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URANIUM IN SOUTH AFRICA

HIGHLIGHTS OF THE URANIUM INDUSTRY IN SOUTH AFRICA

1888 Sir William Crookes shows radioactivity to be the cause of the green fluorescence of minute diamonds recovered from Witwatersrand gold ores.

1923 R A Cooper identifies uraninite in a heavy mineral concentrate from the City Deep Gold Mine.

1944 W Bourret and F West visit South Africa, as part of the Manhattan Project, to assess the uranium potential of the Witwatersrand gold reefs.

1946 Dr G Bain, consultant to the Manhattan Project, and Dr C F Davidson, senior geologist for the British Atomic Energy Board, visit South Africa to continue detailed investigations of reefs shown to be uraniferous by the previous sampling.

1948 Promulgation of the Atomic Energy Act and establishment of the Atomic Energy Board.

1949 Pilot plant erected at Blyvooruitzicht Gold Mine to develop a sulphuric-acid leaching process for the extraction of uranium.

1951 First production of yellow cake at the Blyvooruitzicht pilot plant.

1952 The Prime Minister, Dr D F Malan, opens South Africa's first commercial uranium plant at West Rand Consolidated Mines.

1961 Dr T E W Schumann, Chairman of the Atomic Energy Board, turns the first sod to start construction of the National Nuclear Research Centre at Pelindaba.

1965 The South African Fundamental Atomic Research Installation reactor (SAFARI-1) goes critical.

1967 The Nuclear Fuels Corporation of South Africa (NUFCOR) is established to negotiate uranium sales contracts on behalf of members of the Chamber of Mines.

1967 Feasibility of a locally developed vortex-tube (Helikon) enrichment process demonstrated.

1970 Formation of the Uranium Enrichment Corporation of South Africa (UCOR).

1971 Palabora Mining Company becomes the first company to produce uranium outside the Witwatersrand Basin.

1976 Site work started for Koeberg nuclear power station.

1978 Initiation of a project at Valindaba for the commercial production of enriched uranium.

1979 Commencement of a programme to locate a suitable radioactive waste disposal site.

1980 Peak production of uranium in South Africa — 6 143 t U.

1981 SAFARI-1 fuelled for the first time by fuel elements manufactured from locally enriched uranium.

1983 The Atomic Energy Board becomes the Nuclear Development Corporation of South Africa (NUCOR) and the Atomic Energy Corporation of South Africa (AEC) is formed to control both NUCOR and UCOR.

1983 Ground acquired for the establishment of the Vaalputs Radioactive Waste Disposal Facility.

1984 Koeberg I synchronized into the Eskom grid.

1985 Koeberg II synchronized into the Eskom grid — 7% of South Africa's electricity now produced by nuclear means.

1985 NUCOR and UCOR are brought under the single banner of the AEC with its three major programmes, namely Nuclear Fuels, Nuclear Research and Development, and Corporate Services.

1986 Radwaste '86 Conference held in Cape Town during September.

1986 Vaalputs Radioactive Waste Disposal Facility received its first shipment of low- and intermediate-level waste from Koeberg in November.

1987

URANIUM IN SOUTH AFRICA

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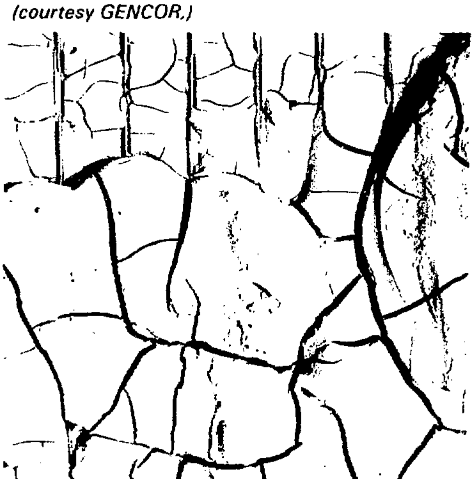
Inset on front cover: Jumbo drill rig at shaft bottom, no. 10 shaft, Vaal Reefs, Klerksdorp (courtesy ANGLO AMERICAN CORP.)

URANIUM DIURANATE (yellow cake) on a drum filter (courtesy GENCOR.)



SAMEVATTING

Wat uraanhulpbronne en -produksie betref, beklee Suid-Afrika die derde posisie in die wêreld, met 'n aandeel van ongeveer 14% in beide gevalle. Tot onlangs was die rol van die land in die kernindustrie beperk tot uraanproduksie, navorsing en 'n mate van kommersiële aktiwiteite. In 1984 het die Koeberg kernkragstasie Suid-Afrika egter op die pad van kommersiële kernkragontwikkeling geplaas, en 'n unieke, plaaslik ontwikkelde uraanverrykingsproses het dit vir Suid-Afrika moontlik gemaak om selfversorgend ten opsigte van sy kernbrandstofbehoeftes te wees.

Die aanwesigheid van uraan in die gouderts van die Witwatersrand is teen die einde van die vorige eeu ontdek, maar eers na die Tweede Wêreldoorlog is met produksie begin en wel in 1952 by die West Rand Consolidated-myn. Teen 1959 het 26 myne erts aan 17 uraanaanlegte gelewer om die jaarlikse produksie op 4 954 t U te staan te bring. Na 1959 het die uraanbehoeftes vir die ontwikkeling van kernkrag afgeneem en daarmee saam die uraanproduksie. Die wêreldoliekrisis in die 1970's het die noodsaaklikheid van die ontwikkeling van kernenergie na vore gebring en die vraag na uraan drasties laat styg. Suid-Afrika se uraanindustrie is hierdeur in so 'n mate gestimuleer dat die jaarlikse uraanproduksie van die land teen 1980 tot 6 143 t U gestyg het. Die wêreldwye afname in ekonomiese groeikoerse asook die vraag na elektrisiteit, gekoppel met die wêreldwye teenkanting teen kernkragontwikkeling in die vroeë 1980's het egter die vraag na uraan laat daal en gedurende 1987 was 13 uraanaanlegte met 'n totale produksie van 3 963 t U in werking. Daar word egter verwag dat die marktoestande geleidelik sal verbeter en dat die wêreldvraag na uraan teen die middel 1990's die produksiekapasiteit met ongeveer 7 000 t U per jaar sal oorskry.

Goud was nog altyd die hoofteiken in die prospektering van die kwartsrolsteenkonglomerate van die Witwatersrand Supergroep, die Dominiumrif Groep, die Mozaan Groep en die Swartrif-Formasie. Die uraanpotensiaal van die gesteente speel geen werklike rol in die keuse van goudteikengebiede nie. Huidige vooruitgang in diepmynbou-tegnologie veroorsaak dat al hoe dieper riwwe ontgin word. Die eksplorasie-onkoste van hierdie diep riwwe is geweldig hoog en daarom gebruik maatskappye deesdae die gesofistikeerde vibroseismiese tegniek alvorens 'n boorprogram aangepak word. Tans is daar 13 maatskappye aktief in die Witwatersrand Kom en hul sukses blyk uit die feit dat 10 nuwe myne gedurende die afgelope sewe jaar reeds aangekondig is en nog aankondigings word verwag. Daar word geraam dat ongeveer R300 miljoen gedurende 1987 aan eksplorasie in die Witwatersrand Kom bestee is. Hierdie bedrag is hoofsaaklik bestee in die soektog na gouddraende riwwe, maar aangesien die meeste goudriwwe ook uraandraend is, vind die uraanhulpbronne van die land ook baat by nuwe goudontdekkings.

As gevolg van die daling in die uraanverkoopprys het die eksplorasietempo buite die Witwatersrand Kom tans 'n laagtepunt bereik. Die meeste maatskappye hou hul opsiegebiede in stand maar geen eksplorasie word uitgevoer nie.

