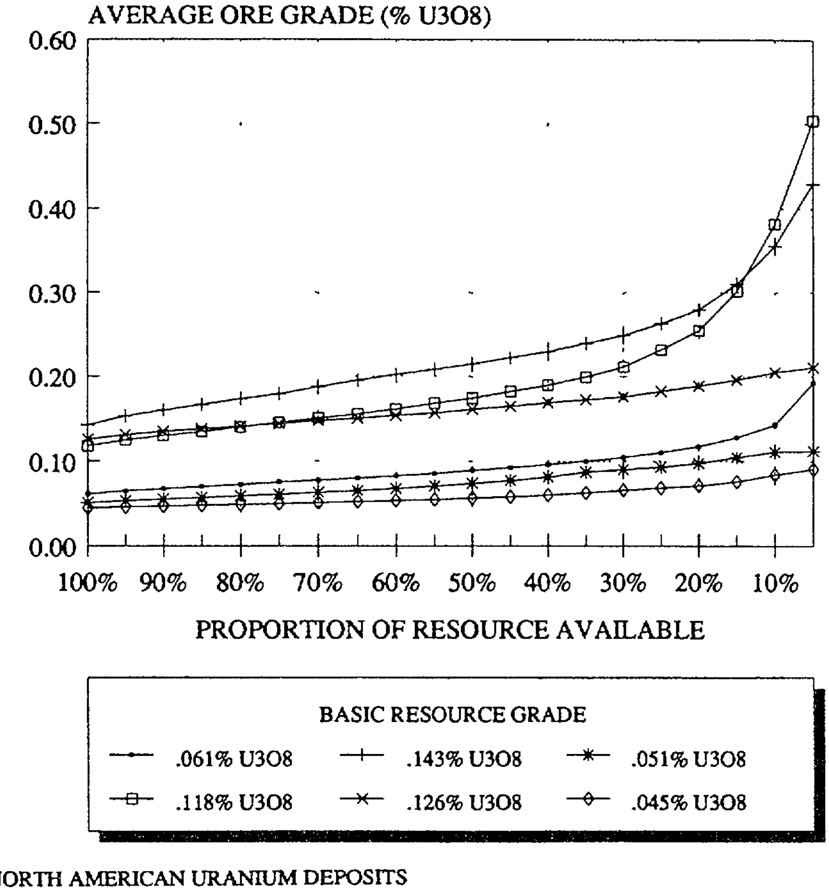


Figure 2
GRADE/RESOURCE CURVES
LOW-GRADE DEPOSITS

curves were compiled by sequentially increasing the cut-off grade from the lowest grade drill hole intersection to the highest grade drill hole intersection. At each cut-off grade, an average deposit grade and the corresponding quantity of resources can be calculated. In order to compare the grade/resource curves for a series of deposits, the quantity of resources has been expressed as a percentage of the maximum available resource instead of an absolute quantity.

For the purposes of this paper, the concept of the grade/resource curve has been carried one step further to a "grade ratio" curve.

The "grade ratio" is the ratio of average deposit grade to the basic resource grade at varying cut-off grades. By plotting a series of these grade ratios versus the

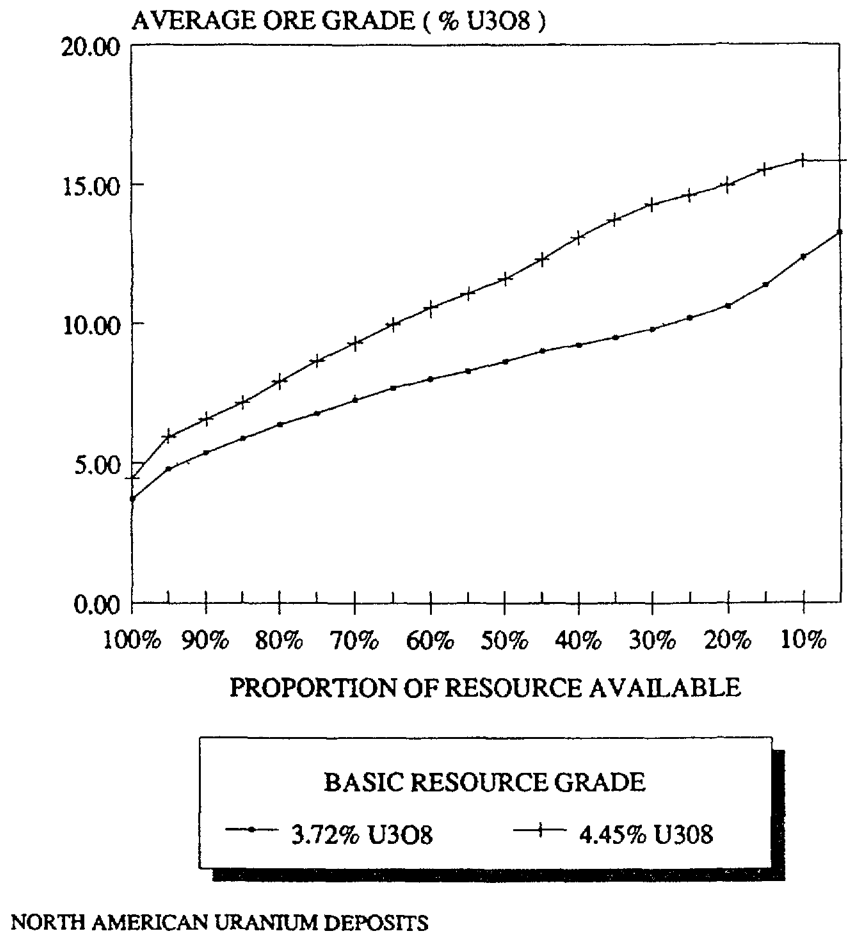
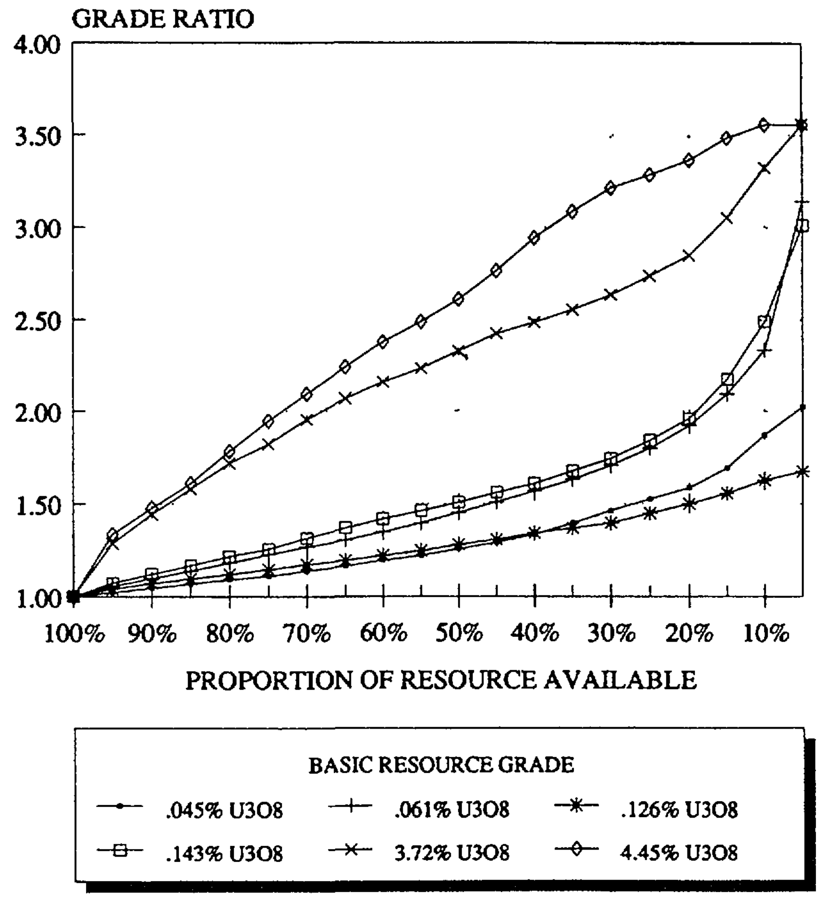


Figure 3
GRADE/RESOURCE CURVES
HIGH-GRADE DEPOSITS

corresponding percentage of available resources, a characteristic curve for a deposit can be generated. A relatively flat curve indicates a fairly homogeneous deposit while a steep curve is indicative of a heterogeneous deposit. The grade ratio curves shown in Figure 4 were calculated directly from the grade/resource curves of Figures 2 and 3. Note that the higher grade deposits provide a higher grade ratio curve.

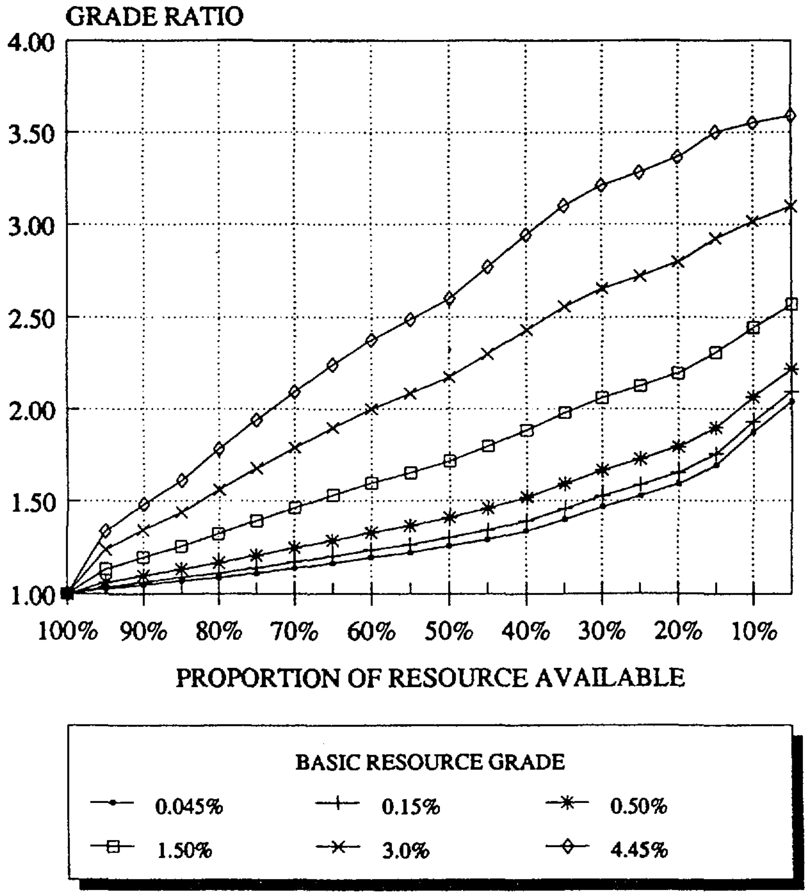
Where available, actual detailed grade/tonnage data from a block model or other type reserve calculation may be used to generate a grade ratio curve for any specific deposit. If such detail is not available, it may be possible to estimate a grade ratio curve from a generic model.



NORTH AMERICAN URANIUM DEPOSITS

Figure 4
URANIUM GRADE-RATIO CURVES

The series of grade ratio curves shown in Figure 4 has been used to compile a generic model of uranium grade ratios. This model is set forth in Figure 5. It is, in essence, a straight line interpolation model between the 0.045 percent grade ratio curve and the 4.45 percent grade ratio curve as that process provided a much better fit than did the various curve equations which were tested. The input to this generic model is simply the average grade of a deposit. The output from the model is the predicted distribution of grades within that uranium deposit. This distribution defines the geologic diversity of the deposit.



GENERIC COMPILATION

Figure 5
URANIUM GRADE/RESOURCE MODEL

OPERATIONAL FACTORS

It has been a long-standing custom in the mining industry to "high-grade" a deposit during periods of low prices and to maximize mine/mill capacity with lower-grade ores during periods of high prices. The result of this high-grading and low-grading is a relatively constant profit margin as illustrated in Figure 6, a profit margin analysis[1] of the Coeur d'Alene silver mining district for the period 1955-1984. During this period, we see a fluctuation in constant-dollar cost of about 50 percent which is almost directly related to the constant-dollar value. Obviously, the mines in this district had a fair amount of operational flexibility which allowed them to

1 Compiled from tax assessment records, Shoshone County, Idaho.

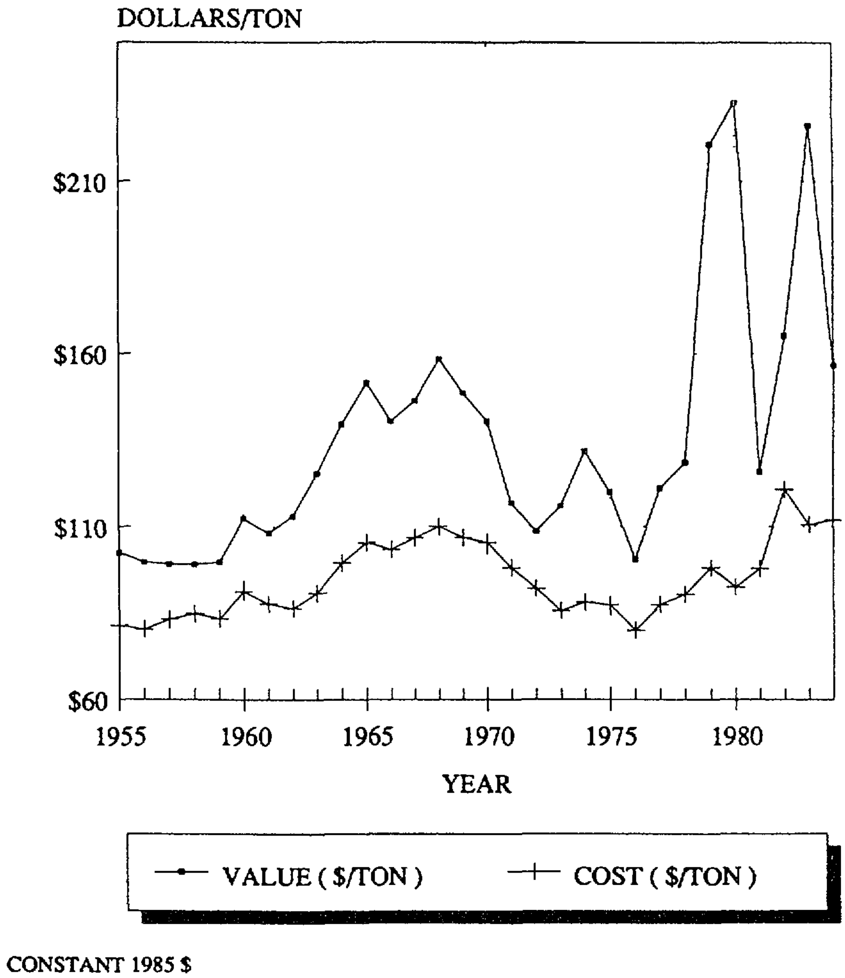


Figure 6
COEUR D'ALENE PROFIT MARGIN

cope reasonably well with changing prices. This flexibility results from the selectivity of the mining method as well as from the cost structure of the particular method.

Selectivity

Certainly, one of the factors contributing to operational flexibility is the availability of a spectrum of ore grades and the ability to selectively mine that spectrum of grades. Consider, for example, the underground silver mines in the Coeur d'Alene district of Idaho. These mines had a series of mining levels, each of which provided access to a series of stopes containing differing grades of ore.

When prices were down, mining could be concentrated in the higher-grade stopes to reduce the cost per unit of output. When prices were up, lower grade stopes could be mined and profitability would not suffer. In this way, both mine life and recovery of the total available are maximized. Room and pillar uranium mines offer much the same type of flexibility except that the time frame for extraction must be compressed, at least in sandstone deposits, because of less-competent ground.

Open pit mines are seen to be somewhat less flexible than underground mines since all ore and waste in the pit must be removed. You do not have the choice of leaving low-grade ore in place in an open pit mine. Your only choices are to mill, stockpile or discard it. The primary flexibility in open pit mining is the adjustment of stripping ratio in accordance with price fluctuations, but mines with relatively low stripping ratios are likely to have more flexibility than mines with high stripping ratios. In the US, a number of open pit uranium mines have had fairly high stripping ratios. Pathfinder's mine Lucky Mc had an overall waste to ore ratio of 24:1, while their Shirley Basin mine has a projected stripping ratio of about 50:1.

Solution mining offers the most favorable situation for selective "mining" because it has two means of grade control: 1) wellfield location, and 2) solution grade control. Wellfields can be located in more or less favorable areas depending on economic conditions at the time. Favorability considerations can include a variety of factors such as: grade, thickness, depth, chemistry and flow rate. In solution mining, you do not have the burden of providing access to all ore zones as in underground mining or of moving the vast quantities of waste associated with open pit mining. Most of the effort in solution mining is related directly to producing "ore", and not to support services. Additionally, solution mining production wells exhibit a characteristic increase/decrease in solution grades related to time. When solution grades fall below the cut off point, the least productive wellfields can be disengaged from production.

Cost Structure

Another factor relating to the Coeur d'Alene district and its ability to cope with changing prices is in the relatively favorable fixed cost/variable cost ratio exhibited by most underground mines. Fixed costs are taken as those costs independent of mine output, while variable costs are tonnage rate dependent. The contention here is that a high proportion of fixed costs limits the effectiveness of any attempt to high-grade an orebody and thus limits the economic flexibility of a mining operation.

For an underground mine (and associated mill), certain fixed costs must be incurred in order to provide for the first ton of ore production. These costs include management and administrative personnel; mine support crew for hoisting, ventilation and development; and mill crew. Variable costs include stoping manpower and supplies as well as operating supplies for the mill. Fixed costs for underground mining projects can be expected to be in the range of 50 to 65 percent of the total cost of full scale production.

By contrast, costs related directly to ore mining in open pit mines may be a very small portion of the total cost since stripping usually requires the major effort for this type of mining. A 10 to 1 stripping ratio, for example, might easily put the fixed cost of an open pit at 90 percent of the total cost. Thus, the annual operating cost for a open pit mine can be almost independent of the tons of ore mined.

For a solution mining operation, fixed costs are notably low and consist primarily of personnel. Well installation, chemicals and power are all variable costs directly

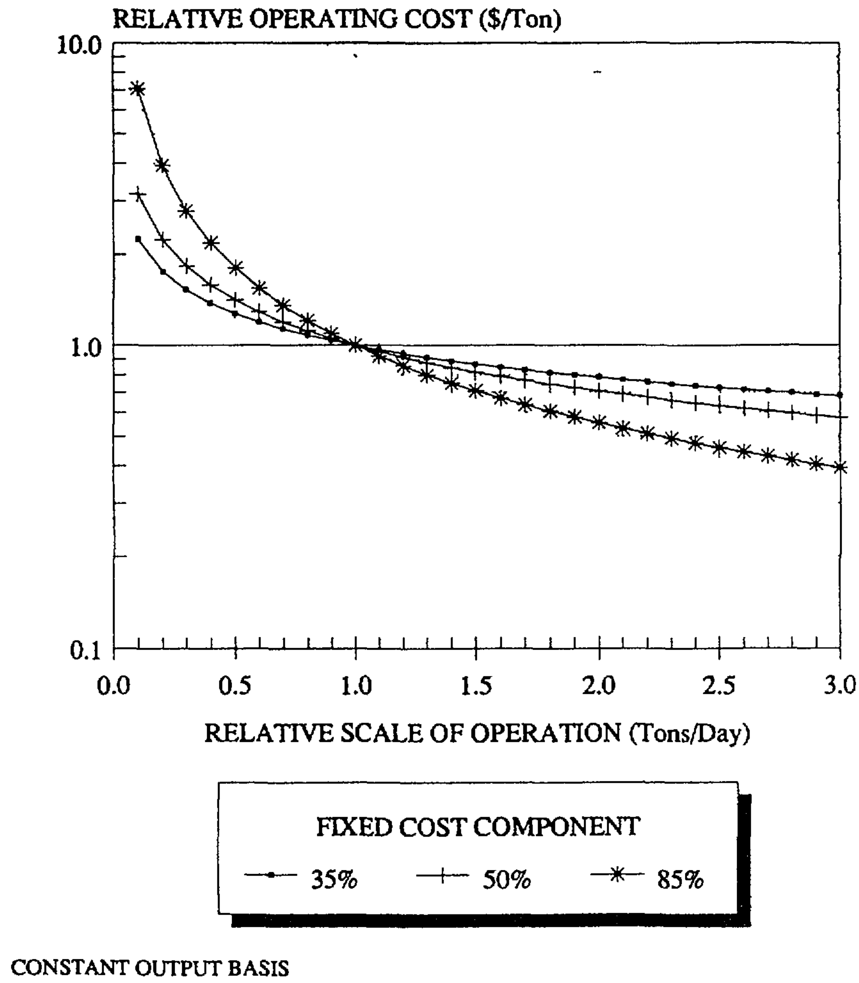


Figure 7
SCALE/OPERATING COST RELATIONSHIP

proportional to flow rate. Simulations on the US Bureau of Mines cost estimation computer program for solution mining indicate that fixed costs are in the range of 35 percent of the total cost for a typical solution mining operation.

Variation in Production Rate

The impact of the fixed cost component of a mining operation on economic flexibility can be seen clearly in Figure 7 which shows a series of curves relating fixed cost percentage, scale of operation and relative operating cost. This analysis is based on the proportional scale/capital cost evaluation method used in the chemical industry which is stated as follows:

$$\frac{Capital\ Cost\ a}{Capital\ Cost\ b} = \left(\frac{Scale\ a}{Scale\ b}\right)^{N}$$

where; N is usually in the range of 0.6 to 0.7.

For a unit operating cost analysis, the formula becomes:

$$\frac{Unit\ Operating\ Cost\ a}{Unit\ Operating\ Cost\ b} = \left(\frac{Scale\ a}{Scale\ b}\right)^{-N}$$

where; N = fixed cost component.

From Figure 7, it is notable that a reduced scale of operation provides a relative economic advantage for operations with a low percentage of fixed costs. That advantage is that operating costs increase more slowly. Where fixed costs are high, an increased scale of operation provides a relative economic advantage.

For a project in current operation or for a proposed project which has been studied in detail, an accurate assessment of fixed and variable costs is likely to be readily available. Lacking such detail, broad generalizations can be used in situations where less accuracy is required. These generalizations might be as follows:

Project Type	Fixed Cost Percentage
By-Project Operations	15 to 25 percent
Solution Mining	30 to 40 percent
Underground Mining	45 to 65 percent
Open Pit Mining	75 to 90 percent

SUPPLY CURVE DERIVATION

By combining the concepts of geologic diversity with those of operational flexibility, a fairly complete project supply curve model can be generated. This project model incorporates the grade/tonnage curve, the fixed cost ratio and the scaling formula to predict the proportion of total resource which would be available at various costs. The model developed may be of two types: an operating cost model applicable to projects currently in production; or, a total cost model incorporating both operating and capital costs which can be applied to undeveloped projects.

The process of developing the operating cost model is as follows:

1) For constant output, the scale of operation is inversely proportional to the grade.

$$\frac{Grade\ a}{Grade\ b} = \frac{Scale\ b}{Scale\ a}$$

2) This identity can be substituted into the scale/cost formula to produce a cost/grade relationship for constant output.

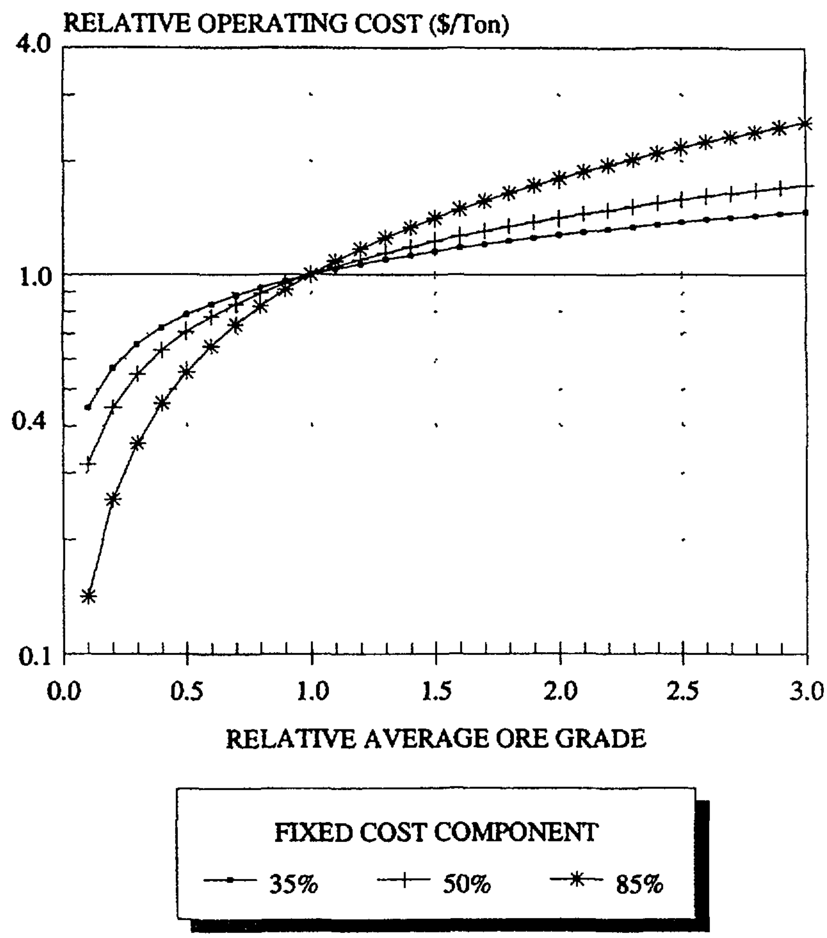
$$\frac{Operating\ Cost\ a}{Operating\ Cost\ b} = \left(\frac{Grade\ b}{Grade\ a}\right)^{-N}$$

$$where;\ N = fixed\ cost\ component.$$

Figure 8 illustrates this grade/cost relationship on a per ton basis. When the ore grade is factored into the tonnage component, the relative cost per unit of metal can be calculated from:

$$Metal\ Cost\ (per\ unit) = \frac{Operating\ Cost\ (per\ ton)}{Metal\ Content\ (units\ per\ ton)}$$

This grade/metal cost relationship is summarized in Figure 9.

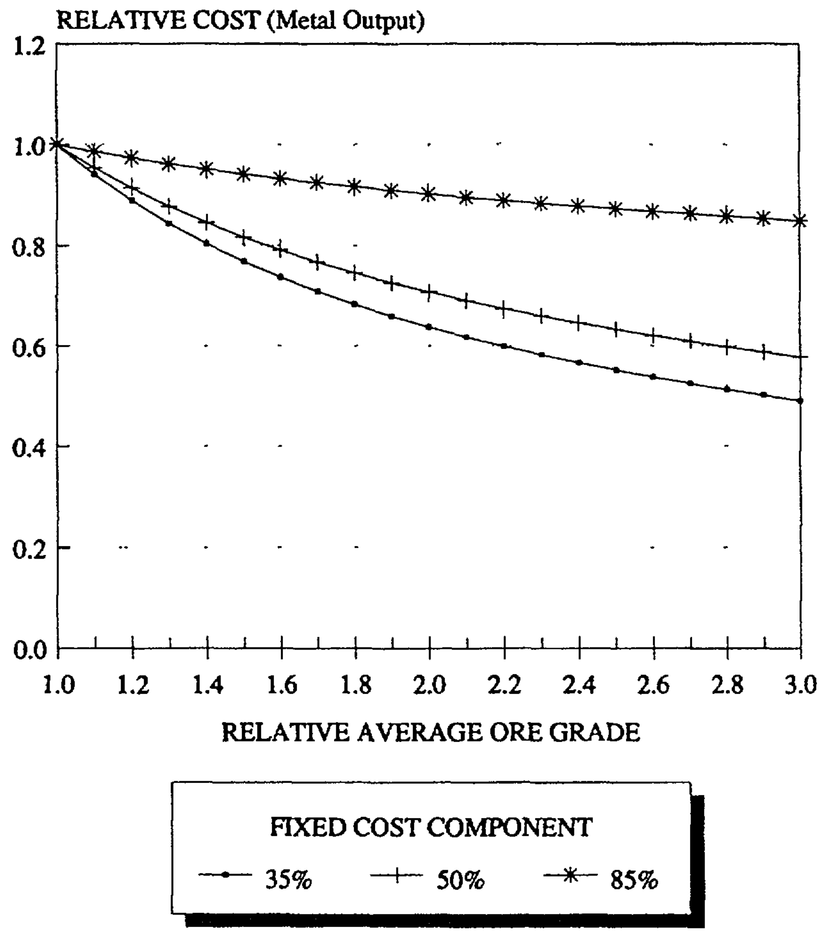


CONSTANT OUTPUT BASIS

Figure 8
ORE GRADE/OPERATING COST RELATIONSHIP

As previously noted, however, the process of cost reduction through mining only the higher-grade ore results in lower utilization of the total resource. This reduced utilization can be evaluated, by combining the grade/resource model (Figure 5) with the grade/metal cost model (Figure 9). The combination of these two models provides an economic supply curve for a uranium deposit. It illustrates the ability of production founded upon that deposit to adjust to changing market conditions.

The results of this combined model are illustrated in Figure 10 for a low-grade open pit mine and a moderate-grade solution mine. Note that the ISL operation exhibits much more economic flexibility than does the open pit. Figure 11



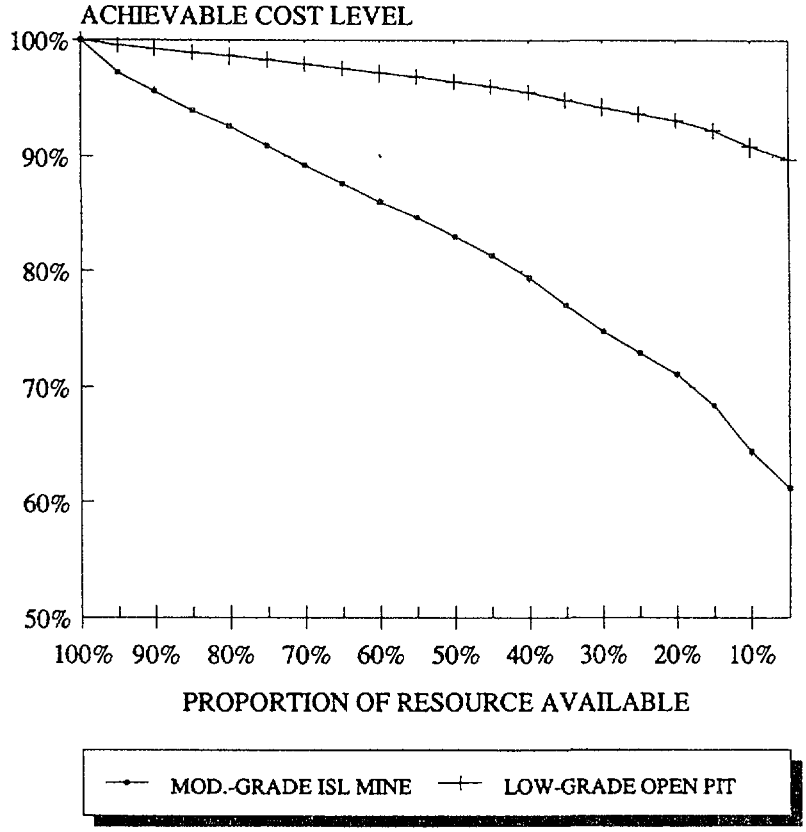
CONSTANT OUTPUT BASIS

Figure 9
ORE GRADE/METAL COST RELATIONSHIP

illustrates the use of this model in evaluating the economic flexibility of a hypothetical ISL project with overall available resources of 5 million pounds U_3O_8 and a base cost of $12 per pound. The average resource grade is assumed to be 0.18 percent U_3O_8.

From Figure 11, it can be seen that significant operating cost reductions are possible for this hypothetical project, but that these reductions are achievable only with a corresponding decrease in available resources.

For projects currently in operation, this decrease in available resources is the major negative impact. For undeveloped projects, however, a decrease in available



CONSTANT OUTPUT BASIS

Figure 10
OPERATING COST/RESOURCE RELATIONSHIPS
EXAMPLE PROJECTS

resources provides a smaller base over which to amortize capital costs. These capital costs can be incorporated directly into the model through the proportional scale/capital cost formula:

$$\frac{Capital\ Cost\ 1}{Capital\ Cost\ 2} = \left(\frac{Scale\ 1}{Scale\ 2}\right)^{N}$$

where; N is usually in the range of 0.6 to 0.7.

Thus, as the scale (tons per day) of the operation is reduced, capital costs will also be reduced; the degree of reduction (constant output basis) depends, again, upon the grade ratio curve. Unit amortization costs can then be calculated in accordance

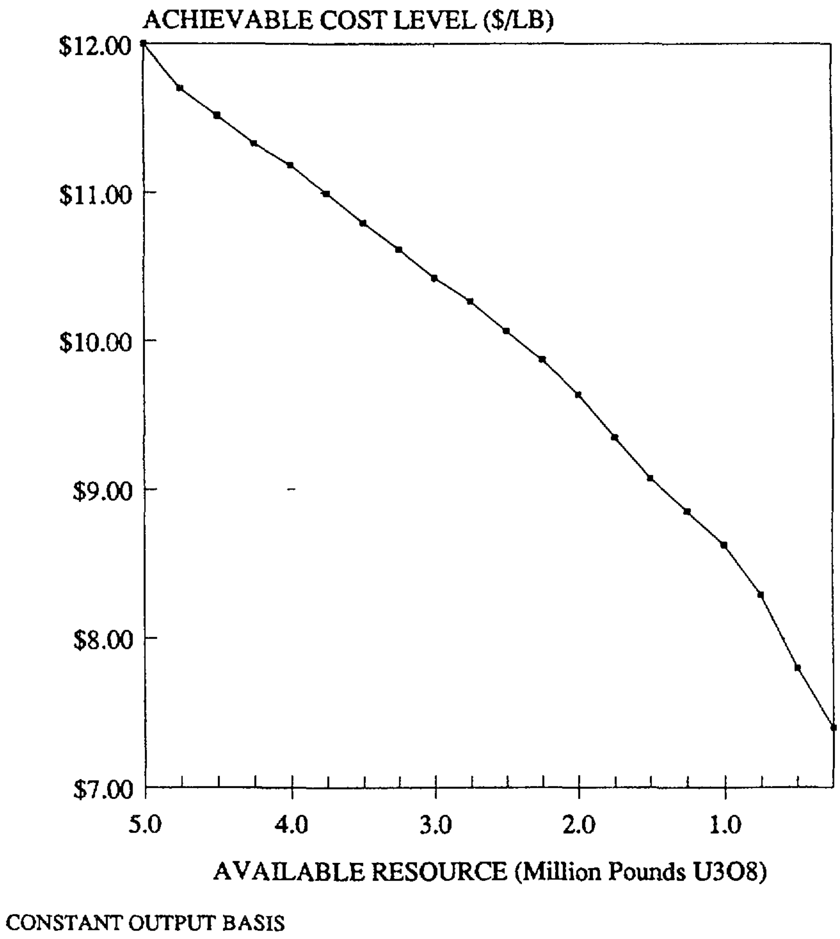
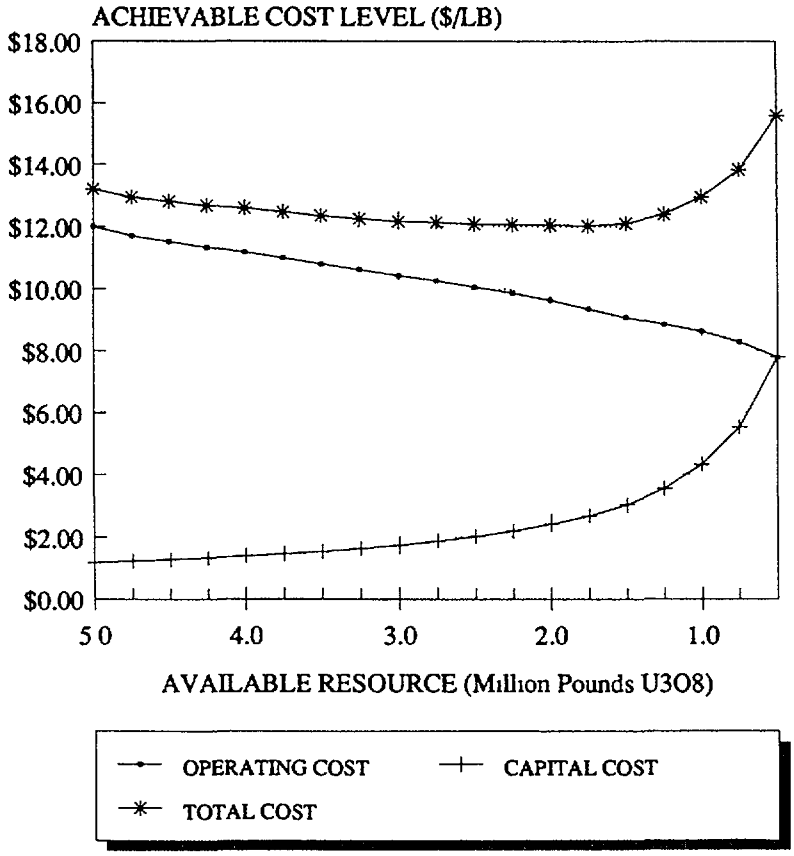


Figure 11
OPERATING COST/RESOURCE CURVE
EXAMPLE ISL PROJECT

with available resources. This process is illustrated in Figure 12 for the example ISL project with a base capital cost of $6 million. Figure 12 also sets forth the previously - developed operating cost curve as well as a total cost curve.