Uraanmineralisasie kom in vyf goed gedefinieerde tydperiodes in die Suid-Afrikaanse geologiese geskiedenis voor. Die oudste tipe mineralisasie is dié wat gedra word deur die kwartsrolsteenkonglomerate wat in ouderdom wissel tussen 2 900 Ma en 2 400 Ma. Alkali-komplekse beslaan 'n tydsduur van 2 000 Ma (Phalaborwa) tot 1 400 Ma (Pilanesberg). Uraan kom ook voor in granietgneise van die periode 1 950 Ma tot 1 000 Ma. Uraan is grootliks afwesig in die periode 1 000 Ma tot 300 Ma, maar maak weer sy verskyning met die begin van die Karoosedimentasie waar dit in sowel sandsteen- as steenkoolafsettings voorkom. Die jongste uraanmineralisasie kom voor in gesteentes van Tersiêre tot Resente tyd, soos byvoorbeeld kalkreet, diatoom-aarde, strandsand en fosfaat.

Hulpbronramings word in verskeie kategorieë ingedeel, nl. Redelik Versekerde Hulpbronne, Geraamde Bykomende Hulpbronne, Kategorieë I en II, en Spekulatiewe Hulpbronne. Hierdie kategorieë dui op die sekerheidsvlak van die bepalings. Verdere indeling in kostekategorieë dui op geraamde koste waarteen die hulpbronne ontgin kan word.

Die grootste gedeelte van Suid-Afrika se uraanhulpbronne, nl. 87%, kom voor as 'n neweproduk van goud in die kwartsrolsteenkonglomerate van die Witwatersrand Kom. Die prys van goud speel dus 'n belangrike rol in die kostekategorisering van die hulpbronne. Vir die doel van die huidige herevaluering is 'n goudprys van \$400/ons en 'n rand/dollar-wisselkoers van R1 = \$0,50 gebruik, wat 'n goudprys van ongeveer R25 700/kg Au daarstel.

Die uraanhulpbronne van Suid-Afrika in die Redelik Versekerde- en Geraamde Bykomende-kategorie-I, herwinbaar teen 'n koste van minder as \$130/kg U, beloop tans 536 500 t U.

In Suid-Afrika word uraan as 'n neweproduk geproduseer. Die grootste gedeelte is afkomstig van die Witwatersrand goudmyne, met 'n klein bydrae van die Palabora kopermyn.

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FOREWORD

Almost two years have elapsed since 1986, the centenary year of the discovery of gold on the Witwatersrand. The geological community in South Africa, who have made such a major impact on the development of the Witwatersrand Goldfields, did not let this occasion slip by without notice and organized Geocongress '86, the largest geological conference ever to be held in the country. Major contributions on Witwatersrand geology were made and tribute paid to those men who, through their knowledge and courage, contributed to the development of this, the largest goldfield in the world.

Since 1986 we have seen yet further developments in this major goldfield with the announcement of new mines, despite the forecasts of those prophets of doom who predicted the demise of the South African mining industry in the near future. Particular examples which come to mind are the announcement by Gencor of their new Oryx venture and JCI's H J Joel mine, both in the southern Orange Free State Goldfield. The lives of several other gold mines, considered to be nearly defunct, have been extended by the gold price reaching new heights after a long period of stagnation. In the meantime great efforts have been made by mining houses to probe two areas where the apparent absence of the Witwatersrand gold reefs has long puzzled geologists. These are the areas between the existing Carletonville, Klerksdorp and Orange Free State goldfields which have become known as the "Potchefstroom Gap", and the "Bothaville Gap", where active exploration is going on, and predictions of the establishment of new gold mines in the near future are already being made.

But this publication is about uranium in South Africa and concurrently with these developments in gold, uranium has benefited, being a major by-product of gold production in the Witwatersrand Basin. The low demand for uranium has resulted in the closure of some recovery plants and this situation has been aggravated by the nuclear accident at Chernobyl in 1986. Yet, prospects for the future of uranium production remain optimistic, since nuclear power still remains one of the more viable alternatives to coal, which is a finite source of energy. Electricity costs in the developed countries of the world still favour nuclear energy. The world uranium overproduction is rapidly being eroded, and a higher uranium price in the near future seems inevitable.

This year marks the occasion of the first industrial-scale production of enriched uranium by the Atomic Energy Corporation of South Africa (AEC) and tribute is paid to the scientists who have contributed through the years to bring this dream to fruition.

South Africa's concern with the back end of the nuclear fuel cycle led to the establishment of the National Facility for the Disposal of Radioactive Waste at Vaalputs in the northwestern Cape Province, where the first low- and intermediate-level waste was received in November 1986.

This site is regarded by many scientists as being the best of its kind in the world. The occasion of the utilization of Vaalputs was preceded by Radwaste '86, the first congress on radioactive waste disposal ever held in South Africa, which was attended by 147 delegates, 57 from overseas, many of whom made excellent contributions.

South African uranium resources are evaluated on an ongoing basis by the AEC in close co-operation with the mining companies concerned, who make certain confidential information available to the AEC. The success of this excercise is largely dependent upon their co-operation, which is gratefully acknowledged. These data are published in summary form biennually and are also made available to various international agencies. Despite increasing isolation in the scientific and technological field, South African scientists are able to make contributions at international forums. The AEC pays tribute to these scientists and to the mining industry whose efforts contribute to maintain our prominent position in the international nuclear field.

J W L de Villiers
Chief Executive
Atomic Energy Corporation of South Africa Limited
June 1988

1 INTRODUCTION

Uranium is the last naturally occurring element in the Periodic Table and was discovered in 1789. It is a dense silvery grey metal which is chemically highly reactive and forms a number of brightly coloured oxides and salts. Prior to the 1940s the only commercial application of uranium was to colour glass and ceramics. It was mere a scientific curiosity.

Uranium is one of the few naturally occurring radioactive elements and one of its decay products is radium. The therapeutic value of this element was recognized by Madame Curie, and in the early part of this century significant quantities of uranium ore were mined to extract the associated radium.

It was the development of the atomic bomb which really brought uranium into prominence. The potential for the use of uranium as an energy source became apparent with the practical demonstration of the theory of fission. Initially the major portion of nuclear developments were restricted to armament applications, with a minor component directed to the peaceful uses of nuclear energy. It was only in 1954 that Russia commissioned the world's first commercial nuclear power station. This 5 MWe plant was the forerunner of a now well-established and important global nuclear power generating programme.

At the end of 1987 a total of 417 nuclear power reactor units were operational in 26 countries throughout the world, with another 120 units under construction in these and six other countries. During 1987, 22 new plants were brought on-line in eight countries, increasing the nett nuclear generating capacity by 9% to 297 497 MWe, representing about 17% of the world's total electricity generating capacity. Nuclear power's share of electricity production in 1987 for individual countries ranged from 70% for France to 0,5% for Brazil, with five countries topping 40%. In absolute terms the USA was well ahead, with 106 reactors with a nett capacity of 92 982 MWe.

Apart from power generation, reactors are used to produce a host of radioactive isotopes. These isotopes find applications in various industrial fields, such as food irradiation and medicine.

South Africa is a major country in terms of uranium resources and production, being ranked in the top three of the world for both, with a 14,9% and 12,4% share respectively. Until recently the country's role in the nuclear industry has been limited to research and the production of uranium with minor commercial activities. The commissioning of the Koeberg nuclear power station in 1984 placed South Africa firmly on the path of commercial nuclear power generation. A unique, locally developed uranium enrichment process will enable South Africa to be self-sufficient in its nuclear fuel needs. Foreseeing the need to cope with radioactive waste from its nuclear industry, South Africa initiated investigations in 1979 to locate a suitable low- and intermediate-level waste disposal site. This culminated in 1983 in the acquisition of land for the establishment of the Vaalputs Radioactive Waste Disposal Facility. Detailed investigations were carried out on the site during 1984 and 1985, and construction of the facility commenced early in 1986. In November 1986 the project culminated in the delivery of the first consignment of low- and intermediate-level waste from the Koeberg nuclear power station. Spent-fuel elements would also be stored at the facility.