PRACTICAL APPLICATION

Either the operating cost or total cost model may be used, as appropriate, to evaluate and characterize an individual deposit. This characterization can lead to an informed judgement as to the ability of a specific deposit to withstand, or profit from, changes in price.



CONSTANT OUTPUT BASIS

Figure 12
TOTAL COST/RESOURCE CURVE

Equally important, however, is the facility with which a series of deposits may be characterized and the results combined into an aggregated supply curve. Such aggregated curves provide a meaningful tool for broad area resource availability evaluation. This is particularly true where the forward cost concept can be utilized in the model.

NUEXCO has estimated forward costs for most of the uranium production available to WOCA countries through the year 2005. Those costs have been processed through the model and combined into a world uranium availability assessment as shown in Figure 13. It should be emphasized that these costs are

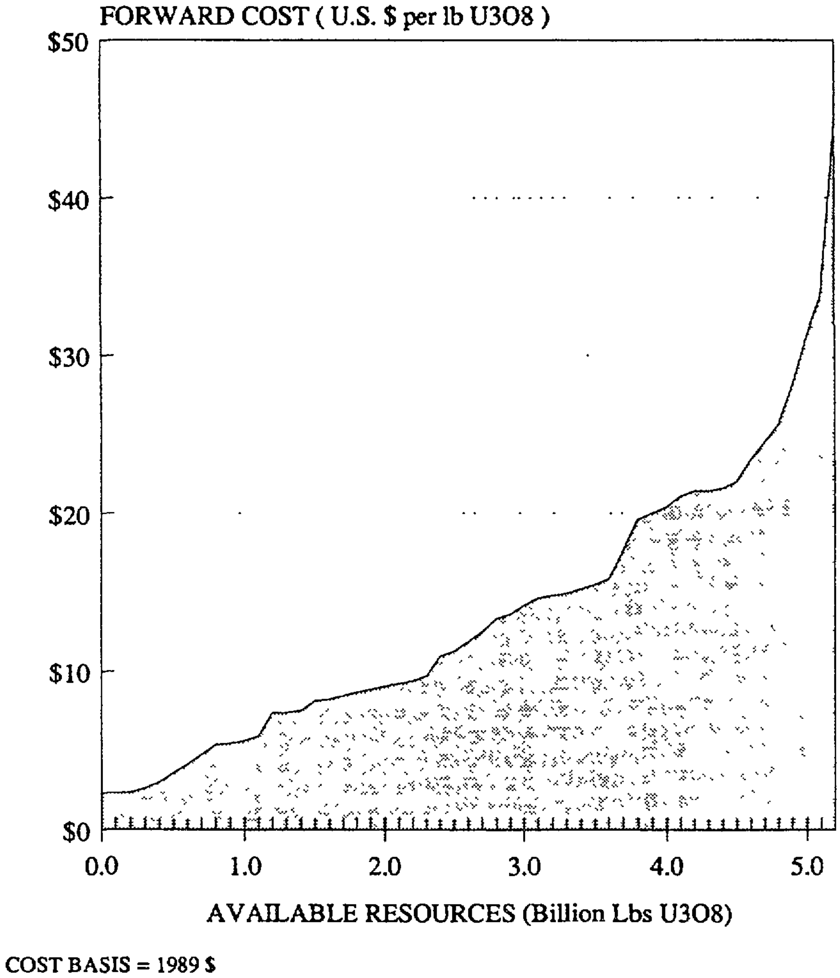


Figure 13
WORLD URANIUM RESOURCE AVAILABILITY

forward direct costs only and do not include such items as interest on borrowed capital, return on investment, taxes, royalties or profit. Nevertheless, this single graph presents a complete summary of world uranium resource quantities and costs.

URANIUM RESERVES EVOLUTION

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France

Abstract

The uranium resources of WOCA, as they are regularly compiled in the NEA(OECD)/IAEA Red Book are assessed in light of current market conditions. Problematic areas analysed in this paper are cost categories, spot price, production cost, as well as availability of uranium resources. The volatile market changes are considered detrimental to an efficient use of uranium resources, as declining prices require selective mining of higher grade portions of ore deposits. A supply curve showing the production cost of the 1987 WOCA uranium production suggests that at mid-1989 spot prices uranium can be mined profitably and that only 80% of the WOCA production could be profitably produced at the lowest cost category (US$ 80/kg U) considered equivalent to the average long term uranium price. In view of recent market developments suggestions are made to adjust the uranium resource estimates their cost categories and degree of resource availability as supply to the realities of the current market.

The OECD/NEA joint efforts are providing uranium Reserves assessments on a regular basis in the Red Book.
The Red Book is the internationally accepted reference.

Downwards pressure on the market brought the mid 1989 spot prices to unprecedently low level.
At below 25 $ per KgU, prices at which some market participants still want to get rid of unwanted inventories, even the lowest cost uranium appears too costly to be profitably mined. The recent laying-off and production restructuring in Western Canada illustrates that point.

Nevertheless the Red Book reserves numbers remains very high with the low cost RAR representing about 40 years of to-day consumption.

On an aggregated basis a slight increase can even be observed. The 1988 Red Book reports 1555 KTU in the low cost category as of 1/1/87. The 1989 update (1989 OECD nuclear energy data) increases the figure to 1625 KTU as of 1/1/88.

At the same time, it is very likely, the very low level of explorations expenses (on a worldwide basis, about 2,5$* for every produced KGU) cannot bear this reserves increase.

The following presentation is attempting to look behind the numbers and to give, on a producer side, a view on the WOCA (World Outside Centrally planned Economy Area) uranium reserves.

1 RESERVES AND PRODUCTION DATA

The figures n°1 and 2 compare production and reserves shares of the main producing areas. Figure 1 uses the 80$/KGU limit, while figure 2 uses the 130$/KGU limit. Concentrating on figure 1, it can be observed that while some areas have a market share of production which compare to their share of resources, this is not the case for all.

South America accounts for more than 10% of RAR below 80$/KGU, yet its 1988 production was much below 1% of total WOCA output.

Australia and Canada are interesting to compare. Their 1988 production shares are the reverse image of their low cost reserve respective shares.

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*Much lower if France which last year accounted for nearly 40% of world exploration expenses is removed.

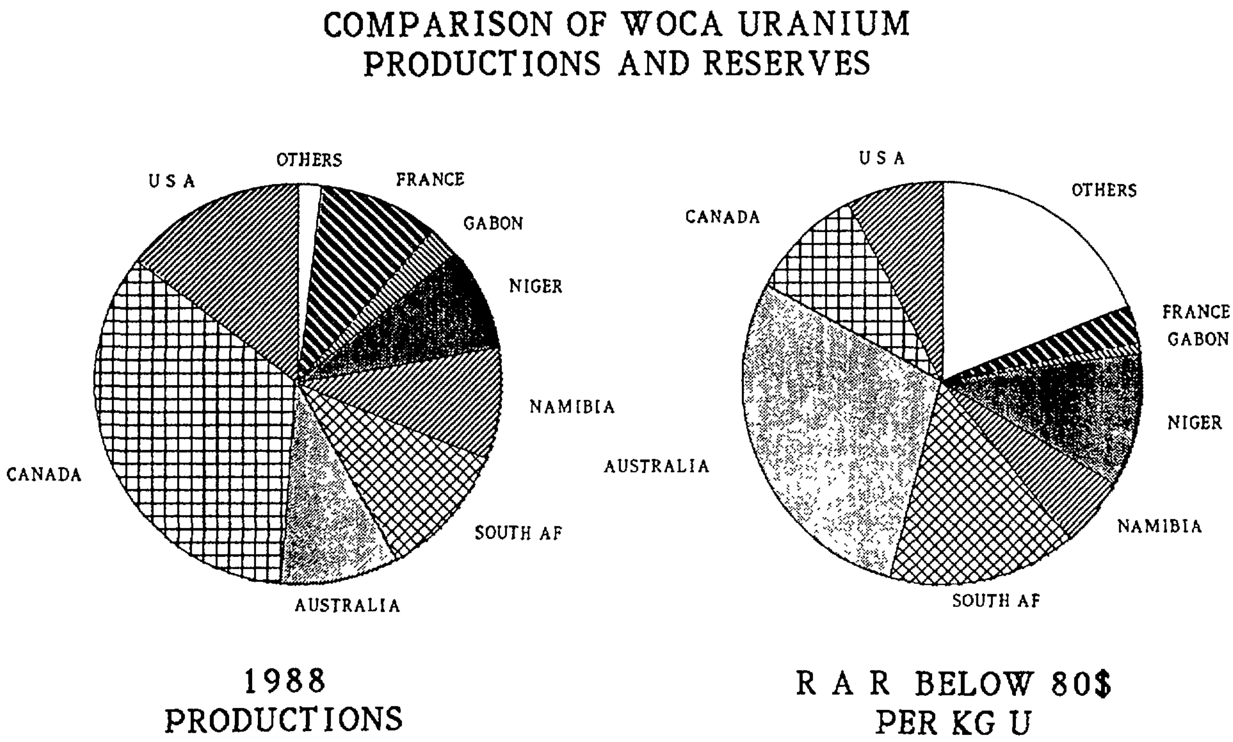
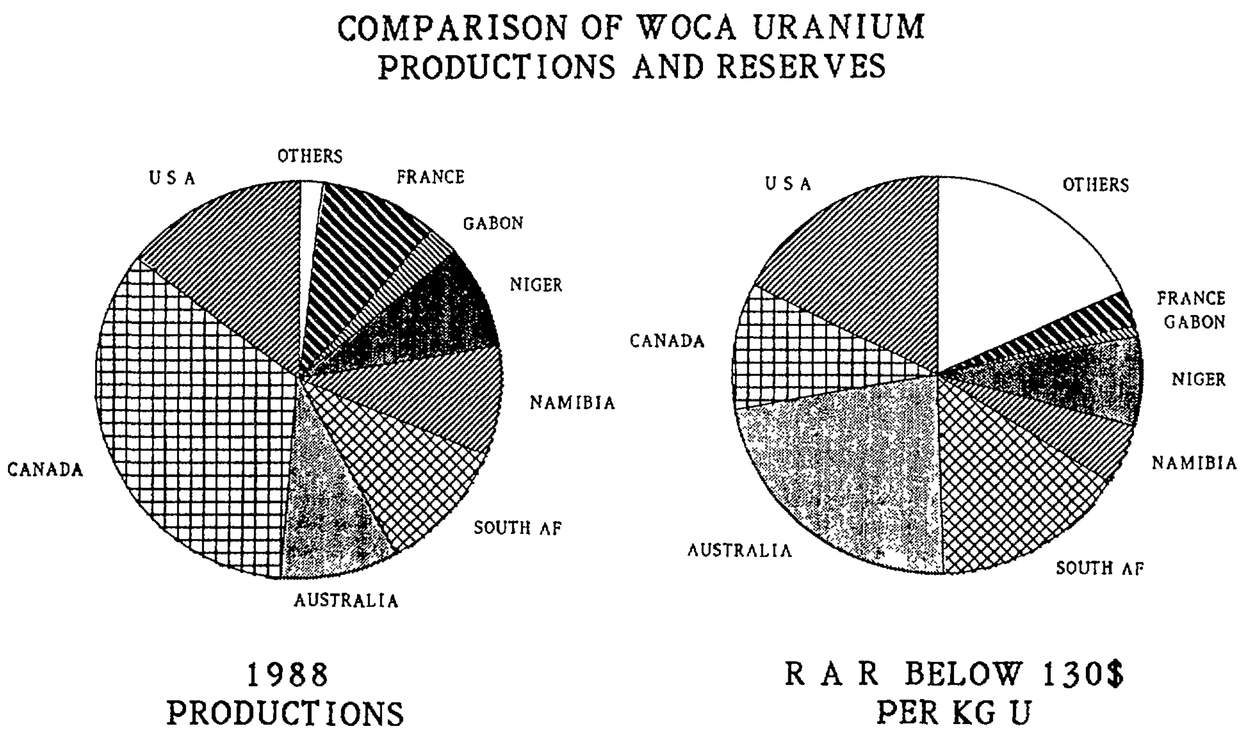

COMPARISON OF WOCA URANIUM
PRODUCTIONS AND RESERVES
OTHERS
U S A
FRANCE
GABON
NIGER
NAMIBIA
CANADA
SOUTH AF
AUSTRALIA
1988
PRODUCTIONS
U S A
OTHERS
CANADA
FRANCE
GABON
NIGER
AUSTRALIA
NAMIBIA
SOUTH AF
R A R BELOW 80$
PER KG U

Fig. 1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R A R BELOW 130$
PER KG U

Fig. 2

France, as well, has a production level larger than the share of its low cost reserves. This is in relation with its very high commitment to nuclear energy.

These contrasting situations are as well observed on the following table which compares the static life of the various producing areas reserves (static life = ratio of known reserves to present production).

	1988 PRODUCTION (TONNES OF U)	RAR STATIC LIFE (YEARS) <80$	<130$
AUSTRALIA	3530	130	150
CANADA	12460	12	20
USA	5000	25	80
FRANCE	3420	15	18
CENTRAL AFRICA	3900	48	50
SOUTHERN AFRICA	7100	48	65

Again comparing CANADA and AUSTRALIA, it is worth noticing that the static life of australian reserves in the low cost category is more than ten times the canadian low cost RAR static life.

Among the various factors that can be associated with these contrasted situations one cannot overlook that:

1) Western Canada orebodies, due to their very high grades, are among the lowest cost producers.

2) With the Australian policy of restricted mines developments, the availability of uranium from this part of the world is limited and subject to considerations not related to the economics of a project.

The following figures present an overview of the various producing areas resources potential. The resources potential adds the

RESERVES AND PAST PRODUCTIONS EVOLUTION

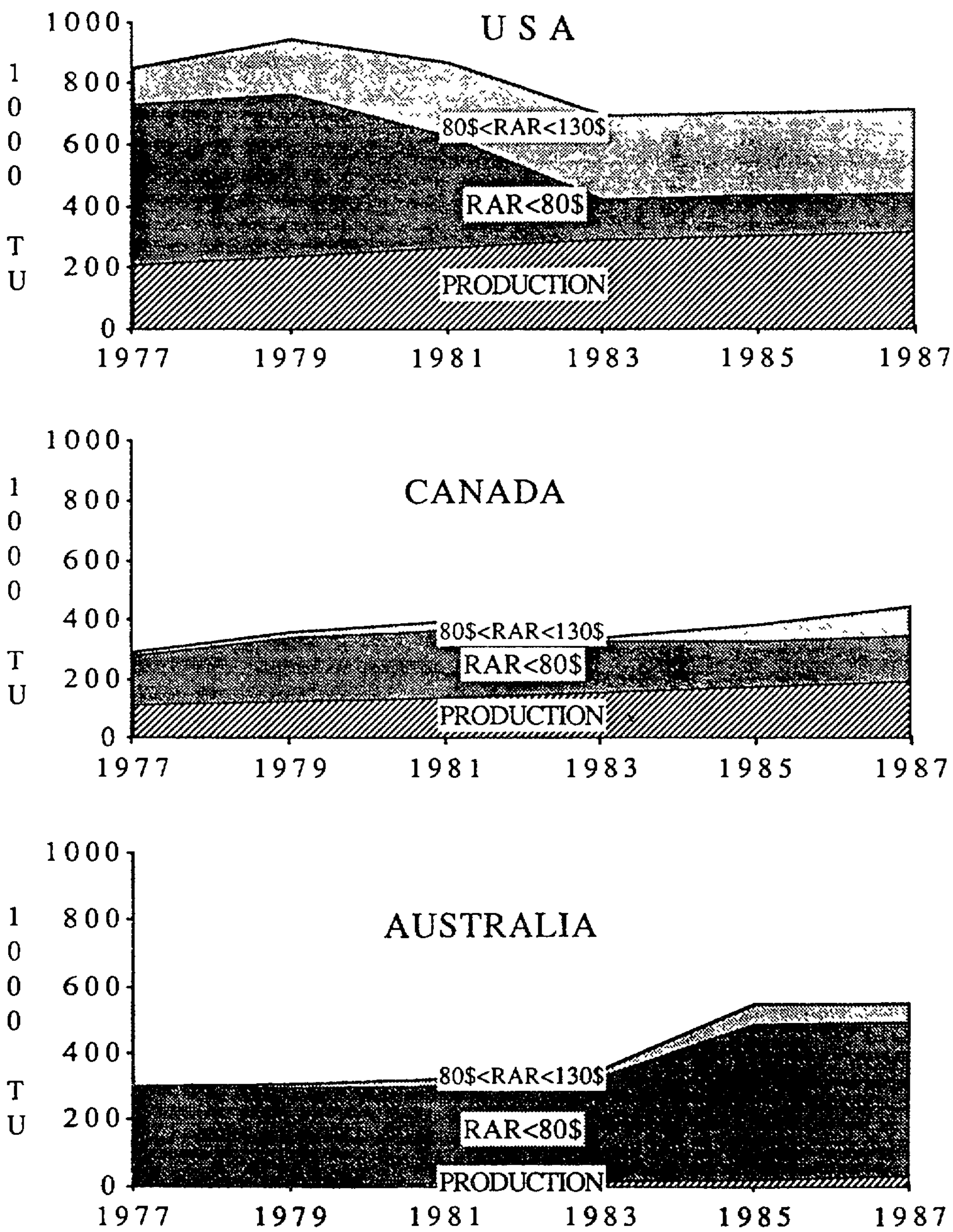

Fig. 3

uranium already produced to the remaining reserves as stated in the two OECD cost categories. The figures present the resources potential evolution of the main producing areas since 1977.

In the figure 3 US, CANADIAN and AUSTRALIAN data are presented.

- In the US case (presented in a more detailed fashion on figure 7), it can be seen that few remains to be extracted. Much of the "low cost reserves" vanished following the closure of many major production centers in the country, during the last seventies and early eighties, when the market entered its depressed state.

- In CANADA, the large production increase of the early eighties filled the void left by its southern neighbour. This was achieved while, on a global basis, the canadian resources base remained about stable, hiding large discrepancies between the evolution of the eastern and the western producing areas.

- AUSTRALIA, which produces about 10% of the world output with about 30% of world low cost RAR, has up to now failed to be the major player it could be entitled to. Again this is due to its restricted uranium mines development policy.
Olympic Dam, which is presently producing around 1000 TU a year bears the bulk of the recent reserves increase.

The figure 4 presents the resources potential of the other main producing areas: Southern Africa, Central Africa and France.

- SOUTHERN AFRICA includes South-Africa and Namibia. While their reserves potential remains large, the ore is low grade, and due to present political situation in both countries, many consumers do not accept any more their uranium.

- CENTRAL AFRICA includes NIGER and GABON. In recent years output remained slighty above 10% of world production with the bulk of reserves in the low cost category.

- FRANCE which recently produced slightly under 10% of world output makes a large use of its reserves in accordance with its large commitment towards nuclear energy.

RESERVES AND PAST PRODUCTIONS EVOLUTION

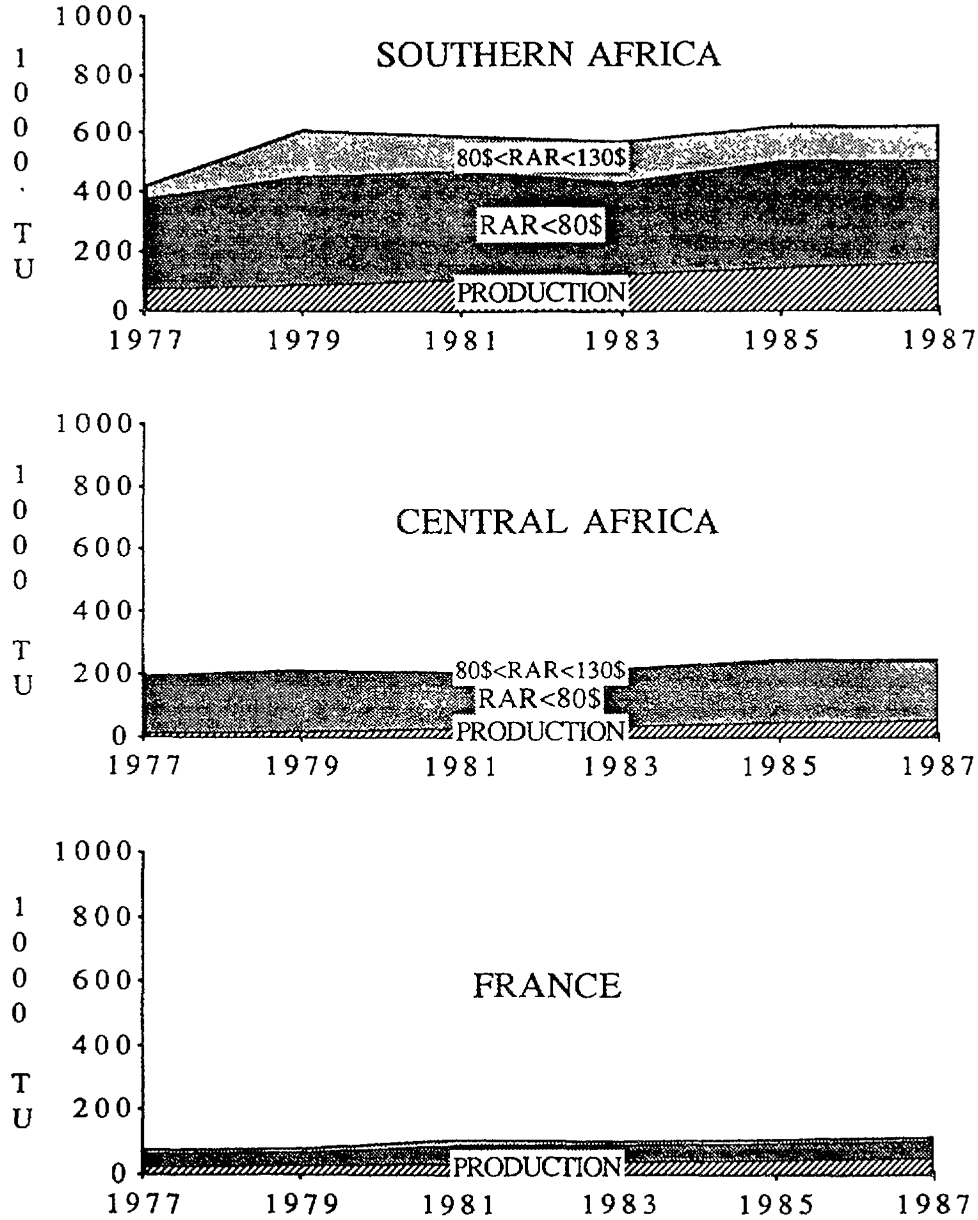

Fig. 4

Taken as a whole, only a part of the RAR, as aggregated in the Red Book, can be made available to consumers.

If we now take into account the reserves figures of the currently operating districts, a comparable observation can be made.
As indicated in the presentation I made during the 1988 Uranium Institute Symposium, the computation of those reserves, as stated by the mines operators "result in a grand total of less than one

million tonnes of U, and about half of what is published by OECD as RAR in the low cost category."

So taken as a whole, only a part of all the RAR that can be made available to consumers, are really offered to them.

2 RESERVES AND MINING

As a general rule, the orebody reserves are known only when it is mined out.
Provided market conditions do not worsen during the mine life, the standard practice shows that the cumulative mine production is much more than initially foreseen. New reserves are discovered while mining.

The market collapse of the early 1980s was accompanied by drastic changes in the situation of some producers. The most apparent was the premature closing of some of the producing centers which were booming in the 1970s. In some cases, facilities were closed right after completion, having not yet started to produce.

The reserve situation at a mine is not only related to the overall market situation. Moreover each mine, which is dependent upon its own market conditions, has its own lifetime.

This can be seen when comparing reserves situation to cumulative production of uranium mines closed in the last ten years.

Figure n° 5 presents the canadian mine of Beaverlodge and compares its reserves potential evolution to the "Exchange Value", the spot market indicator that Nuexco is publishing. The graph shows the drastric consequences, on Beaverlodge reserves estimates between 1977 and the mine closure, of the fall of the spot price indicator to a third of its peak value.

BEAVERLODGE RESERVES EVOLUTION

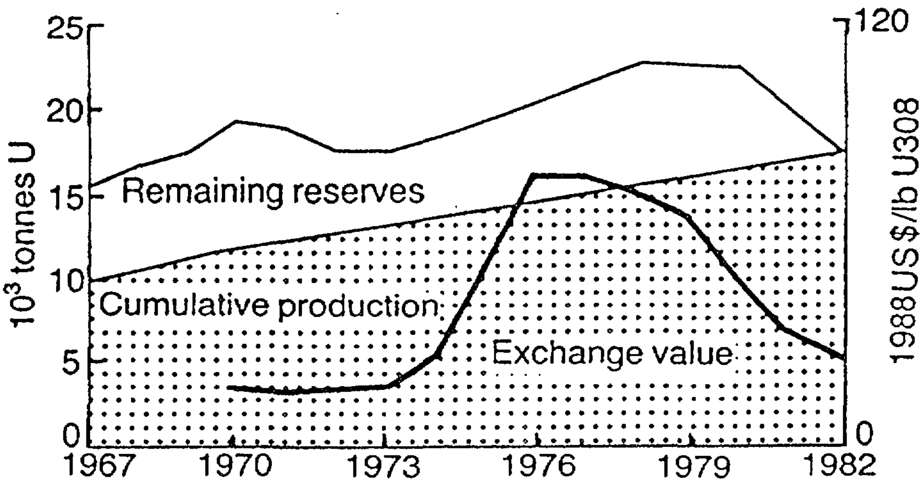

Fig. 5

BOIS NOIRS RESERVES EVOLUTION

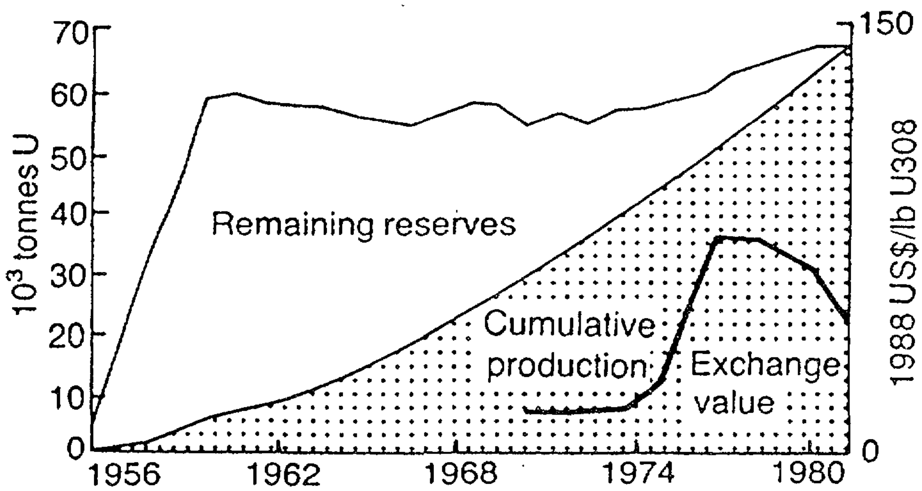

Fig. 6

In the Bois Noirs case, presented on figure n°6, reserves were well known in the early years of operations and fully depleted when the mine closes in 1980 by the time the market collapses.

In a falling price market, a producer who cannot rely on a cost floor price formula, has to adjust its operations, in order to diminish its costs and remain profitable. So:

- exploration and advanced mine preparation works are no more undertaken,
- ores are upgraded by selectively mining the richest areas.

In these circumstances, higher quality reserves cannot any more be found, and the average grade of the remaining reserves reduces to a point where the orebody is not economically mineable. In the best case, a drastic increase of the selling price would allow the miner to mine and mill his remaining reserves with profit, and the decision can then be to mothball the operations and wait for the market to improve.
In other cases (as is generally true in undergroung mining), skimming the ore can destroy the orebody structure and what remains is not mineable, whatever the market conditions. The reserves have essentially vanished.

Taking the previous remarks into account, one has to be very cautious when assessing the future availability to the market of the remaining reserves of the prematurely closed mines, the so called "operations on stand-by".
The expected supply that they are supposed to provide may be wishful thinkings.

The figure n° 7 details the US resources potential (cumulative past production and reserves in the various cost categories), and compares it to the spot price indicator evolution. Following the spot price evolution, the potential increased in the seventies, and then declined in the early eighties. More of that, a drastic reduction of low cost reserves followed the price decline. Those appear to have been only very partially replaced by reserves in the higher cost categories.

The economic reserves are as well presented on figure n°7. They represent what the US mining companies estimate they can extract, according to their contractual obligations, and what they would be able to supply at "Market Price" (i.e. spot price). The "economic reserves" level is a good indicator of the actual US reserves status.

US RESERVES EVOLUTION AND SPOT PRICES

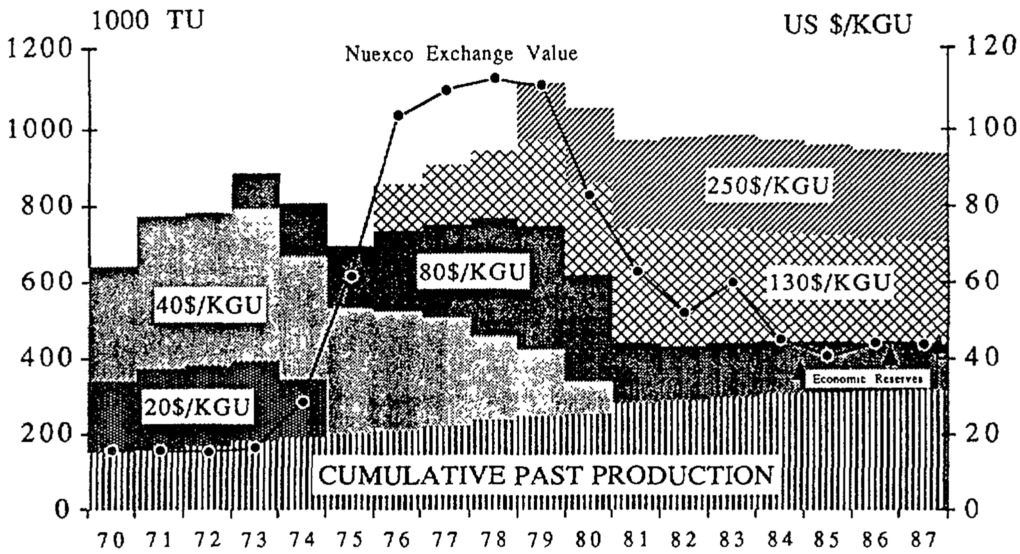

Fig. 7

If the history of the uranium production industry is too short to draw definite conclusions, it is nevertheless safe to say, as illustrated by the figures 5 to 7, that rapid and changing market conditions are detrimental to the good use of uranium reserves.

Those which are non-renewable natural resources can be definitely lost.

3 URANIUM PRODUCTION COST STRUCTURE

The figure 8 is an in-house estimate, based on various public sources, of costs for the uranium production industry. The main sources of information are companies annual reports and technical press analysis.

The costs calculation takes into account annual expenses that must be born by the mining companies revenue. It includes variable production costs as well as financial costs and taxes.
Production is cumulated in percentage, going from the lower to the higher cost producer. Prices are computed in US$/KGU.
1987 companies data are used.

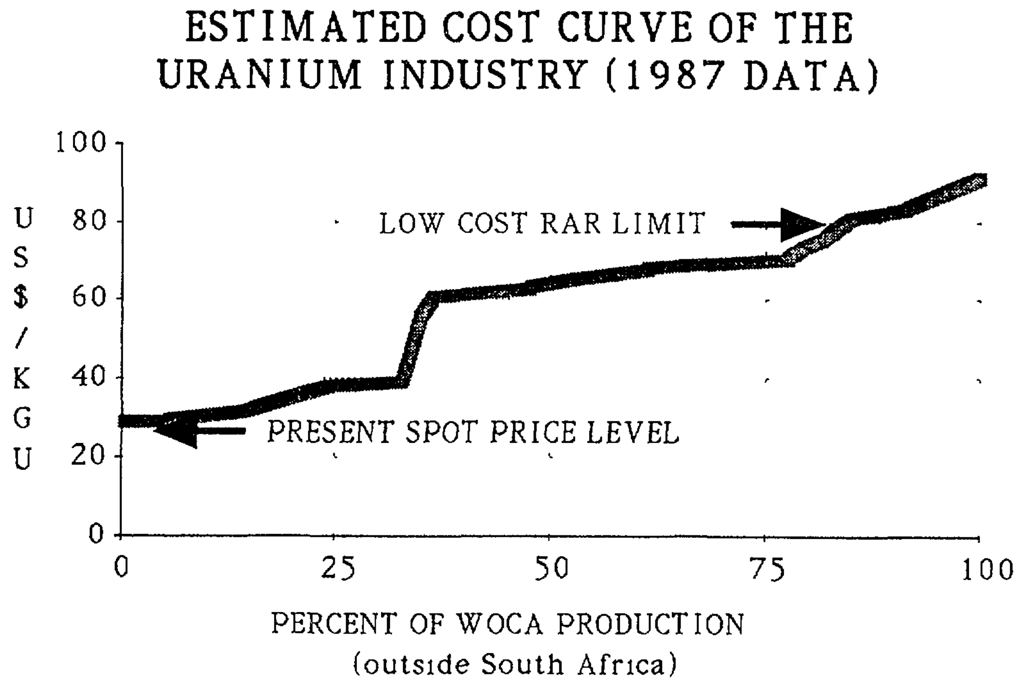

Fig. 8

At mid 1989 spot price level, the curve shows that no uranium is profitably mined.

At the low cost RAR limit, which represent about the average long term price of the recent years, 20% of world needed production would be mined with a loss.

There are certainly many uncertainties surrounding this curve drafting. Nevertheless the present market situation provides some confirmations. According to various press reports, the"producers" having to supply on spot, are rather buying available inventories on the market and leaving their operations on stand-by.

How long this situation is sustainable?

While there is no simple answer to this question, two points are worth noticing:

- Market economy countries inventories estimates, which according to various sources, are in the range of 150 KT to 200 KT of contained natural uranium, may be overstated.

There is no estimate of the share really available to replace fresh uranium production.

- The willingness of producers, who benefit from high grade ore*, to increase their market share, may have come to an end, after the recent restructuring of the production industry in North America.

4 THE R.A.R COST LIMITS

The aim of the RED BOOK exercise is to give an estimate of the amount of fresh uranium available for the market economy countries nuclear programs. This exercice is as well undertaken to make sure uranium resources are abundant enough, for the NEA objective of promoting the peaceful use of nuclear energy.

This has been well achieved in the early seventies, as illustrated by the figure n° 9. This figure compares for the past both the requirements estimates and the level of reserves as they were stated in the various Red Books.

During these years, the market mechanisms, which translated into prices increases, allowed the reserves level to match the 20 years forward requirements increases.

In order to insure this proper match, low cost RAR limits had to be quickly increased as can be seen on figure 10.

Since their 1975 peak, 20 years forwards requirements were divided by three (figure 9) and RAR remained at about their peak level at the same cost limits, as fixed in 1977 (see figure 10).

While the weight of some old long term contracts still maintains the average long term price around the 80$/KGU level, their share is

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* The average grade of the richest operating orebody is 80 times higher than the average grade of the poorest.