2 HISTORICAL REVIEW

The first clues of the presence of uranium in South Africa were found late in the 19th century when the green fluorescence of minute diamonds recovered from gold ores of the Witwatersrand was shown to be caused by radioactivity. Some years later uraninite was identified in heavy-mineral concentrates from the City Deep Gold Mine, but because of its lack of commercial value, this raised little interest. A world-wide investigation into sources of uranium following the development of the first atom bomb, re-focussed attention on South Africa's uranium resources.

Commercial uranium production commenced in 1952 at the West Rand Consolidated Mines and this was followed closely by the commissioning of four more uranium plants in 1953. Production accelerated rapidly until 1959, when 26 mines were feeding 17 plants for a total production of 4 954 t U In the early years South Africa's entire output was committed to supplying the Western World's nuclear armaments programme. After 1959 the needs of these programmes declined, the commercial nuclear power programmes did not materialize as planned either and uranium production in South Africa followed suit, reaching a nadir of 2 262 t U in 1965.

At that time relative abundance and cheapness of fossil fuels did little to encourage development of the embryonic nuclear power industry. The situation changed drastically in the 1970s with the advent of the world oil crisis, and demand for uranium rose rapidly. The resultant steep rise in price stimulated South Africa's uranium industry to the extent that by 1980 it had almost trebled its production, i.e. to 6 143 t U.

A century of gold mining activities on the Witwatersrand has left vast tonnages of surface tailings containing substantial reserves of low-cost uranium. The favourable uranium price in the late 70s led to the establishment of three large tailings treatment operations in the East Rand, Klerksdorp and Welkom areas, all of them becoming significant uranium producers. One, the Chemwes plant at Klerksdorp, was established specifically to produce uranium, whereas the other two also extract gold and pyrite from the tailings. This boom period for uranium also saw the establishment of the Beisa mine, which was brought on stream in 1982 as South Africa's first primary uranium producer.

The expected boom in the nuclear power industry declined in pace with the lower economic growth resulting from the higher oil prices, and active energy savings programmes instituted throughout the Western World. The Three Mile Island incident in 1979 also triggered an increased anti-nuclear campaign. In the wake of this the growth of the nuclear power industry declined, with a number of planned nuclear plants, as well as coal-fired plants, being cancelled in various parts of the world. Demand for uranium dropped and consequently so did its price, which, by the end of 1984, had fallen to about a third of its peak level, attained in 1978. It has since risen marginally but is still less than 40% of its peak levels in 1978. Substantial rationalization took place in the South African uranium industry in the period from 1984 to 1986, resulting in the closure of a number of uranium plants. At the beginning of 1987, 13 plants were in operation which produced 3 963 t U during the year.

3 URANIUM MARKET CONDITIONS

During 1987, the nuclear power plant capacity of the Western World amounted to 252,4 GWe. NUKEM, in their monthly report on the Nuclear Fuel Cycle, expects the overall installed capacity to reach 351 GWe by the year 2000, representing a 39% increase.

The demand for natural uranium to fuel reactors reached 41 800 t U in 1987, and is projected to increase to 55 000 t U by the year 2000. The Western World's total uranium production remained below demand for the third consecutive year and during 1987 amounted to 37 800 t U.

Fig. 1 shows the historical and projected annual uranium demand and production of the Western World for the period 1965 to 2000.

The gap between production and demand increases rapidly in the projected years from 1988 to 2000. Current world excess inventory levels are estimated by NUEXCO to be about 98 000 t U. By 1993, this excess will have been used up and additional supplies will be needed to maintain minimum inventory levels. Reprocessing will alleviate some of the pressure, but new production centres will have to be capable of producing 12 000 t U by 1995 and 30 000 t U by the year 2000 according to a NEA/IAEA publication. The estimated capital investments needed to construct the new mines and mills are about US $1 200 million and US $1 800 million in 1995 and 2000 respectively. As these mines will exploit known resources, they will be located in currently known resource countries. In the light of the large capital requirements mentioned above, South Africa would be in a favourable position to meet some of the demand by utilizing current excess and mothballed production capacity with the minimum capital requirements.

No major uranium price changes are expected until the early to mid-1990's, when demand could begin to exert pressure on supply.

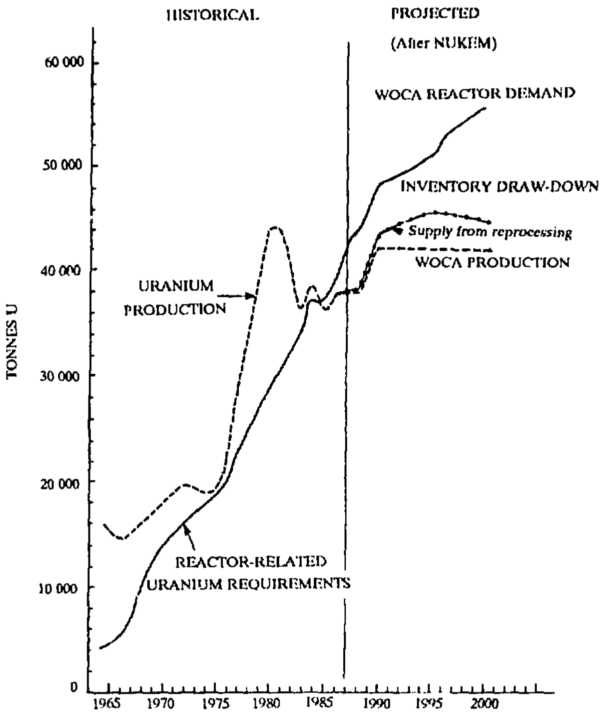


Fig. 1 Western World uranium production and demand 1965 to 2000

The uranium market seems to be moving into a more stable situation and, as NUKEM puts it, panic sales of excess inventories carried by utilities with cancelled reactor projects no longer exist, producers with uncommitted excess production no longer have to compete with inventory sellers, and uranium purchases by producers who had to close their high-cost operations and fulfilled their delivery obligations by purchases of low-price uranium have diminished. Uranium producers can now start relying on a solid base of operating nuclear power stations and the demand for uranium will be based more and more on real consumption rather than on expectations of the requirements of future generating units.

The US import ban on Southern African uranium had no severe short-term impacts on the contractual situation of the South African producers or on the fuel supply of the Western World utilities concerned. In anticipation of the import ban, advanced deliveries of large quantities of uranium were made to the USA in 1986 for end-use in that country and by other long-term South African clients.

4 URANIUM EXPLORATION

Uranium has always been of secondary importance to gold as a target commodity in the exploration of the quartz-pebble conglomerates of the Witwatersrand Supergroup, Dominion Group, Mozaan Group and Black Reef Formation. A marked increase in the price of uranium in the late 1970s brought the metal into greater prominence and led to the establishment of two primary uranium producers, the Beisa Section of St. Helena Gold Mines Limited and the Afrikander Lease Limited. The subsequent slump in the uranium price caused the untimely closure of both these operations. The latter ceased operations in 1982 and is on a care and maintenance basis, whereas the former was shut down completely in 1984. In 1987 it was announced that Beisa would be reopening as the Oryx mine. Exploration identified another economic reef in the area adjoining the old mine and this has been incorporated into the new lease area. It will primarily be a gold producer, but at least for the initial years it will also produce uranium.

Currently the very favourable gold price in rand terms has stimulated extensive exploration in various parts of the Witwatersrand Basin but the uranium potential is of little importance in determining target areas and levels of expenditure. A significant factor in determining target areas is the advances in deep-mining technology, making deeper reefs accessible for exploitation. A result of this is the rapid escalation of the costs of exploring for these deep reefs and recently companies have been making extensive use of the sophisticated vibroseismic technique to define targets more accurately prior to drilling. Time is also an important factor in drilling deep holes and recently three oil drill rigs have been imported into South Africa for use in Witwatersrand drilling. Their rate of penetration is far higher than that of conventional rigs and will substantially shorten the time needed to prove an ore reserve sufficient to support a mining venture.