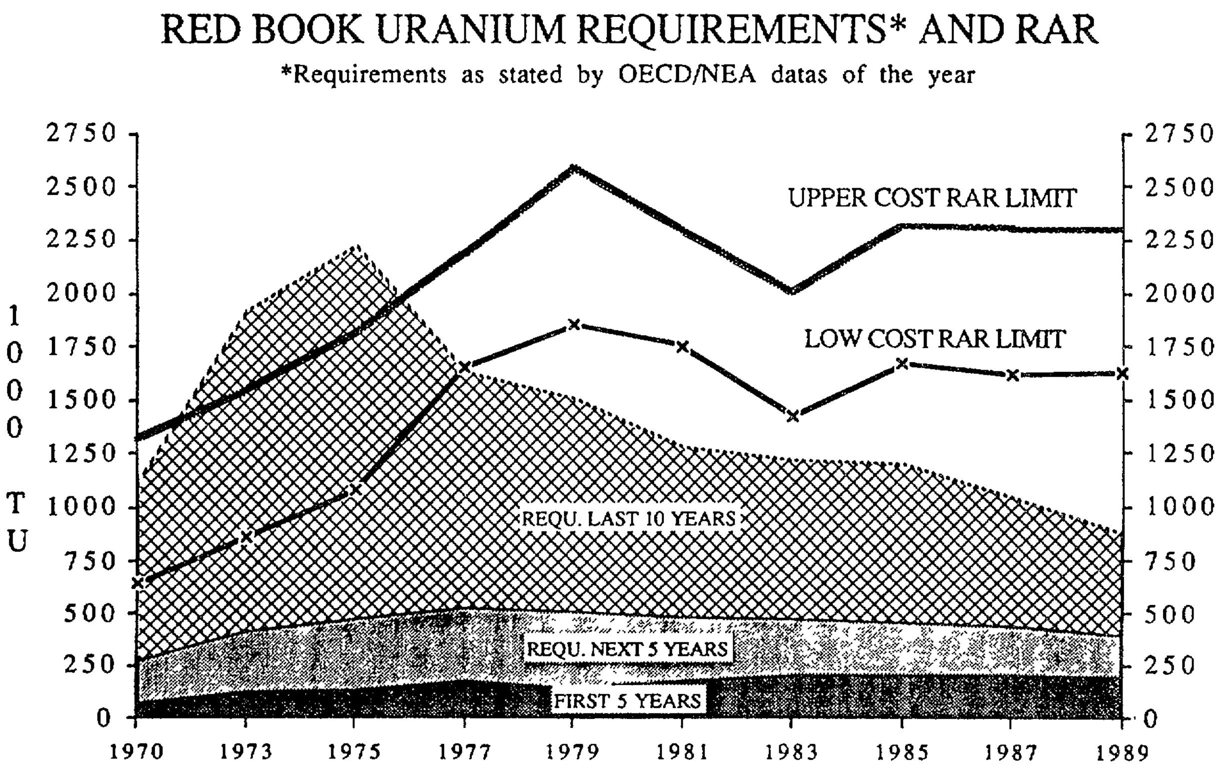

Fig. 9

decreasing as they are replaced by more recently signed contracts with lower base prices. More of that, the gap between the spot indicator and the low cost RAR upper limit is presently very high.

Furthermore, the very low level of exploration efforts does not allow adequacy to be maintained in world reserves estimates. In many cases "updated data" remain the same from previous to new Red Book editions.

The end results are reserves numbers at very high level which represent many years of future needs (figure 9).

Concerning the supply side, the general feeling remain that the large amounts of unwanted inventories will have to find their way to the market. As in the recent past, it is expected, this will provide for few years to come, all the demand that fresh uranium production will not cover.

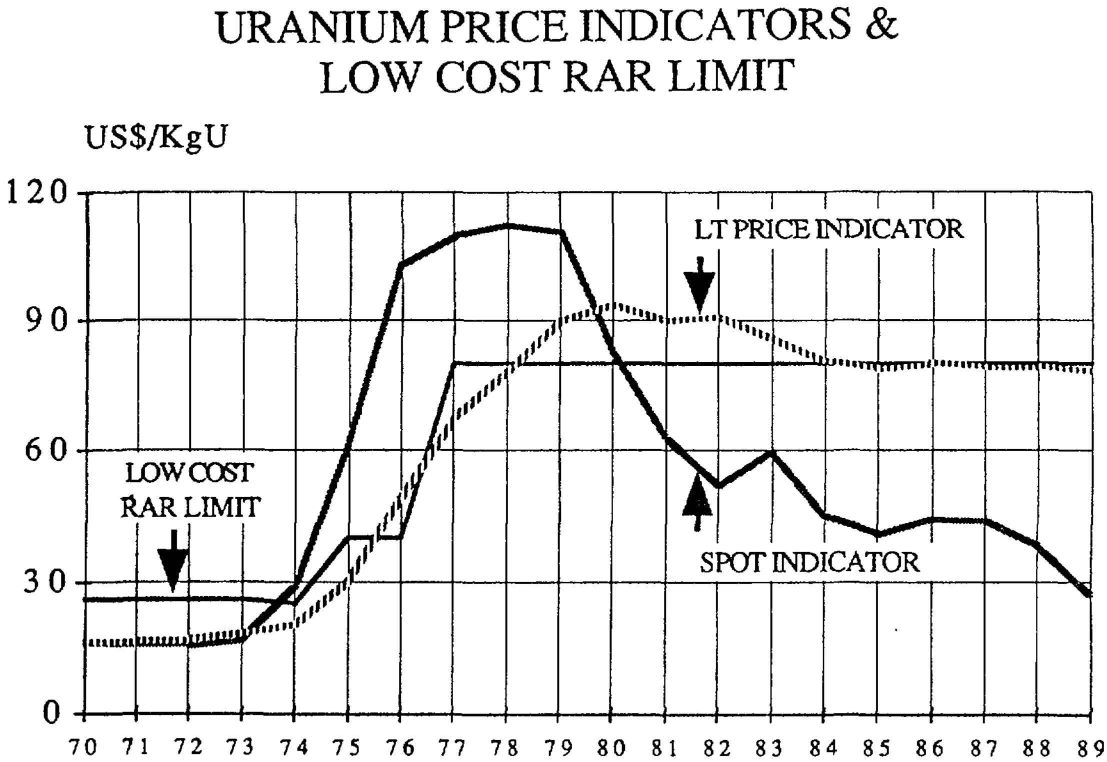

Fig. 10

What happen after that will depends upon the market ability to provide enough incentives, for the production side to fill the void, when unwanted inventories are drawn down.
When this occurs, unneeded tensions are likely to dominate the market.
In order to avoid such a situation, an updating of reserves might be the proper answer.

Time may be right to reconsider the way uranium reserves are assessed.

In that respect it is suggested:

- To lower the present cost limits, which have become too much market discarded.
As of mid 1989, the lower cost limit (80 US$/KGU) is three times higher than the spot price, which is 5 times the upper RAR limits (130 US$/KGU).

- to separate available reserves from the reserves which for any reason (present market perception, political veto...) cannot be offered to customers.

- to discriminate between mining areas developped reserves and undevelopped reserves in non mined zones.

The "economic reserves", as stated in the USA, is a possible answer.

If undertaken, this reassessment of data could provide the necessary adjustments of the reserves picture and avoid, on the consumers side, too rude an awakening, when inventories are gone.

LONG TERM URANIUM REQUIREMENTS EVALUATION FOR WOCA

Results of an OECD/NEA study

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Abstract

For a projection of long term reactor related uranium requirements (through 2030) two steps are required; the projection of nuclear electricity generation and the reactor strategies. The methodology for the projections of two nuclear energy generation scenarios is described. As regards the foreseen development of reactor strategies, the present strategy is assumed to change after the year 2000. For the time 2000 - 2030 three scenarios have been assumed, characterised by a LWR strategy (reference case), a plutonium recycling strategy and a FBR strategy (after 2020). Based on these cases, reactor related uranium requirements through 2030 have been determined, which will be included into the NEA(OECD)/IAEA Red Book 1990.

INTRODUCTION

The results presented thereafter are derived from two studies conducted by OECD/NEA. The objective was to obtain uranium requirements evaluations for WOCA, up to 2030, in order to compare these requirements with supply projections, for the purpose of the "Red Book" prepared by the Uranium Group of IAEA and OECD/NEA.

The task was carried out by two "ad hoc" working groups, and the results, obtained in the spring of 1989, will be published in the next Red Book.

As such an evaluation is very sensitive to the methodology and the hypothesis adopted, these aspects will be briefly described, then the results will be presented and discussed.

METHODOLOGY

The first step, to reach uranium requirements evaluation, is to forecast nuclear electricity generation and the second one to define nuclear reactor strategies.

- Long term forecasting of nuclear electricity generation

Nuclear electricity is one of the sources available to face primary energy requirements. Although various studies have been published, dealing with energy consumption forecasts in the long term, the review of existing methods and models is a bit disappointing. The modeling approach is not satisfactory, on a world basis and for long term purposes, because it needs the introduction of many exogeneous parameters that can't be predicted within a reasonable range of uncertainties. The judgmental approach, based on expert advices, is difficult to apply when dealing with a large number of countries.

To avoid both difficulties it was thus choosen for this study to adopt a very pragmatic approach, based on simple mathematical formulations of the links between economic growth and electricity consumption and of nuclear energy market share evolution.

For each of the three regions of WOCA, one central projection of electricity consumption was derived from GDP growth rates assuming elasticity factors.

Two nuclear electricity generation scenarios were then built based upon this unique electricity demand projection.

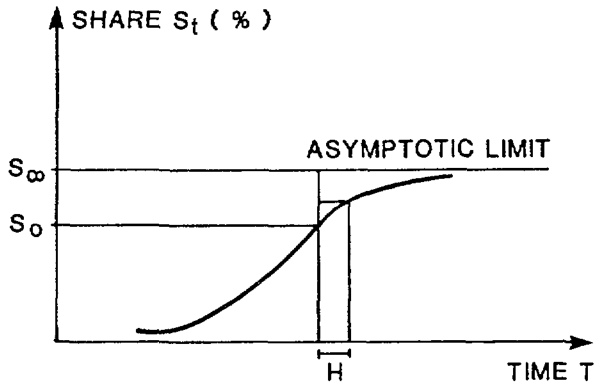
In OECD countries nuclear electricity market penetration was simulated by a logistic function (fig.1), the parameters of the S curve beeing choosen by the expert group, following countries advices.

For non-OECD countries a bottom-top approach was adopted, the capability of each country to build nuclear power plants beeing evaluated on the basis of available data and experts knowledge.

- Reactor strategies and data base

A large number of reactor types and fuel cycle options may be developed until 2030. Each strategy is defined by the share of any reactor type in the global installed nuclear capacity and its evolution, and also by the fuel cycle options choosen.

Each strategy is described on a year by year basis, in order to allow uranium calculations using an appropriate code. The code choosen in



	LOW SCENARIO		HIGH SCENARIO	
	S_∞	H	S_∞	H
OECD AMERICA	20%	20 YEARS	25%	17 YEARS
OECD EUROPE + PACIFIC	40%	20 YEARS	60%	20 YEARS

FIG. 1. Nuclear scenarios.

this study is SCENARIOS, which was developped by IAEA, for the INFCE exercice.

A comprehensive data bank was created, based upon countries submissions and available litterature. It includes reactor caracteristics, fuel cycle lead and lag times, losses at each step of the fuel cycle and, more generally, every information needed to calculate uranium requirements.

HYPOTHESIS

Up to 2000 nuclear electricity generation forecasts are given to OECD/NEA by member states in their responses to an annual questionnaire (*). These data, completed by IAEA informations for other WOCA countries, were taken as a unique scenario for the period 1990-2000.

- Electricity demand scenario

After 2000, in order to project electricity demand, economic growth rate assumptions were adopted, derived from the Word Energy

(*) Nuclear Energy Data, OECD (NEA) annual publication.

Conference data. According to this source, GDP growth rates of 2.6 per cent for OECD and 3.2 per cent for non OECD WOCA, over the period 2000-2030 were adopted.

Electricity consumption is linked with economic growth by an elasticity factor defined as the radio between electricity demand growth rate and GDP growth rate :

$$E = \frac{\Delta\ CEL/CEL}{\Delta\ GDP/GDP}$$

E = Elasticity factor of electricity

CEL = Electricity consumption.

GDP = Gross Domestic Product.

This elasticity factor was assumed to be 1.0 for Developing Countries, according to historical data analysis and current expectations as expressed by experts, as well as founded upon relevant studies.

On similar basis, for OECD, an elasticity factor of 0.7 was adopted for 2000. As the trend in energy savings, associated with efficient techniques development and implementation, is supposed to prolong during the next decades, the elasticity factor is assumed to decrease afterward, falling to 0.55 in 2015 and 0.5 in 2030. However it should be underlined that such a trend will not extrapolate in the very long term as energy, and electricity intensities would stabilize.

- Nuclear electricity generation scenarios

The low and high nuclear scenarios are contrasted, but realistic, and extreme cases have not been considered. It means that neither a widespread moratorium on nuclear energy development, nor a major swing to this energy source as a result of concern over air pollution associated with fossil fuels burning, have been envisaged.

For the low scenario it is assumed that present trend will continue in most countries. The major factors impeding nuclear development will not be eliminated, and the nuclear share of energy supply will remain quite low. Such a situation could result, inter alia, of a lack of public acceptance, an increased competitiveness of fossil fuels and especially gas, greater concern over nuclear safety and, for Developing Countries, inadequacy of financing capacity and insufficient technology transfer.

The corresponding parameters of the logistic function are, for OECD America a 20 % asymptotic nuclear share with a 20 years halving time (see fig. 1) and for OECD Europe and Pacific a 40 % asymptotic nuclear share with a 20 years halving time. For developing WOCA nuclear electricity generation would only double between 2000 and 2030, as a limited number of countries would make progress toward the implementation of a nuclear programme.

The high scenario corresponds to a real, although modest compared to earlier expectations, revival of the nuclear option. It could be induced by a come back of the American nuclear industry by the turn of the century, based upon advanced medium size reactors with new safety features. Public acceptance problems could also be greatly alleviated by excellent performances of operating nuclear plants and the worsening of the environmental problems, linked with the greenhouse effect. For Developing Countries the high scenario would materialize provided innovative financing procedures, like the B.O.T., will have some success and if North South cooperation would strengthen in order to solve energy supply problems. Fossil fuel prices rise, due to increasing demand and unbalance between supply and requirement, would reinforce nuclear electricity competitiveness and favor the high scenario.

In that case the parameters of the logistic function are for OECD America, 25 % asymptotic market share and 17 years halving time and for OECD Europe and Pacific 60 % asymptotic market share and 20 years halving time. For developing WOCA, as most of the nuclear programmes contemplated to day would materialize, the nuclear electricity generation would more than quadruple between 2000 and 2030.

- Reactor strategies

The strategies adopted are intended to demonstrate general trends for uranium requirements to be expected in WOCA over the next four decades. The reactor types considered have thus been limited to those most likely to be deployed and most "illustrative" as far as uranium consumption is concerned.

Although some advanced reactor and fuel cycle concepts may be developed in some countries during the time frame considered, such as HTR, advanced HWR or ATR, they are not expected to be introduced on a

REACTOR TYPE		URANIUM LIFETIME REQUIREMENTS (30 YEARS 70% LOAD FACTOR)
AGR		4605 TONNES
PWR	33000 MWd/t	3756 TONNES
	43000 MWd/t	3396 TONNES
BWR	38000 MWd/t	3617 TONNES
LWR (*)		3470 TONNES
HWR		3559 TONNES
ADVANCED (SEU) HWR		2725 TONNES
HTR		3350 TONNES

(*) AS DEFINED IS THIS STUDY :

1/3 BWR (38000 MWd/t) + 2/3 PWR (43000 MWd/t)

FIG. 2.

large scale worldwide before 2030. Moreover the impact of their introduction on global uranium requirements will remain marginal, compared to the savings induced by plutonium recycling either in LWRs or in FBRs.

A rough evaluation of the effect of some reactor type introduction upon uranium requirements is given by the comparison of their lifetime uranium consumption (see fig. 2).

Up to 2000 the shares of the various reactor types are given by countries programmes.

Post 2000, a reference strategy based upon LWRs and two variants have been studied. The first variant corresponds to plutonium recycling in LWRs and the second to FBRs deployment, after 2020.

The reference strategy assumes that beyond 2000 the additional nuclear power plants installed are all LWRs, meaning 1/3 BWR and 2/3 PWR ; this strategy is described in fig. 3.

The LWR MOX variant, as well as the FBR variant, may be implemented only in countries or regions where plutonium is available. It

REFERENCE LWR STRATEGY

UP TO 2000

ACCORDING TO NATIONAL PROGRAMMES

POST 2000

ALL CAPACITY ADDITIONS OR REPLACEMENTS ARE LWRS

Except : HWRs replaced by HWRs
MOX LWRs and HTRs introduced
according to national programmes

FIG. 3.

seems unlikely that OECD North America and developing WOCA would embark on reprocessing programmes early enough to allow plutonium recycling at an industrial scale before 2030. The plutonium recycling strategies were thus limited to OECD Europe and Pacific, where reprocessing capacities yet exist.

The LWR MOX variant is illustrated fig. 4. In this strategy, MOX fuel (UO_2- PuO_2) is introduced according to plutonium availability limited by the reprocessing capacity which remains at 5 700 t.HM/year over the period 2000-2030. Only one third of each MOX-LWR core is fuelled with MOX, because it was assumed that 100 % MOX fuelled LWRs would not be commercially available before 2030, taking into account the technical and administrative lead times needed before their industrial deployment.

The FBR variant, as illustrated fig. 5, is also limited to OECD Europe and Pacific, according to reprocessing constraints. Moreover, according to countries expectations and programmes, 2020 was choosen as a starting point to launch FBRs industrial and commercial deployment. Before this date the plutonium available is recycled in MOX-LWRs, reserving however sufficient plutonium inventories to allow breeder deployment when needed. The rate of penetration of FBRs, after 2020, is simulated by a logistic formula, assuming that by 2030 the breeders will capture the whole market of new reactor orders.

LWR MOX STRATEGY

UP TO 2000

ACCORDING TO NATIONAL PROGRAMMES

POST 2000

ALL CAPACITY ADDITIONS OR REPLACEMENTS ARE

30 % MOX FUEL LWRS

INTRODUCED ACCORDING TO PU AVAILABILITY

FIG. 4.

FBR STRATEGY

UP TO 2000

ACCORDING TO NATIONAL PROGRAMMES

POST 2000

ALL CAPACITY ADDITIONS OR REPLACEMENTS ARE

30% MOX FUEL LWRS

Introduced according to Pu availability, having made sufficient allowance for FBR requirements

POST 2020

FBR INTRODUCED ON S CURVE

FIG. 5.