At present 13 companies are actively exploring within the Witwatersrand Basin. It is estimated that in 1987 more than 150 drill rigs were operating in the Basin and that the total explorational expenditure was of the order of R300 million. The success of the activities is shown by the initiation of 10 major mining ventures, either as new mines or extensions to existing mines, since the beginning of the decade. These projects involve capital expenditure, as estimated at the initiation of the project, amounting to more than R6 000 million. In addition, a large number of smaller ventures, mostly involving reopening of defunct mines, have been brought on stream in the last five years. The level of current exploration makes it highly likely that further mining ventures will be announced in the near future.

Exploration in the Witwatersrand Basin is taking place along its entire northwestern and western margin, in the search for extensions to the known basin. The most promising areas are the southern Welkom Goldfield, and the Potchefstroom and Bothaville gaps. The two latter areas are particularly exciting because although it was believed until recently that no economic reefs had been developed in these areas, they are now bustling with activity, with promising intersections being made.

The presence of uranium in Karoo sediments was first noted in 1967 during drilling for oil. One year later, in 1968, the application of a Colorado Plateau-type model resulted in exploration being started in the southern Karoo. This escalated rapidly and spread to other parts of the Karoo Basin, and at one stage 11 companies were active in the area. A number of deposits were identified but the drastic slump in the uranium market in the early 1980s led to a decline in exploration and by 1982 only one company was still active, with all work stopping in early 1985. A similar fate overtook the uraniferous coal deposits of the Springbok Flats, where exploration is currently also at a standstill.

5 URANIUM PROVINCES

Uranium mineralization is present in rocks which encompass almost the whole of the geological history of South Africa. However, significant mineralization is restricted to five fairly well-defined periods. Each period is characterized by a distinct type or combination of types of mineralization. The oldest type is that hosted by quartz-pebble conglomerates which fall in the time span from 2 900 Ma to 2 400 Ma. Uranium-bearing alkaline complexes cover a wide time scale from 2 000 Ma (Phalaborwa) to 1 400 Ma (Pilanesberg). Uranium is also found in granite-gneisses which span the period from 1 950 Ma to 1 000 Ma.

A hiatus in the occurrence of uranium in South Africa exists between 1 000 Ma and 300 Ma. It is only with the onset of Karoo sedimentation that uranium mineralization reappears in the South African stratigraphic column. Uranium occurs in both coal seams and sandstones of the Karoo Sequence. The youngest uranium mineralization occurs in a variety of Tertiary to Recent sediments which include calcretes, peaty diatomaceous earths, beach sands and phosphates. All these types of uranium deposits characterize mineral provinces, the distribution of which is shown in Fig. 2.

5.1 Quartz-pebble conglomerates

Uraniferous quartz-pebble conglomerates in South Africa are found in four distinct sequences of rocks, namely the Pongola Sequence, the Dominion Group, the Witwatersrand Supergroup and the Transvaal Sequence. The Pongola Sequence is the oldest, having been dated at ± 3 000 Ma, and is the least important of the four. The Sequence has two subdivisions, and uranium associated with gold is known to occur in a conglomerate at the base of the uppermost Mozaan Group. The Sequence has only been investigated to a limited extent, and virtually no resources have been identified.

Considerably more important is the Dominion Group, which forms part of the Witwatersrand Province and is somewhat younger than the Mozaan, having an age of ± 2 800 Ma. It is restricted to the northwestern part of the Witwatersrand Province where it rests on Archaean granites and is overlain by the Witwatersrand Supergroup. Two conglomerate horizons occur near the base of the Group and these carry gold and

Waste disposal facility building at Vaalputs

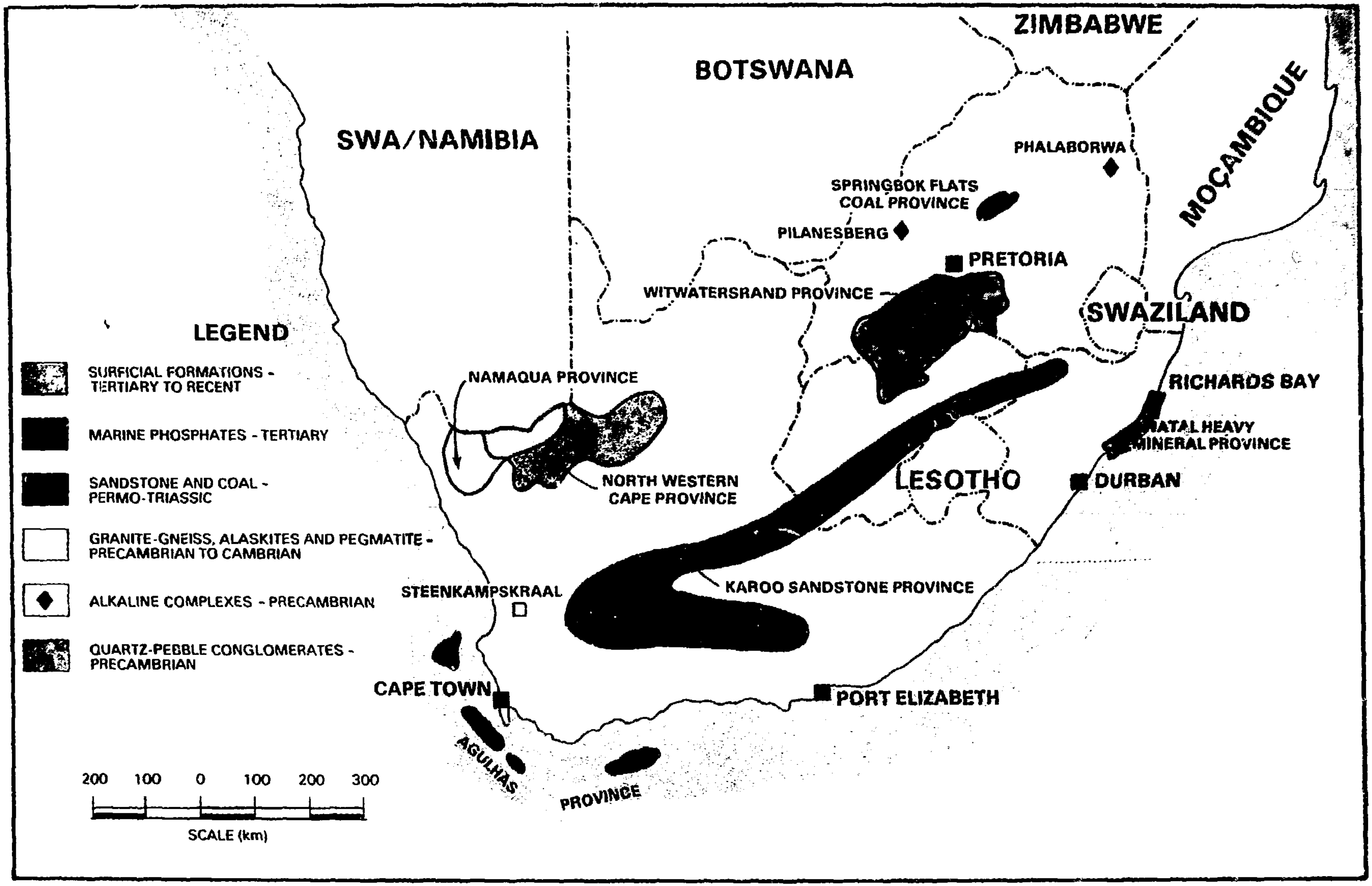


Fig. 2 Uranium provinces of South Africa

uraninite mineralization, which was exploited in the past. Substantial resources have been proved and more are believed to exist, but the latter are largely in the speculative category.

The Witwatersrand Supergroup is divided into the lower West Rand Group and the upper Central Rand Group. Both Groups have uraniferous and auriferous quartz-pebble conglomerates but the latter Group is by far the more important, having the bulk of the uranium and gold resources of the Witwatersrand Supergroup, and containing 83% of South Africa's uranium resources in the lower cost categories.

The West Rand Group was deposited mainly under tidal and subtidal conditions and conglomerates are uncommon. Significant amounts of uranium are found only in one zone of conglomerates in the Government Subgroup. The sediments of the Central Rand Group are generally coarser than those of the lower Group, having been deposited in a fluvial fan environment, and conglomerates are more common. Six major fluvial fans have been identified along the northwestern margin of the basin and these constitute the Evander, East Rand, West Rand, Carletonville, Klerksdorp and Welkom Gold Fields. From the bottom upwards the major uranium-bearing conglomerate reefs in these fans are the Beisa Reef at Welkom, the Carbon Leader in the Main Conglomerate Formation, a number of the Bird Reefs on the West Rand, with their equivalents the Vaal Reef at Klerksdorp, the Basal Reef in the Welkom Gold Field, and the Elsburg Reefs of the West and East Rand. Uranium can also be profitably extracted, as a by-product of gold, from other reefs such as the Commonage and Kimberley Reefs.

The Black Reef Formation of the Transvaal Sequence was mined in the past for gold. The mineralization is hosted by quartz-pebble conglomerates which are also uraniferous in places. The reefs are similar to those of the Witwatersrand Supergroup but have a lower uranium grade, generally below 0.05 kg U_3O_8/t.

Mining for gold on the Witwatersrand has been in progress for just over 100 years and vast amounts of tailings have been generated. A significant proportion of these tailings, especially those in the older dumps, contains economic albeit low concentrations of gold, uranium and pyrite. Three large operations are currently reworking selected dumps for these minerals and a number of smaller concerns are extracting only gold.

5.2 Alkaline complexes

Several alkaline complexes occur in Southern Africa, two of the more important ones being the Phalaborwa Igneous Complex situated in the Republic of South Africa, and the Pilanesberg Complex situated in the neighbouring Republic of Bophuthatswana.

The Pilanesberg Complex forms an almost perfectly circular outcrop and is the largest of a number of bodies of alkaline rocks found in Southern Africa. It is situated within Bophuthatswana about 50 km NNW of Rustenburg, at the junction of the granites and mafics of the Bushveld Igneous Complex. The Pilanesberg Complex has an east-west diameter of 28 km, a north-south diameter of 24 km, and covers an area of approximately 530 km². It has been dated at 1 400 Ma and was emplaced by an involved sequence of volcanic explosions, lava flows and ring fracturing with upwelling of magma. Like similar complexes elsewhere, especially in Africa and Greenland, some of the Pilanesberg rocks contain concentrations of elements such as beryllium, strontium, yttrium, rare earths, zirconium, hafnium, niobium, tantalum, zinc and also uranium and thorium. Preliminary investigations have indicated that the Complex has considerable potential as a major source of these elements, provided that economically viable metallurgical extraction techniques can be developed under suitable market conditions.

It is estimated that the *in situ* resources of the Pilanesberg Complex amount to 25 000 t U per 100 m depth below surface. These resources are classified as Estimated Additional Resources - Category II. The cost of recovering the uranium is estimated to be between $130 - $260/kg U, with the proviso that some of the other contained metals can be recovered profitably as co-products. These resources are not included in the RSA assessment.

The Phalaborwa Igneous Complex (2 000 Ma), located in the Archaean shield of the northeastern Transvaal and geomorphologically expressed as a low hill called Loolekop, attracted the attention of prospectors more than a century ago. Prospecting by Dr Hans Merensky during the early 1900s led to the exploitation of apatite from the pyroxenite surrounding Loolekop. The presence of vermiculite was discovered during the course of these early mining activities, but its economic significance was realized only several years later, and production of vermiculite commenced in 1946. The presence of the radioactive mineral uranothorianite in Loolekop was established in 1952 by a unit of the Geological Survey of South Africa and triggered a prospecting programme by the then Department of Mines. Investigations showed the deposits of radioactive minerals to be economically unattractive, but resulted in the discovery of a very large low-grade, disseminated copper ore body hosted by the carbonatite and surrounding foskorite. The presence of considerable quantities of the zirconium mineral baddeleyite was also identified.

The State owned the mineral rights of the copper deposit and it was decided that its exploitation was a matter for private enterprise. A joint venture comprising Rio Tinto Zinc Corporation and Newmont Mining Corporation procured a prospecting lease and the Palabora Mining Company Ltd (PMC) was consequently formed in 1956 to prospect and develop the ore deposit

No attempts were made to exploit the radioactive mineral deposits until 1967, when studies were undertaken by PMC into possible methods of recovery. Towards the end of 1969, following the development of novel and successful gravity concentration and chemical extraction techniques, feasibility studies were completed and the construction of a full-scale plant commenced. This was completed in mid-1971 and production of uranium oxide began in August of that year.

Provision is made for recovery of thorium sulphate. The ratio ThO_2:U_3O_8 is of the order of 2,5:1, so that thorium could become an important by-product should its potential as a nuclear fuel ultimately be exploited.

PMC is the only South African uranium producer outside the Witwatersrand Basin, and a total of 2 300 t U had been extracted as a by-product of copper mining up to the end of 1987. Table I shows Palabora Mining Company's historical uranium production.

Original projections of the life of the mine extended through 1992. In August 1979, following extensive engineering studies, PMC announced plans to enlarge the open pit in all dimensions to extend the life of the project to 1999. The open pit will be expanded by an average of 200 m in diameter and to a final depth of 725 m below surface. PMC will therefore be able to produce approximately 150 - 200 t U per year till the year 2000.

It should also be noted that the depth extremity of the Phalaborwa carbonatite plug has not been encountered. If it extends down to 2 000 m, the life of the mine would be extended considerably.

TABLE I

PALABORA MINING COMPANY'S HISTORICAL PRODUCTION

YEAR	TONNES U	% OF RSA
1971	52	1,59
1972	119	3,72
1973	111	4,06
1974	106	3,91
1975	106	4,26
1976	121	4,39
1977	75	2,23
1978	119	3,00
1979	103	2,15
1980	144	2,34
1981	198	3,23
1982	219	3,77
1983	185	3,05
1984	135	2,36
1985	185	3,79
1986	157	3,41
1987	149	3,76

5.3 Karoo sandstone

The Karoo Sequence of Permo-Triassic age covers approximately 66% of South Africa. The presence of uranium in the Karoo was first noted in 1967 during radiometric logging of boreholes drilled by SOEKOR. Uranium deposits and occurrences have been located in a broad arc of some 1 200 km stretching through Beaufort West in an east-west direction, and from the southern Karoo through the southern Orange Free State to the eastern Orange Free State and Qwa-Qwa. In the eastern Orange Free State uranium was discovered in the Molteno Formation and in Qwa-Qwa in the Elliot Formation.

Uranium mineralization in the southern and central Karoo occurs in rocks belonging to the Adelaide Subgroup. The *Abrahamskraal and Teekloof Formations of this Subgroup* consist of alternating units of sandstone and mudstone and/or siltstone. The average thickness of sandstone is 15 m, and that of the mudstone/siltstone 22 m. Mineralization generally occurs in the thicker parts of channel sandstones, especially in the lower part where they frequently contain discontinuous siltstone and mudstone lenses or interfinger with argillaceous rocks. Mineralized sandstones are dark grey to black and often calcareous, less commonly bleached white or yellowish brown. Mineralized zones are discontinuous and seldom exceed a few metres in extent. Their thicknesses vary from a few centimetres to a maximum of about 7 m. Within individual channel sandstones, mineralization may be preferentially associated with certain sedimentary structures, and carbonaceous debris is almost invariably present. Thus, local permeability differences and the availability of carbonaceous debris are two of the more important controls on the location of mineralization. Uranium, mainly in the form of coffinite, is associated with organic carbon or calcite or both, with the relationships being regionally controlled. The concentration of molybdenum tends to favour organic-rich pods but is not exclusive to calcite-rich lenses. Other associated elements are Cu, As, Pb, Zn, Co, V, Mn and P.