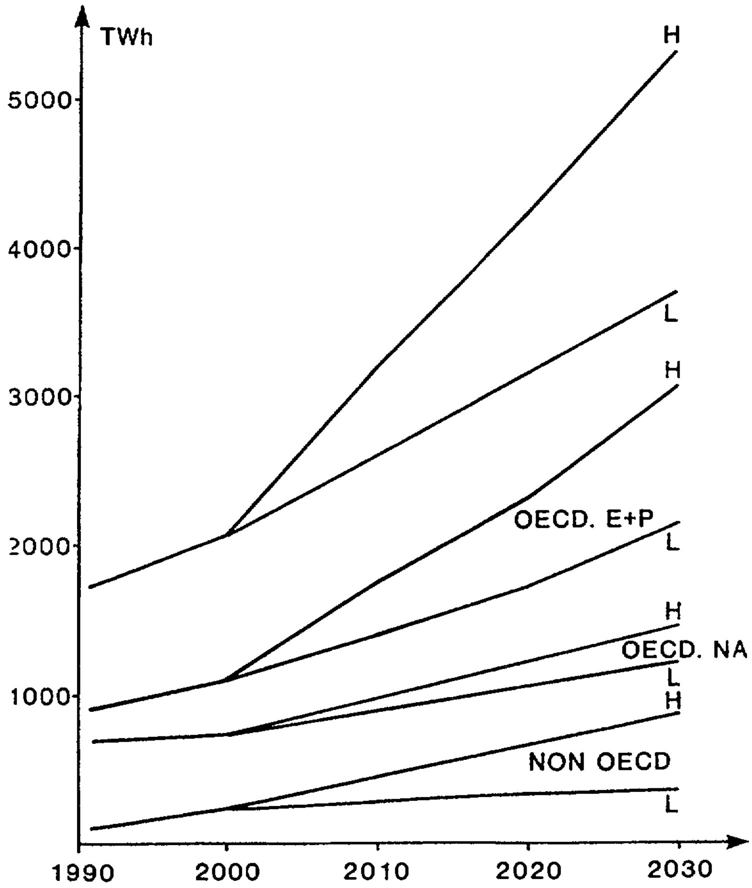


FIG. 6. Nuclear electricity generation in WOCA.

PRESENTATION OF THE RESULTS

Uranium requirements corresponding to each of the two nuclear scenarios and the three reactors strategies, were calculated from 1990 to 2030 in the three regions of WOCA considered.

- Nuclear electricity generation

Nuclear electricity generation in WOCA will grow from 1 695 TWh in 1990 to 2 071 in 2000, at a mean annual growth rate of 2 %. In the low scenario, this growth rate will remain at the same level (1.95 % per year) past 2000 and nuclear electricity generation will reach 3 704 TWh in 2030. In the high scenario WOCA's nuclear electricity generation will increase at an average annual growth rate of some 3 % between, 2000 and 2030 and reach 5 280 TWh at this latter date, as illustrated in fig. 6 and table I.

TABLE I

NUCLEAR ELECTRICITY GENERATION IN WOCA

BY REGION TWh (share %)

	1990	2000	2010 L (*)	2010 H (*)	2020 L	2020 H	2030 L	2030 H
OECD NA	690(41)	729(35)	909(35)	991(31)	1069(34)	1233(29)	1204(32)	1458(28)
OECD E+P	895(53)	1096(53)	1401(54)	1758(55)	1744(56)	2333(55)	2135(58)	2940(56)
NON OECD	110(6)	246(12)	287(11)	460(14)	328(10)	673(16)	365(10)	882(17)
TOTAL WOCA	1695	2071	2600	3209	3141	4239	3704	5280

(*) L = Low scenario.
H = High scenario.

The two scenarios are much more contrasted for OECD Europe and Pacific and for non OECD-WOCA than for OECD North America. The share of OECD Europe and Pacific in WOCA nuclear electricity generation will remain at some 55 %, in both scenarios, similar to the value it has reached by the end of the eighties ; the share of OECD North America will decrease from some 40 % by now to some 30 % by 2030 and the share of non OECD WOCA will more than double.

- <u>Uranium requirements, reference LWR strategy</u>

Annual requirements corresponding to the reference LWR strategy grow from 41 600 tonnes U in 1990 to 72 800 tonnes in 2030 in the low scenario and to 108 700 tonnes in the high scenario.

As illustrated in fig. 7 this represents an average growth rate of 1.4 % by year in the low scenario and of 2.4 % per year in the high one. The range between the low and high scenarios reachs 36 000 tonnes U by year in 2030 for WOCA total, representing plus or minus 20 % around the central value of 90 750 tonnes U.

The regional distribution of uranium requirements reflects the low penetration of nuclear electricity generation in developing WOCA. The OECD Europe and Pacific region will keep its share of 50 per cent of

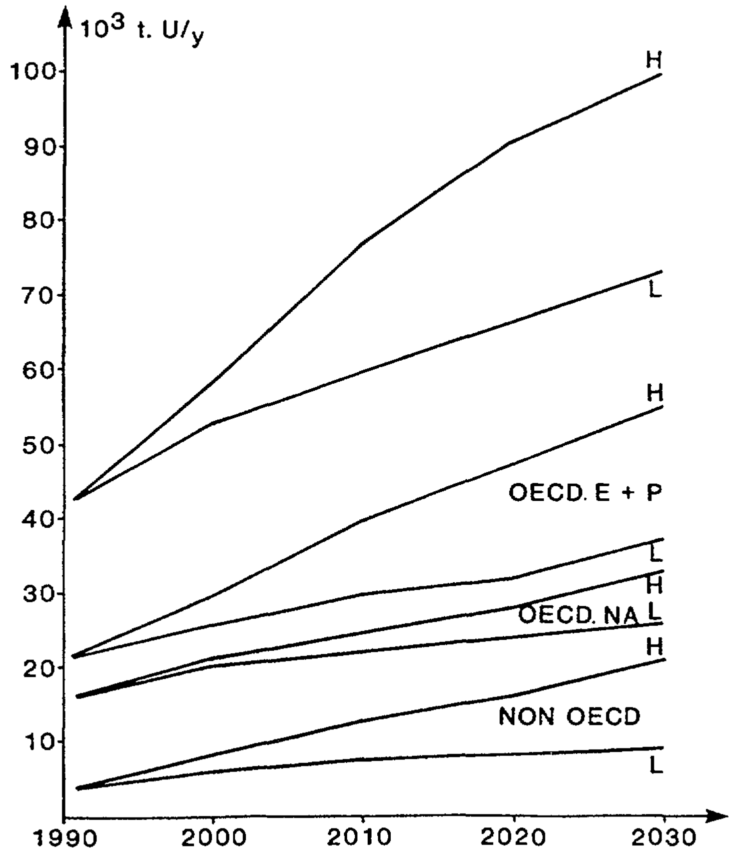


FIG. 7. Annual uranium requirement LWR strategy.

WOCA's uranium requirements all along the period considered, while North America's share will decrease from 40 % in 1990 to roughly one third by 2030 and non OECD WOCA's share will increase to reach some 15 %.

Cumulative uranium requirements from 1990 to 2030 for WOCA range from 2.4 million tonnes in the low scenario to 3.1 million tonnes in the high scenario (fig.8). It means that by 2015 the known reserves (RAR ≤ 80 \$/kg U) will have been exhausted.

- MOX LWR variant strategy

If MOX fuel is introduced in LWRs in OECD Europe and Pacific, where plutonium is available, uranium requirements will be reduced. According to plutonium availability constraints, nearly 20 % of the nuclear electricity generating capacity in WOCA could be MOX fueled LWRs in the high scenario and some 25 % in the low scenario. Uranium annual savings associated with this strategy will amount to some 4 % by 2030 for OECD Europe and Pacific (table III). However for WOCA total the impact would obviously be more modest and limited to 2 % by 2030. Cumulative

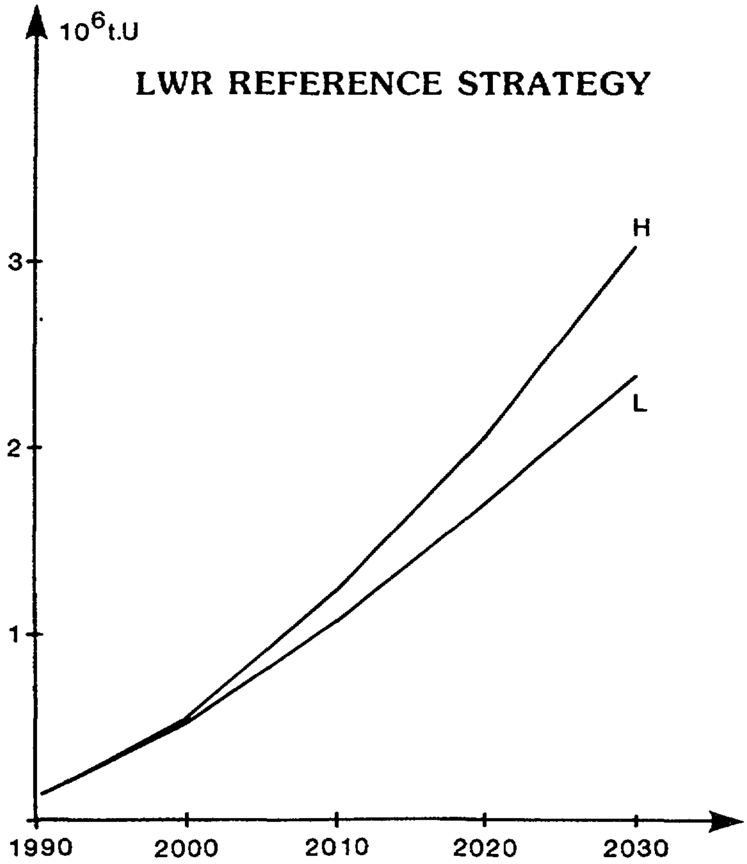


FIG. 8. Cumulative uranium requirements in WOCA.

TABLE II

ANNUAL URANIUM REQUIREMENTS BY REGION

LWR REFERENCE STRATEGY

10^3 t.U (share %)

	1990	2000		2010		2020		2030	
		L	H	L	H	L	H	L	H
OECD NA	16.7 (40)	20.2 (38)	20.9 (36)	22.3 (37)	24.8 (32)	23.5 (37)	27.7 (31)	26.4 (36)	32.7 (30)
OECD E+P	21.2 (51)	26.2 (50)	29.4 (50)	29.9 (50)	39.3 (51)	31.9 (50)	46.0 (51)	37.3 (51)	55.0 (51)
NON OECD	3.7 (9)	6.3 (12)	8.1 (14)	7.5 (13)	12.8 (17)	8.1 (13)	16.9 (18)	9.1 (13)	21.1 (19)
TOTAL WOCA	41.6	52.7	58.4	59.7	76.9	63.5	90.6	72.8	108.8

TABLE III

ANNUAL URANIUM REQUIREMENTS IN OECD E+P
FOR THE THREE STRATEGIES
10^3 t.U

	1990	2000		2010		2020		2030	
		L	H	L	H	L	H	L	H
LWR reference	21.2	26.2	29.4	29.9	39.3	31.9	46.0	37.3	55.0
MOX variant	21.2	25.5	28.5	26.7	36.1	29.4	43.3	35.7	52.6
FBR variant	21.2	25.9	28.3	28.7	38.8	29.0	42.4	28.2	41.2

savings would nevertheless reach 75 000 to 81 000 tonnes U. in 2030, or some 5 % of WOCA's uranium reserves (RAR ≤ 80 $/kg U).

- FBR variant strategy

In order to fully appreciate the impact of this variant strategy it should be remainded that FBRs would be largely deployed only by the end of the period considered, in 2020, and that accordingly they could induce only marginal savings before 2030. Obviously the advantage of FBRs regarding uranium resources management would become more impressive in the very long term, by 2050 and further on.

In OECD Europe and Pacific, the introduction of FBRs will lower annual uranium requirements by some 25 % in 2030 (table III). However by 2000 this variant strategy entails higher uranium requirements than the MOX one, since before 2020, plutonium needs to be retained in order to fuel the FBRs that will be commissioned thereafter.

For WOCA total, the annual uranium savings associated with FBR variant strategy amount to some 12 % by 2030.

The impact of the FBR variant strategy is illustrated fig. 9, showing that in the long term the introduction of FBRs will not only stabilize, but further on reduce annual uranium requirements, while in the LWR reference strategy, and even in the MOX variant one, these requirements will continue to grow.

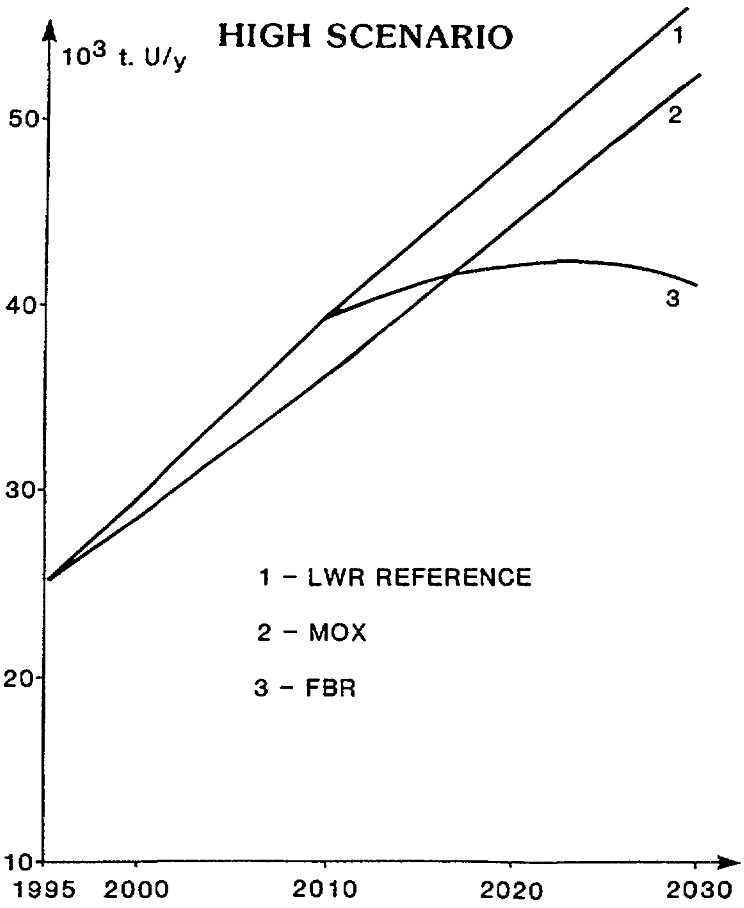


FIG. 9. Annual uranium requirements (OECD Europe and Pacific).

Within the limits of the constraints of the FBR variant strategy adopted here, the cumulative uranium savings, over the period considered, will only be marginal. For OECD Europe and Pacific these savings will not exceed 2 % of the cumulative uranium requirements up to 2030 and for WOCA total the reduction will only be of 1 % (table IV).

CONCLUDING REMARKS

The results presented are to be taken just as an attempt to give some possible trends for uranium requirements evolution in WOCA over the next decades.

Although simple assumptions, and hypothesis, had to be choosen in order to simulate nuclear electricity generation equipment and fuel management in WOCA up to 2030, the results could be considered as reasonable projections, at least as far as orders of magnitude and tendencies are concerned.

TABLE IV

CUMULATIVE URANIUM REQUIREMENTS IN WOCA
FOR THE THREE STRATEGIES
10^3 t.U

	1990	2000		2010		2020		2030	
		L	H	L	H	L	H	L	H
LWR reference	42	520	540	1090	1235	1710	2078	2403	3091
MOX variant	42	518	537	1065	1209	1656	2022	2328	3010
FBR variant	42	519	539	1080	1230	1684	2060	2303	2984

Taking account of all the parameters influencing uranium consumption worldwide it is not possible to forecast precisely the requirements up to 2030. However in any case these requirements will increase quite steadily over the next decades ; their annual growth rate will be, in all the scenarios and strategies considered here, higher than 1 %.

It should be noted that the main source of uncertainty is the nuclear scenario. The range between the uranium annual requirements corresponding the high and low nuclear scenarios exceed 30 % by 2030, while, at the same date, the range between the LWR reference strategy and the FBR one is only of some 12 %.

This is due, obviously, to the fact that strategies are constrained by technological parameters and scenarios are much more influenced by political and other types of arguments whose evolution is essentially volatile.

To summarize, it seems likely that uranium requirements will continue to grow, at least over some decades, as nuclear electricity will remain one of the source of energy supply worldwide, and as technical improvements in reactors efficiency will be introducted quite slowly.

PROCEDURES FOR PROJECTING WOCA URANIUM SUPPLY AND DEMAND

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Abstract

Annually, the U.S.-Department of Energy is required to determine the economic viability of the U.S. uranium mining industry. For this purpose a short term (-2010) uranium supply-demand projection including a uranium market analysis to obtain a price projection is produced using national and international data, such as a reactor by reactor electricity generating capacity, fuel cycle strategies as well as uranium production and supply at different cost levels.

Introduction

I am pleased to be here to describe the work of the Energy Information Administration of the United States Department of Energy for projecting uranium supply and demand. The Energy Information Administration, or EIA as we call ourselves, is an independent statistical and analytical agency within the U.S. Department of Energy. Each year several monthly, quarterly, and annual surveys are sent to U.S. companies by the EIA to collect information on energy imports, production, consumption, and financial statistics. Data on uranium reserves, production, and deliveries, and nuclear power plant status, fuel plans and spent fuel discharges are also collected. With the rapid expansion of the use of personal computers in the United States, some of these surveys are now being collected on PC diskettes.

In addition to collecting historical data, EIA uses the data to perform analyses to project the energy outlook for the next ten to twenty years and, in some cases, beyond. One of our annual analyses concerns uranium supply and demand in the World Outside Centrally Planned Economic Areas (WOCA) for use by the Secretary of Energy in an annual determination of the viability of the U.S. uranium mining and milling industry. The viability determination is required annually for the years 1983 through 1992 as the result of a law passed by the U.S. Congress in 1983 amending the Atomic Energy Act of 1954. This periodic review of the industry was requested, in part, because the U.S. Government restrictions on the enrichment of imported uranium were completely removed by January 1984. Four criteria are used to evaluate the viability of the industry: the adequacy of U.S. uranium resources to meet domestic nuclear power needs for uranium; the sufficiency of the production capacity of U.S. uranium mines and mills and other extraction facilities to meet uranium requirements; the financial solvency of the uranium industry; and the level of dependence on imports. The viability of the industry is evaluated by determining its ability to respond to a disruption of free market conditions. I will now describe the analytical procedure and data used to produce the projection of WOCA uranium supply and demand under free market conditions.

WOCA Demand

Estimates of the demand for uranium through the year 2005 are derived in a series of steps. First, nuclear capacity and generation projections are made for each country by evaluating the status of the nuclear plants under construction and measures of future economic growth. In the United States, the nuclear capacity projected to be operable through 2005 is based only on units that are currently operable or under construction. Any future new orders for nuclear plants are not expected to occur in time to be operable before 2005. Currently, there are 110 units, representing 97 gigawatts of capacity, that have been issued a full power operating license by the Nuclear Regulatory Commission and are operating or expected to operate after an extended shutdown. One unit, Seabrook 1, has a low power operating license authorizing fuel loading and low power testing. Only 5 units, representing 5.7 gigawatts, are still under construction. Their construction and licensing status is monitored through a semi-annual EIA survey and schedules for the Nuclear Regulatory Commission to hold hearings for operating licenses.