Grades vary from trace amounts to more than 20 kg U_3O_8/t, with an average of about 1 kg U_3O_8/t, over a 1 m width. Molybdenum is the only accessory element present which could attain economic importance.

5.4 Karoo coal - Springbok Flats

The Springbok Flats constitutes a subsidiary basin of Karoo age situated in the northern Transvaal. Coal deposits with associated uranium mineralization were discovered in the Roedtan, Settlers and Warmbad areas during the mid-1970s. This coal basin, approximately 200 km long and 60 km wide, has an irregular ovoid shape and is almost entirely surrounded and underlain by Bushveld granite and felsite which form a subdued palaeomorphological system within the Springbok Flats Basin. Coal seams of Ecca age were deposited between the felsitic palaeoridges. This was followed by the deposition of the Beaufort Group and the filling in and compaction of the coal swamps. The uranium was brought into the Springbok Flats Basin from the surrounding granites, possibly during the deposition of the Molteno Formation. The Karoo sedimentation was then completed by the deposition of the Elliot and Clarens Formations. Uranium grades in the Springbok Flats are similar to those found in the Karoo sandstone type deposits. There is no decision as yet as to how and when to exploit this dual energy resource.

5.5 Granite gneisses

Uranium occurs in low concentrations either in disseminated form or associated with fracture zones in the granitic and metamorphic rocks of the Namaqua/Natal belt (1 000 Ma) in the northwestern Cape, in southern Natal and within the Bushveld Complex (1 950 Ma).

There are large tonnages of low-grade mineralization, approximately 0,1 kg U_3O_8/t, in a number of localities in the northwestern Cape.

5.6 Younger surficial sediments

Tertiary to Recent (10 Ma - 0,1 Ma) surficial uranium occurrences have received much attention in South Africa following their discovery in Australia and South-West Africa/Namibia during the early seventies. Exploration started in South Africa during the mid-1970s, employing largely airborne radiometric surveys. In South Africa the occurrences are located within the palaeodrainages of the major river systems of the northwestern Cape. All are tributaries of the Orange River and flow in a northerly direction away from a transcontinental warp axis. The whole area lies within the 200 mm isohyet, which appears to be one of the main limiting factors regarding the distribution of the occurrences. The uranium is derived from the underlying granitic and metamorphic rocks, and also from the Dwyka tillite of Permian age.

The uraniferous surficial deposits occur either in calcrete deposits formed under oxidizing conditions or in association with a peaty diatomaceous earth deposited under reducing conditions. In the calcrete type the uranium mineralization occurs largely in the form of carnotite as grain coatings around pebbles or associated with the finer matrix material. In a number of localities in the northern Cape uranium occurs in association with diatomaceous peaty earth representing palaeomarsh or bog conditions which developed as a result of ponding within the channels. The mineralization is usually associated with organic-rich bands. Uraninite is the main uranium mineral, but some uranium may occur as an organo-complex. Most of the deposits investigated to date appear to be of too limited an extent or too low a grade to justify exploitation at present. Average uranium grades vary between 0,1 and 0,5 kg U_3O_8/t.

5.7 Heavy-mineral sands

Extensive deposits of black sands lie immediately to the north of Richards Bay, stretching about 20 km northwards to Lake Hlobane, and are confined to a 2 km wide dunal strip parallel to the coastline.

The heavy-mineral suite of the deposit is being exploited primarily for ilmenite, rutile, zircon and monazite. The monazite concentrate which is exported has an average uranium grade of 0,3 kg U_3O_8/t. None of the radioactive elements are, however, extracted locally

5.8 Marine phosphates

Phosphorite nodules of Tertiary age occur between the 0 and 1 000 m isobaths, vary from oval- to slab-shaped in form and are up to 300 mm in diameter. The thickness of the nodule layer is estimated to be 100 mm. The phosphate content varies from 7% P_2O_5 to slightly more than 20% P_2O_5 with an average grade of 16% P_2O_5. Areas with grades of more than 20% P_2O_5 occur on the western and southern part of the Agulhas Bank. Uranium is associated with the phosphorite nodules and the uranium content varies from 0,001 to more than 0,36 kg U_3O_8/t.

6 URANIUM RESOURCES

To facilitate reporting to international agencies, South Africa conforms closely to the terminology and definitions recommended by the NEA/IAEA Working Group on Uranium Resources as detailed in this section. The NEA/IAEA requested national authorities to submit their resource estimates in terms of uranium metal recoverable from mineable ore, i.e. after accounting for expected mining and processing losses. Most of the major producing countries have complied with this request in submitting their resource estimates.

6.1 Terminology and definitions

Resource estimates are divided into separate categories that reflect different levels of confidence in the quantities reported. As yet uniformity of nomenclature and category definitions has not been achieved among the countries submitting resource estimates to the NEA/IAEA. The terminology used by the NEA/IAEA is defined as follows:

Reasonably Assured Resources (RAR) refers to uranium that occurs in known mineral deposits of such size, grade and configuration that they could be recovered within the given production cost ranges with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably Assured Resources have a high assurance of existence and in the cost category below $80/kg U are considered as reserves for the purpose of this report.

Estimated Additional Resources - Category I (EAR-I) refers to uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extensions of well-explored deposits and in deposits in which geological continuity has been established but where specific data and measurements of the deposits and knowledge of the deposits' characteristics are considered to be inadequate to classify the resource as RAR. Such deposits can be delineated and the uranium subsequently recovered, all within the given cost ranges. Estimates of tonnage and grade are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best-known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for RAR.

Estimated Additional Resources - Category II (EAR-II) refers to uranium in addition to EAR-I that is expected to occur in deposits believed to exist in well-defined geological trends or areas of mineralization with known deposits. Such deposits can be discovered, delineated and the uranium subsequently recovered, all within the given cost ranges. Estimates of tonnage and grade are based primarily on knowledge of deposit characteristics in known deposits within the respective trends or areas and on such sampling and geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for EAR-I.

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

The resource categories are further separated into levels of exploitability based on the estimated cost of their exploitation. The cost brackets are: less than $80/kg U ($30/lb U_3O_8), $80-130/kg U ($30-50/lb U_3O_8) and $130-260/kg U ($50-100/lb U_3O_8).

In conformity with the classification recommended by the IAEA, the cost categories refer to the cost of production inclusive of capital costs. Fig. 3 indicates the interrelationship of the resource and cost categories defined above within the total resource context. The horizontal axis expresses the level of confidence in the actual existence of given tonnages and grades while the vertical axis expresses the economic feasibility of exploitation.

As indicated by the shading, EAR-II and SR are distinct from RAR and EAR-I because of the much lower degree of confidence that can be placed in the amounts reported.

Outside the shading are resources recoverable at costs greater than $130/kg U since there is less assurance that these will be exploited. The dashed lines between RAR, EAR-I, EAR-II and SR in the $130-260/kg U cost category indicate that the distinctions of level of confidence are not always clear. The shaded area indicates that, because of the degree of confidence in their existence, RAR and EAR-I recoverable at less than $130/kg U are distinctly important: they are referred to in the text as "known resources".

Resource estimates are expressed in terms of metric tons of uranium metal (t U) recoverable after due allowance for ore dilution, and for mining and milling losses.

6.2 Resource estimates

A major part (83%) of South Africa's known uranium resources is present as a by-product of gold in the quartz-pebble conglomerates of the Witwatersrand Basin. The price of gold is thus of importance in categorizing these uranium resources, as is the dollar/rand exchange rate. Both these factors have exhibited considerable volatility, thus, for the purposes of this evaluation, the gold price was set at $400/ounce and R1 = $0,50, giving a price of approximately R25 700/kg Au.

On 1 January 1987 the South African uranium resources recoverable at costs less than $130/kg U were 536 500 t U (Table II).

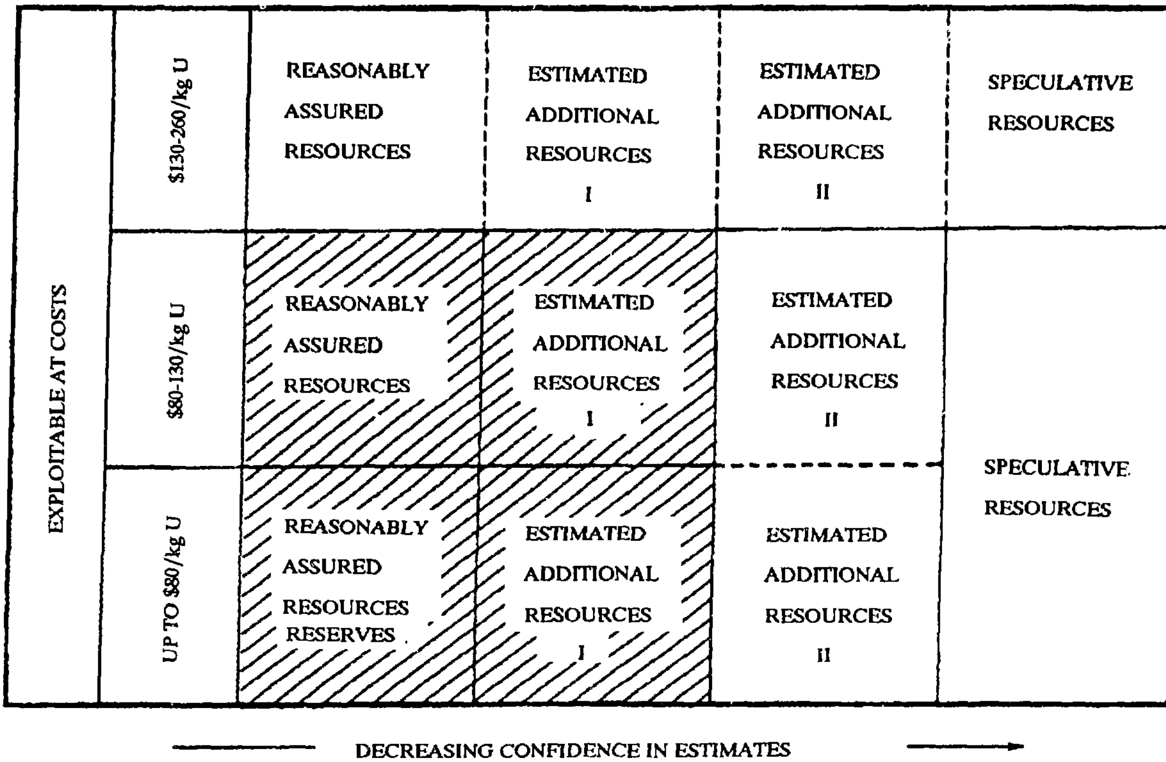


Fig. 3 NEA/IAEA classification scheme for uranium resources

TABLE II
URANIUM RESOURCES AS AT 1 JANUARY 1987

PRINCIPAL DEPOSITS OR DISTRICTS	TONNES U			
	REASONABLY ASSURED RESOURCES (RAR)		ESTIMATED ADDITIONAL RESOURCES CATEGORY I (EAR-I)	
	Recoverable at costs less than $80/kg U	Recoverable at costs between $80-130/kg U	Recoverable at costs less than $80/kg U	Recoverable at costs between $80-130/kg
Witwatersrand				
— Conglomerates	238 600	63 600	64 000	30 500
— Tailings	39 500	7 500		
Phalaborwa	5 200			1 600
Karoo Sequence	41 500	29 700	8 600	5 100
Surficial		700		400
TOTAL	324 800	101 500	72 600	37 600

This is 53 200 t U higher than the resources reported for 1 January 1985 and represents an 11,0% increase. During 1985 and 1986 South Africa produced 9 482 t U and, taking this into account, 62 682 t U have been added to South Africa's resources since 1 January 1985.

The intensive exploration in the Witwatersrand Basin contributed significantly to the increase, but also important was the falling dollar/rand exchange rate. This gave increased uranium and gold prices in rand terms and effectively reduced mining costs in dollar terms. Resources thus moved into lower cost categories, particularly those in the Springbok Flats coal deposits. The cut in mining costs in dollar terms is a temporary phenomenon and these costs are escalating rapidly, those on the Witwatersrand having risen by 36% from the end of 1984 to the end of 1986.

The resources in the RAR and EAR-I categories recoverable at costs between $130 and $260/kg U are presented in Table III.

In addition to the above resources, estimates have been made of EAR-II and SR which are believed to be present in South Africa (Table IV). The resources assigned to these categories are by definition very speculative and should be viewed with circumspection.

The Dominion and Witwatersrand Basins are the most likely environments for the discovery of further resources in the cost categories below $130/kg U. The presence of gold is a strong incentive for exploration and further important deposits will undoubtedly be discovered.

The Karoo still remains to be fully explored and an upturn in the uranium market would certainly stimulate further exploration both for sandstone and coal deposits. Further discoveries could be confidently expected, but will probably be in the higher cost categories.

TABLE III
HIGHER-COST URANIUM RESOURCES AS AT 1 JANUARY 1987

PRINCIPAL DEPOSITS OR DISTRICTS	TONNES U Recoverable at costs between $130-$260/kg U	
	RAR	EAR-I
Witwatersrand		
— Conglomerates	43 200	64 400
— Tailings	5 000	
Karoo Sequence	20 200	6 500
Surficial	800	2 500
Namaqua/Natal Belt		200
TOTAL	69 200	73 600

TABLE IV
ADDITIONAL CONVENTIONAL RESOURCES AS AT 1 JANUARY 1987

PRINCIPAL DEPOSITS, DISTRICTS OR AREAS	TONNES U	
	EAR-II	SR
	Recoverable at costs less than $130/kg U	Cost category uncertain
Witwatersrand	470 200	620 000
Mozaan Basin		15 500
Basement Rocks and Namaqua/ Natal Metamorphic Belt		100 000
Karoo Sequence	1 000	189 800
Northwestern Cape		9 000
Agulhas Bank		178 600
Phalaborwa	4 300	
TOTAL	476 000	1 112 900