The electricity generation projected to be produced by these nuclear units is based on their historical performance and expected improvements. The boiling-water reactors are grouped into four categories with equilibrium cycle capacity factors ranging from 51 percent to 70 percent. The pressurized-water reactors are grouped into five capacity factor categories ranging from 51 to 83 percent. Assumptions are then made on how the capacity factors will change over time. For example, in 1988 there was a sharp increase in the nuclear average annual capacity factor over recent history for U.S. units. Whereas the average capacity factor was around 57.6 percent since 1979, it rose to 63.5 percent in 1988. A preliminary analysis has revealed at least two reasons for the increase. One is that the newest units, those that were in their first refueling cycle during 1988, operated at nearly the same performance level as mature units, which is a departure from what is typical for new units. A second conclusion was that the average refueling time decreased from 88 days in 1987 to 76 days in 1988, a 19 percent reduction in time which translates to a capacity factor improvement. EIA is continuing to investigate the issue to determine if the productivity improvement programs that have been reported by a number of utilities and vendors have begun to pay off and if this improvement can be expected to continue.

The projections of nuclear capacity and generation for the other WOCA countries are prepared in two steps. Initially, an analysis of each country's nuclear program is prepared to determine likely completion dates for units under construction or in advanced planning stages. The "World List of Nuclear Power Plants" published by Nuclear News, "World Nuclear Industry Handbook"

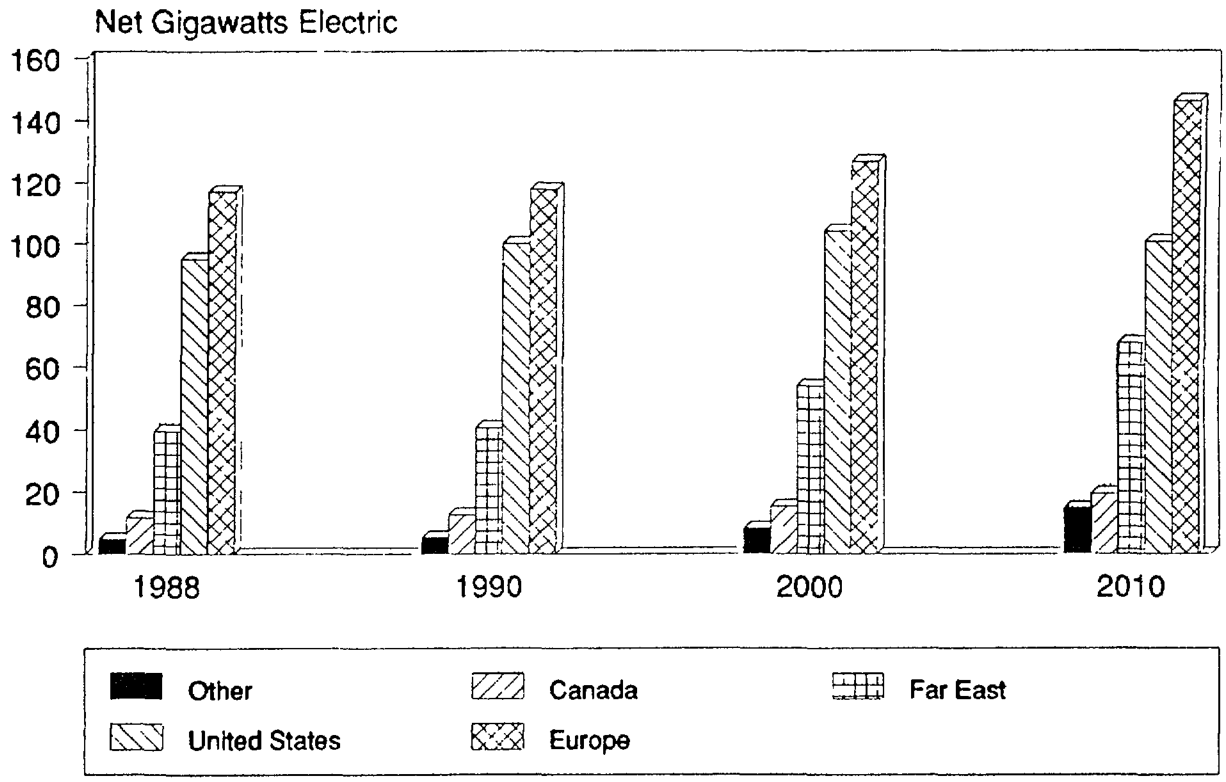

FIG. 1. WOCA operable and projected nuclear capacities for 1990, 2000 and 2010.

published by Nuclear Engineering International, Nuclear Power Reactors in the World published by the International Atomic Energy Agency, and the Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries published by the Organization for Economic Cooperation and Development are used as references. Because the construction pipeline is exhausted in different years for different countries, a model called the World Integrated Nuclear Evaluation System or WINES is used to extend the projections through the year 2010. The WINES model can be run on an IBM-compatible personal computer and based on judgmental input assumptions projects the economic growth rate as measured by the increase in Gross Domestic Product, demand for delivered energy, the electrical share of delivered energy, and the nuclear share of electrical generation. The nuclear generation is then converted to nuclear capacity for the projection year using an average capacity factor for each country. For your information and comment, I have attached to your copy of this paper, the input assumptions for the WINES model that we used in our latest projections. Figure 1 shows the resulting capacity projections for five country groups in 1990, 2000, and 2010. Total WOCA nuclear capacity is projected to be 348 gigawatts in 2010.

Once the nuclear capacity projections are developed, a nuclear fuel cycle model, called the International Nuclear Model, is used to project uranium requirements. Historical data and utility fuel management plans are examined to determine trends in cycle length, nuclear fuel burnup, enrichment product and tails assays, and plans for reprocessing and recycling. These trends are used to develop the input data for the International Nuclear Model. The model is an accounting model, which is used to simulate nuclear fuel cycle

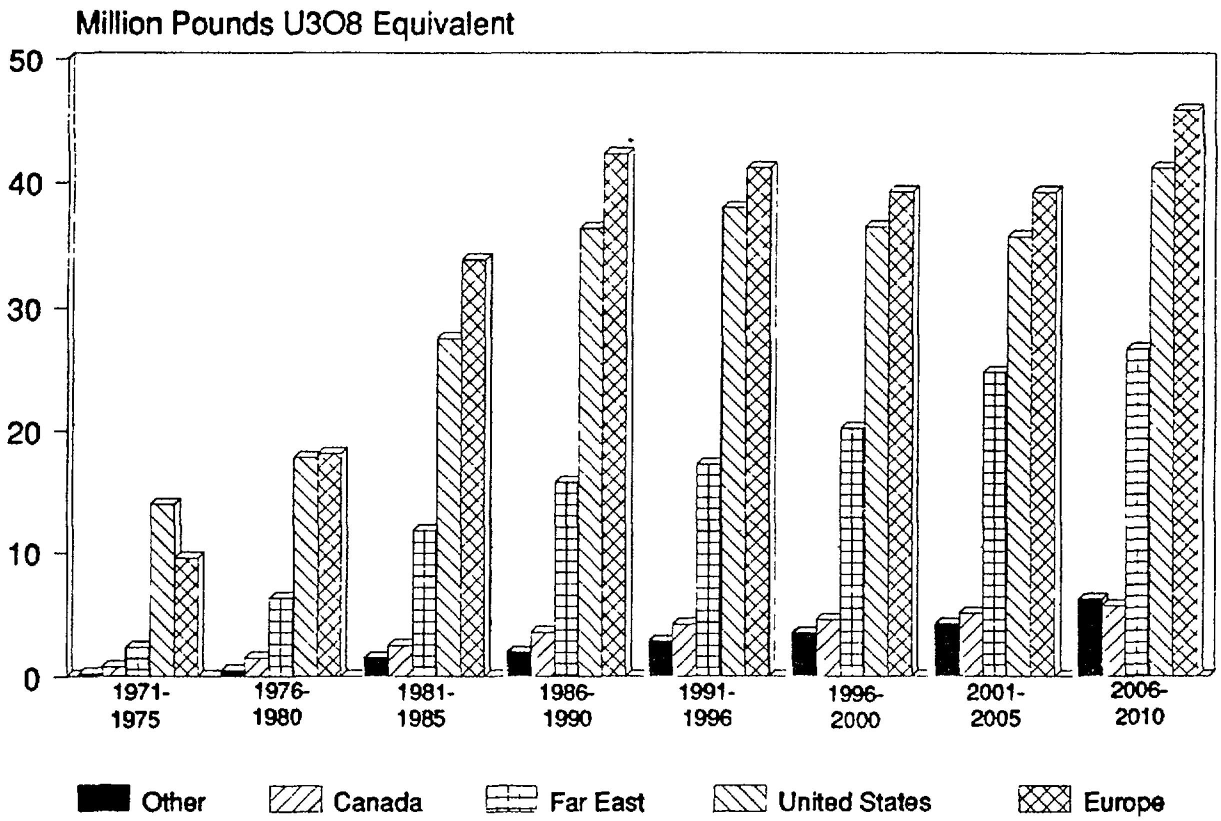

FIG. 2. WOCA uranium requirements, 1970–2010.

operations. To calculate the annual requirements for uranium, the date for the start of each fuel cycle for each reactor over its operating life is determined, as well as the amount of enriched or natural uranium that will be loaded into the core. The uranium concentrate, that is, U_3O_8, is assumed to be required 15 months prior to the start of each fuel cycle for reactors using enriched uranium. This is typically when the uranium concentrate is delivered to a conversion plant.

Each reactor is assumed to operate with a fuel management plan that can vary over time, so that changes such as increasing fuel burnup can be modelled. The fuel management plans consist of core weights, refueling weights, full power days, product assays, and fuel cycle capacity factors. The fuel management plans are not unique for each reactor; instead, a group of generic plans have been developed based on the type of reactor or the reactor manufacturer. We have extensive data on the nuclear fuel plans for the next five refuelings of U.S. nuclear units from one of our surveys, the RW-859, or, "Nuclear Fuel Data" survey. The fuel cycle plans for nuclear generating units in foreign countries are based primarily on data that we purchase from the Nuclear Assurance Corporation and assumptions that we make concerning the amount of recycling of mixed-oxide fuel into the light-water reactors. Figure 2 shows our latest projections of uranium requirements. The annual requirements for WOCA nuclear powerplants are projected to be 126 million pounds of uranium concentrate.

In the United States, the main factors affecting uranium requirements are the assumed capacity factors, the tails assays selected for enrichment, and the planned burnup. As I mentioned earlier, there was a large increase in the average annual capacity factor for U.S. nuclear power plants in 1988. In addition, U.S. utilities reported to the Office of Enrichment Services of the Department of Energy that they plan to request tails assays of .28 to .29 percent through 1995 as compared to the .25 to .26 they reported last year. Both of these factors tend to cause uranium requirements to increase. However, actual and projected increases in discharge burnup could result in a reduction in uranium requirements. Figure 3 shows the equilibrium cycle burnup trends for U.S. boiling-water reactors and pressurized-water reactors since 1972. In 1989, the average burnup for boiling-water reactors is projected to be 27,600 megawatt days thermal per metric ton of initial heavy metal and the average for pressurized-water reactors is 36,200.

WOCA Supply

Along with estimates of the uranium requirements, estimates of potential uranium supply must also be developed. Potential production from every major production center in the world is included. However, production from a country with a centrally planned economy is only included if the country is a potential net exporter. A production center is defined as an existing or potential mine-mill combination, an in-situ leaching facility, or a by-product recovery facility. The production center may be a

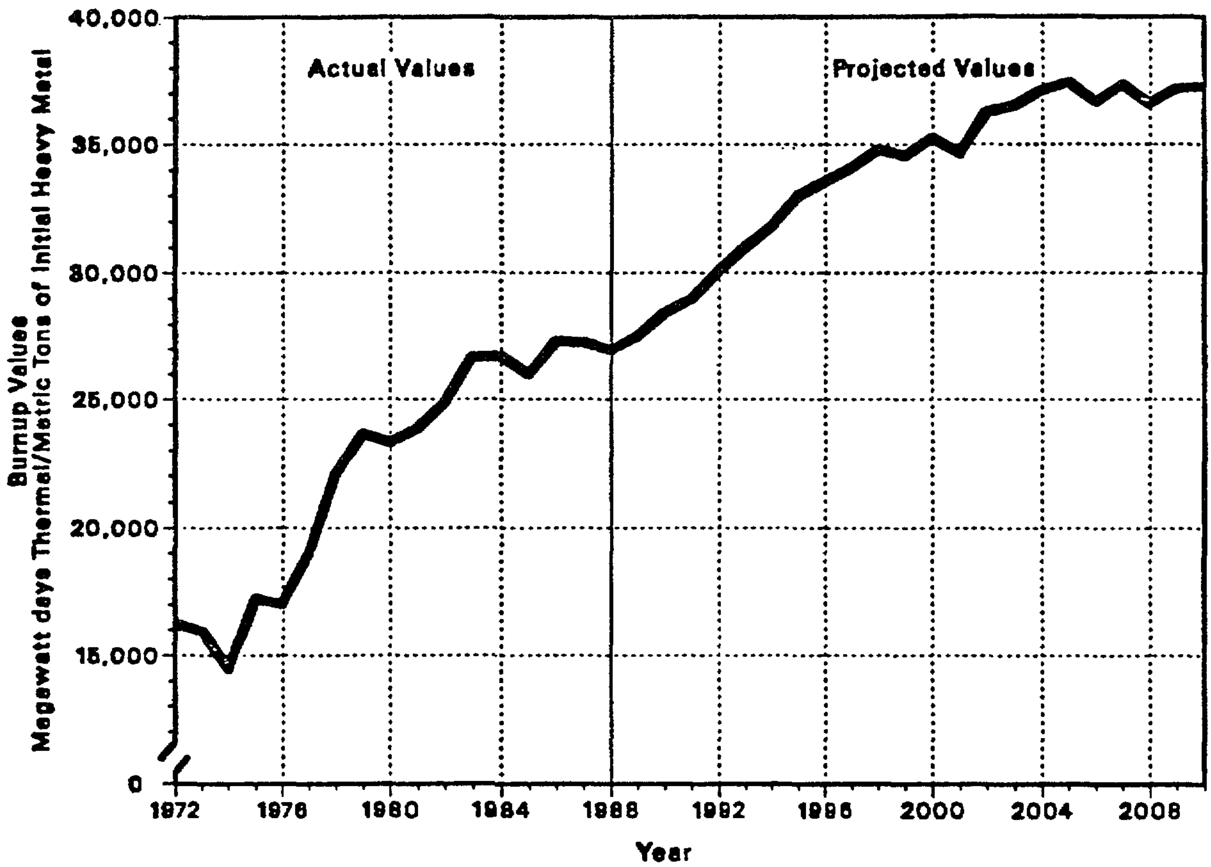

FIG. 3a. Average equilibrium cycle discharge burnup for US boiling water reactors, 1972–2010.

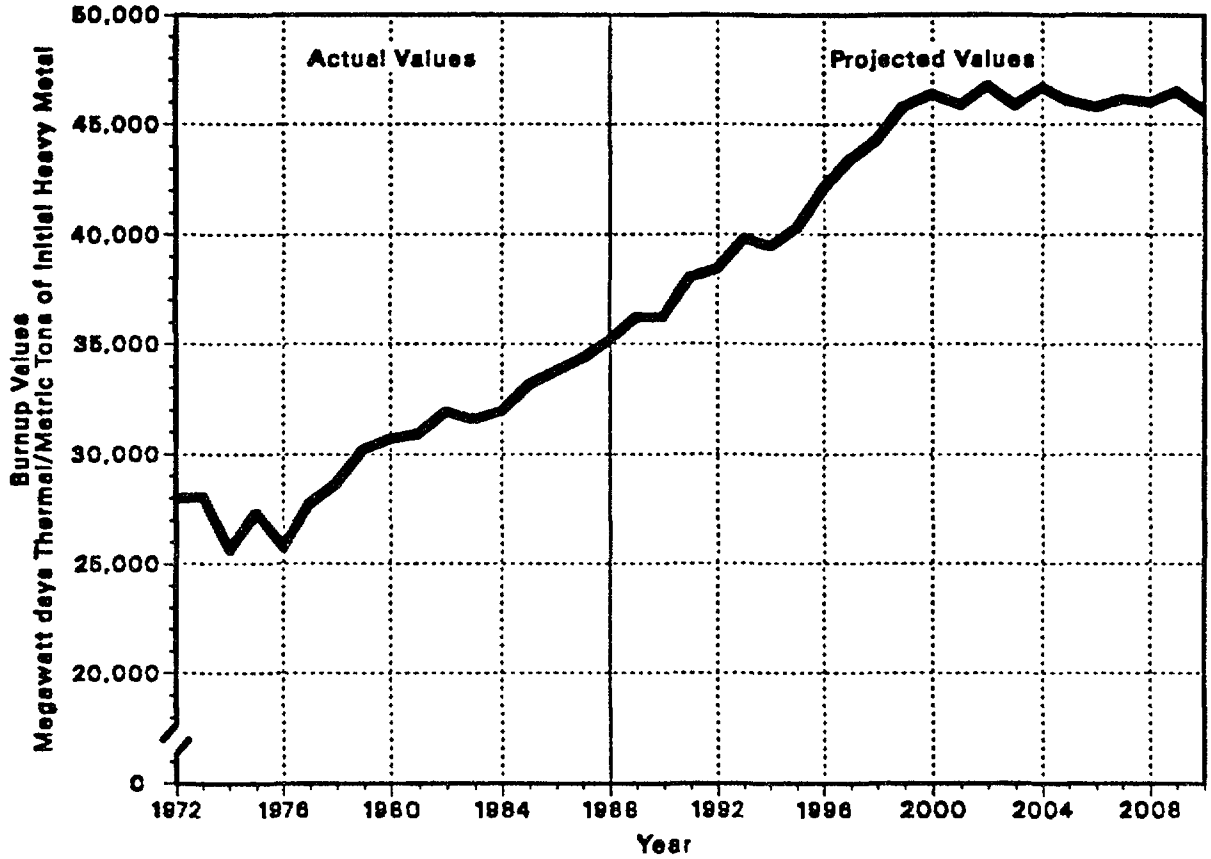

FIG. 3b. Average equilibrium cycle discharge burnup for US pressurized water reactors, 1972–2010.

currently operating facility, a facility under development and planned for future production, or a hypothetical as-of-yet undiscovered deposit. Another source of supply that is accounted for is the excess inventories of electric utilities. Potential production from each center in each year and the minimum acceptable forecast selling price are estimated. Production centers come online, produce uranium, and deplete their reserves depending on geologic, engineering, market and political conditions. The production center is represented with increments of production at different prices. Production costs are estimated by taking into account the size of the reserves; annual production capacity; ore grade; type of production; capital, labor and other costs; taxes and royalty requirements; and a fair market rate of return. Government subsidies, variations in exchange rates, and floor prices are also included. The data on the production centers is primarily based on information from the Nuclear Assurance Corporation. It is also developed from reports from technical journals, information exchanges with Energy, Mines and Resources Canada, the EIA-858 "Uranium Industry Annual Survey," and visits to production centers.

Figures 4 and 5 list some of the information that EIA collects on production centers in the United States. Production centers that were active in 1988 are shown along with their plant capacities. A few of these centers were inactive at the end of 1988: these are the conventional mills at Shirley Basin, Wyoming and La Sal, Utah and the In-Situ Leach facility in Lamprecht, Texas.

Mill Owner	Location	Tons of ore per day
Chevron Resources	Hobson, TX	2,500
Homestake Mining	Grants, NM	3,400
Pathfinder Mines	Shirley Basin, WY	1,800
Rio Algom Mining	La Sal, UT	750
Umetco Minerals/ Energy Fuels Nuclear	Blanding, UT	2,000

FIG. 4. Conventional uranium mills operating during 1988.

Plant Location	Pounds U3O8 per Year	Plant Type
Highland, WY	2,000,000	In Situ Leach
Bingham Canyon, UT	120,000	Copper Byproduct
Hobson, TX	650,000	In Situ Leach
Crow Butte, NE	50,000	In Situ Leach
Sunshine Bridge, LA	420,000	Phosphate Byproduct
Uncle Sam, LA	750,000	Phosphate Byproduct
Plant City, FL	607,500	Phosphate Byproduct
New Wales, FL	750,000	Phosphate Byproduct
Christensen Ranch, WY	4,500	In Situ Leach
Irigaray, WY	350,000	In Situ Leach
El Mesquite, TX	634,000	In Situ Leach
Bill Smith, WY	60,000	Mine Water
West Cole, TX	200,000	In Situ Leach
Kingsville Dome, TX	1,300,000	In Situ Leach

FIG. 5. Non-conventional uranium plants operating at the end of 1988.

Uranium Market

Now I will describe the Uranium Market Model that is used to project how uranium will be supplied by the mining and milling industry to meet the demand for uranium by electric utilities with nuclear power plants. The model makes projections of uranium production, consumption, prices, imports and exports, and inventory levels for nine regions - the United States, Canada, Australia, South Africa, Other Africa, Europe, Latin America, the East, and Other. Figure 6 shows a flow diagram of the Uranium Market Model.

In the model, uranium supply is represented by a step function supply curve consisting of increments of potential production which are available at different market prices. The length of each step of the supply curve corresponds to the quantity available that year and the height of each step represents the price at which that supply increment would be made available for sale in the market. The supply curve is updated on an annual basis to reflect mine openings or closings, production expansion or contraction, and inventory drawdown or change in inventory management policy.

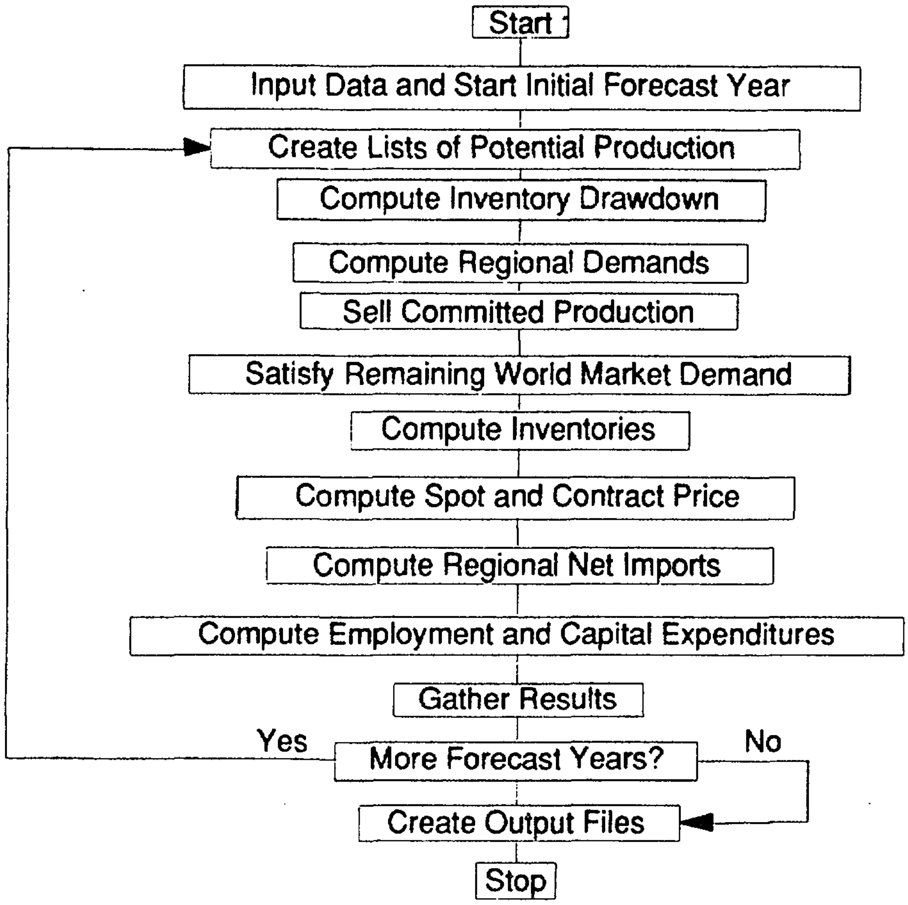

FIG. 6. Flow diagram of the uranium market model.

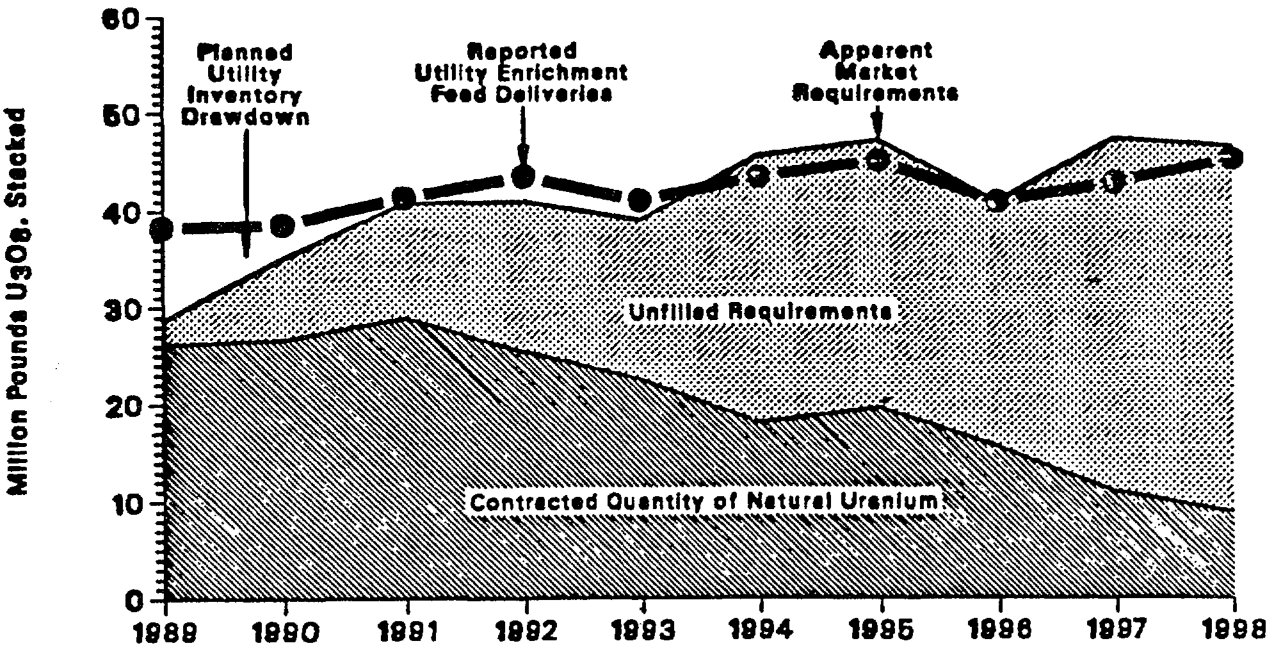

FIG. 7. Contracted and unfilled supply of natural uranium in the USA vs. projected market requirements.

Unused reserves arising from capacity underutilization are available for production in future years. The aggregated supply quantities are distributed to the nine regions so that contract commitments can be satisfied first and then the unfilled requirements. Contract commitments between utilities and producers are used as a lower bound on the amount to be sold by particular production centers. Figure 7 shows the U.S. contract commitments with domestic and foreign suppliers versus the projected uranium requirements. The Uranium Market Model will project how the unfilled requirements will be satisfied.

The demand for uranium in each region is the sum of the utility demands in the region. The annual demand for uranium by a utility consists of four components. The first component is nuclear reactor requirements as described previously. The second component arises from enrichment contract overcommitments and the third component is overcommitments with uranium producers. The fourth component of demand is the level of inventory that a utility wishes to hold to meet any contingency. This is typically expressed in terms of the number of years of forward coverage, such as two years worth of reactor requirements.

Worldwide supply and demand curves are used to determine market equilibrium. It is assumed that the suppliers who are willing to sell uranium at the lowest prices are those who actually capture the market and obtain the sales. The production levels which are forecasted within the model are from those producers with the lowest minimum acceptable selling prices in that year and include utilities' use of their own inventories. The sales include deliveries of uranium under contracts agreed upon in previous years, deliveries under contracts consummated in the current

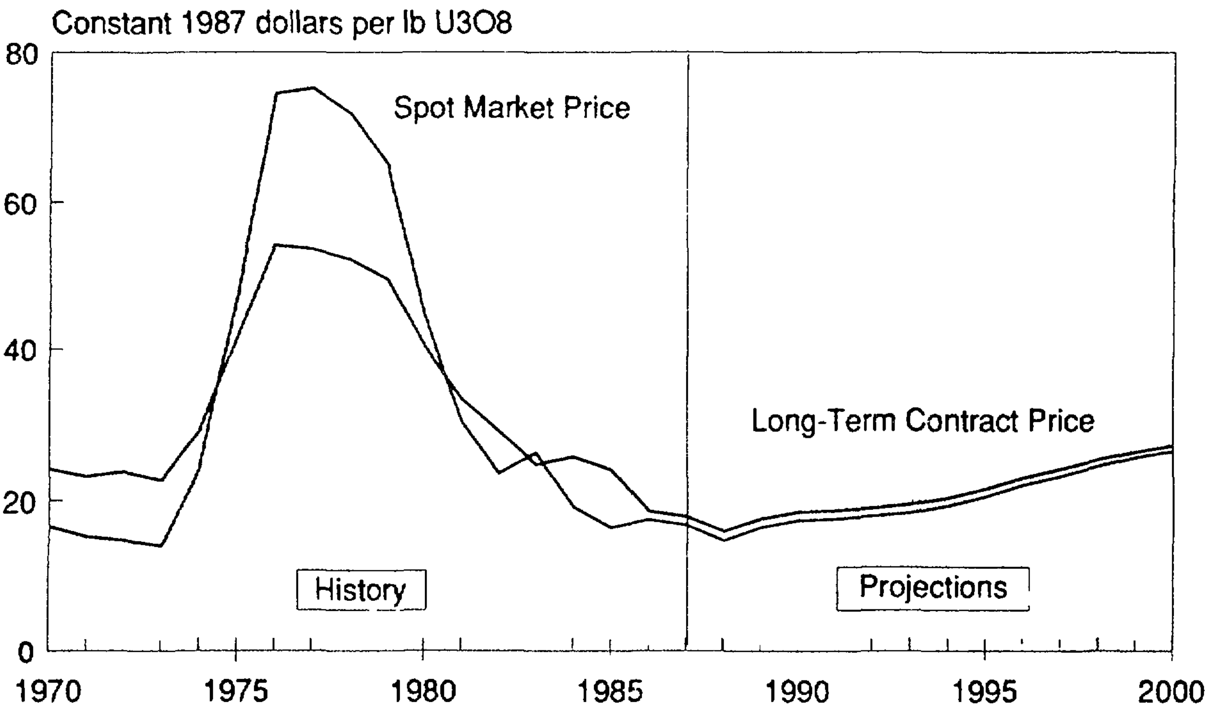

FIG. 8. Long term contract and spot market prices for uranium under current market conditions, 1970–2000.

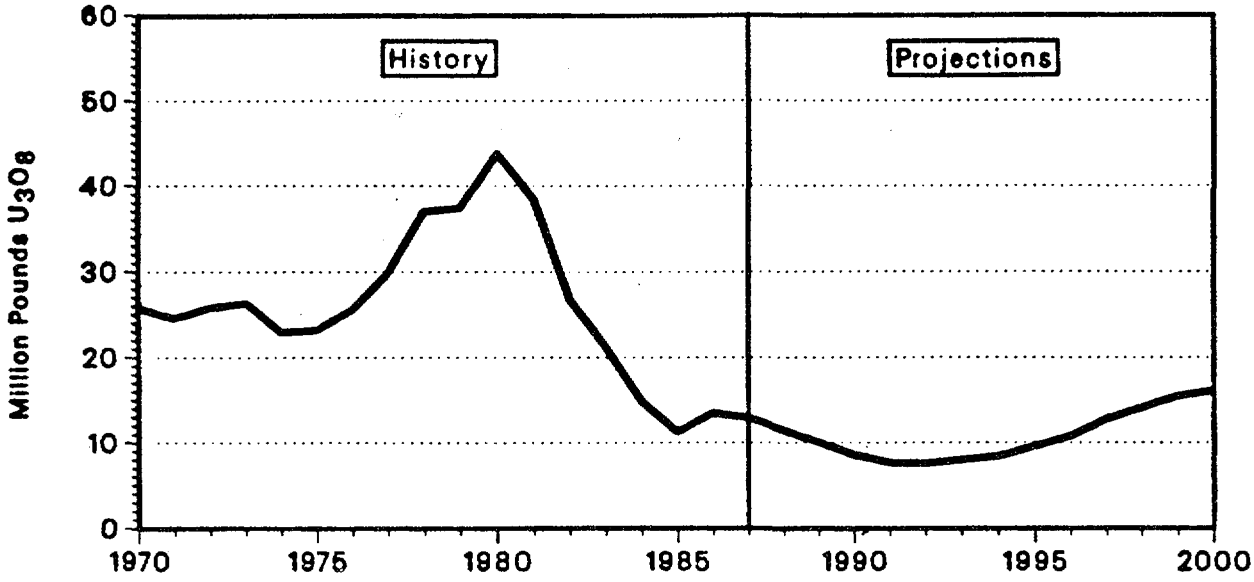

FIG. 9. US uranium production under current market conditions, 1970–2000.

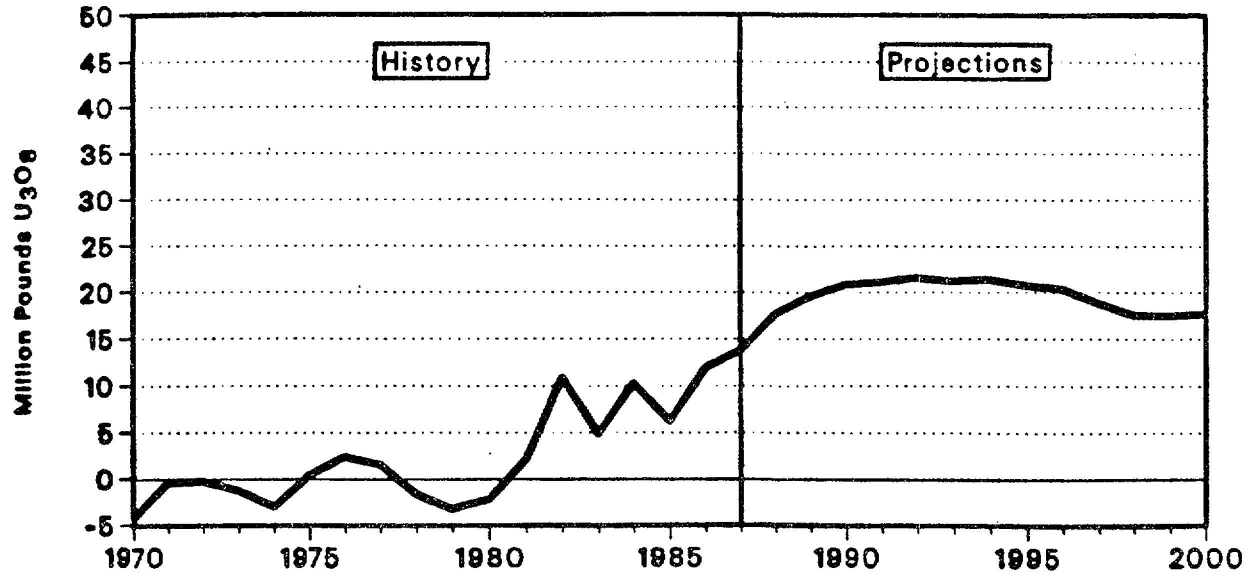

FIG. 10. US net imports of uranium under current market conditions, 1970–2000.

forecast year, and spot market sales. Since each step in the supply curve identifies a unique source of uranium, the suppliers who are projected to sell are easily identified.

The model projects both spot prices and contract prices. These prices are derived from the equilibrium spot price obtained from the worldwide supply and demand curves. The spot price is estimated by taking a weighted average of the previous year's projected spot price and an adjustment of the current forecast year's equilibrium spot price. The contract price is a function of the spot price developed from a regression analysis.

The following figures show the projections of uranium prices, U.S. production, and U.S. net imports that were developed for the viability assessment last year. The projections for this year's report are being prepared now. The drop in the spot price in 1989 can be expected to cause some change in the viability assessment. Also, new estimates of reactor requirements and production center data may have an impact.

Summary

This discussion was designed to show you the detail used by EIA in developing WOCA uranium supply and demand projections. The information available on U.S. nuclear power plants and uranium production centers is extensive. We are continually working to obtain information on nuclear power programs and uranium production and reserves in foreign countries.

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