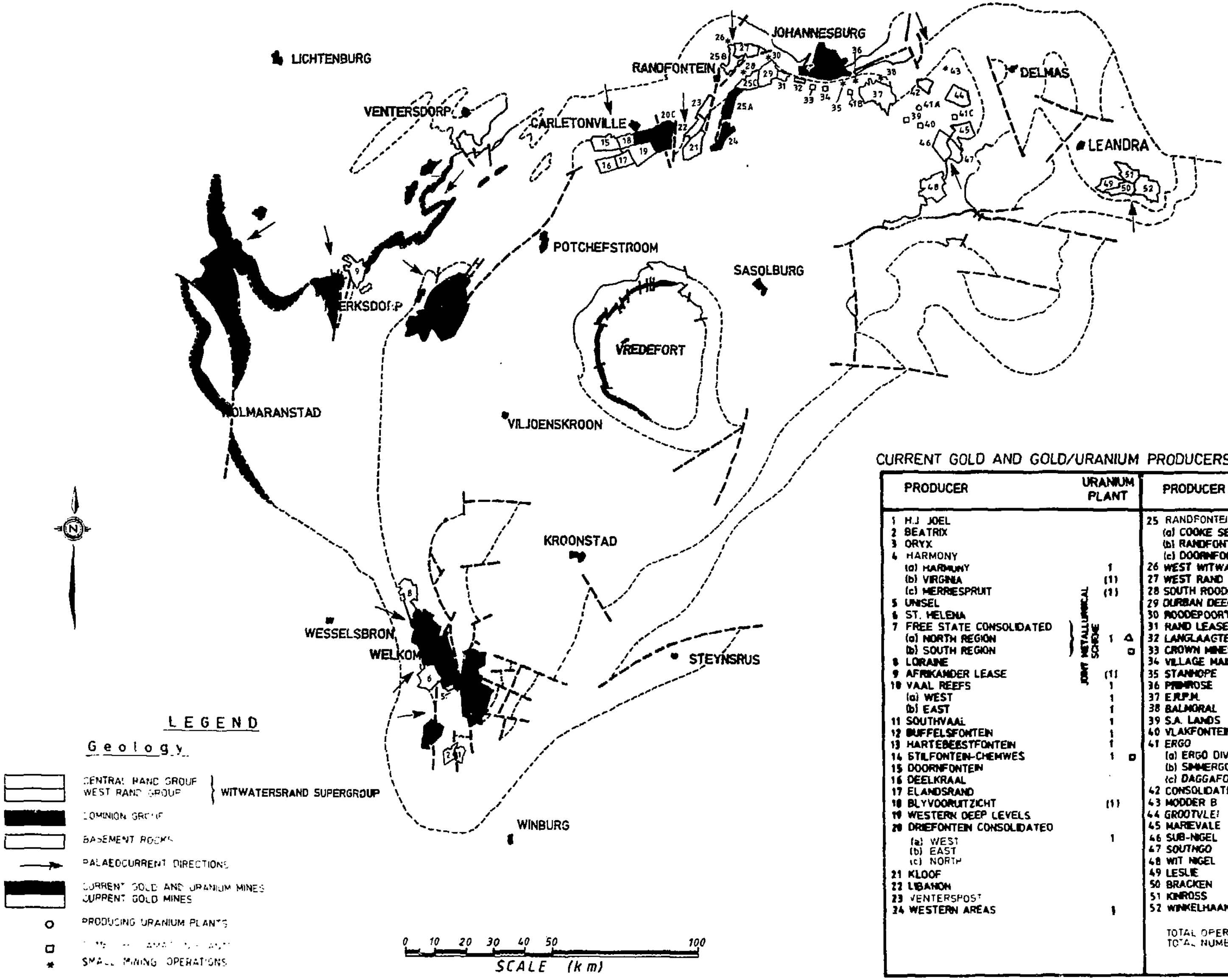
TABLE V
PRODUCTION CAPACITY

Company and Property	Producing Uranium Plants as at 31-12-86	1986 Production tonnes treated (000)	1986 Production tonnes produced (U)	Producing Uranium Plants as at 31-12-87	1987 Production tonnes treated (000)	1987 Production tonnes produced (U)	Capacity Ore tonnes/d (000)	Capacity Production tonnes U/a	Capacity Start-up Date	Type of Production
(A) GOLD MINING BY-PRODUCT										
ANGLO AMERICAN CORPORATION										
Vaal Reefs	3	9155	1636	3	7524	1421	24-31	1000-2000	1953 1956 1977	Underground and reclaimed tailings dumps
ANGLOVAAL										
Hartebeestfontein	1	3154	394	1	3185	352	9-10	200-500	1956	Underground and reclaimed tailings dumps
GENERAL MINING UNION CORPORATION										
Buffelsfontein	1	2898	506	1	2746	379	8-9	500-1000	1957	Underground and reclaimed tailings dumps
GOLD FIELDS OF SOUTH AFRICA										
Driefontein Cons.	1	882	69	1	823	63	3-5	200-500	1956	Underground and reclaimed tailings dumps
JOHANNESBURG CONS. INVEST. CO.										
Randfontein Estates	1	3243	509	1	2719	391	9-11	500-1000	1954	Underground
Western Areas	1	690	225	1	561	174	3-3,3	150-300	1982	Underground
RAND MINES										
Harmony	2	4813	280	1	3157	151	4-6	50-200	1955	Underground and reclaimed tailings dumps
(B) TAILINGS MINING BY- AND CO-PRODUCT										
ANGLO AMERICAN CORPORATION										
East Rand Gold and Uranium	1	20022	132	1	20237	133	50	100-250	1978	Reclaimed tailings dumps, 39 dumps to be treated
Joint Metallurgical Scheme	1	5141 [a]	449	1	4352 [b]	392	50	500-1000	1977	Reclaimed tailings dumps, also some concentrates from gold plants treated for uranium
GENERAL MINING UNION CORPORATION										
Chemwes	1	2577	245	1	3463	358	8-9	200-500	1979	Reclaimed tailings dumps
(C) COPPER MINING BY-PRODUCT										
Palabora	1	2160 [c]	157	1	2160 [c]	149	50	100-250	1979	Open pit, selected ore treated for uranium
TOTAL	14	54735	4602	13	50927	3963				

a Includes 460 000 t from pyrite plant

b Includes 414 000 t from pyrite plant

c Gravity concentrate sent to uranium plant



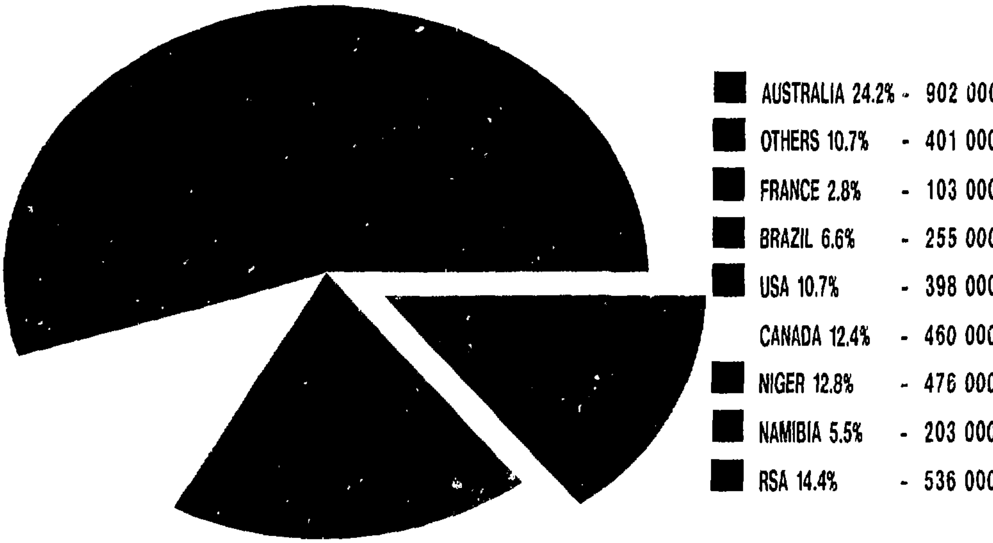
CURRENT GOLD AND GOLD/URANIUM PRODUCERS AS AT 31 DECEMBER 1987

PRODUCER		URANIUM PLANT	
1 H.J JOEL			
2 BEATRIX			
3 ORYX			
4 HARMONY			
(a) HARMONY		1	
(b) VIRGINIA		(1)	
(c) MERRIESPRUIT		(1)	
5 UNISEL			
6 ST. HELENA			
7 FREE STATE CONSOLIDATED	JOINT METALLURGICAL SCHEME		
(a) NORTH REGION		1	△
(b) SOUTH REGION			◻
8 LORAINE			
9 AFRIKANDER LEASE		(1)	
10 VAAL REEFS		1	
(a) WEST		1	
(b) EAST		1	
11 SOUTHVAAL		1	
12 BUFFELSFONTEIN		1	
13 HARTEBEESTFONTEIN		1	
14 STILFONTEIN-CHEMWES		1	◻
15 DOORNFONTEIN			
16 DEELKRAAL			
17 ELANDSRAND			
18 BLYVOORUITZICHT		(1)	
19 WESTERN DEEP LEVELS			
20 DRIEFONTEIN CONSOLIDATED			
(a) WEST		1	
(b) EAST			
(c) NORTH			
21 KLOOF			
22 LIBANON			
23 VENTERSPOST			
24 WESTERN AREAS		1	

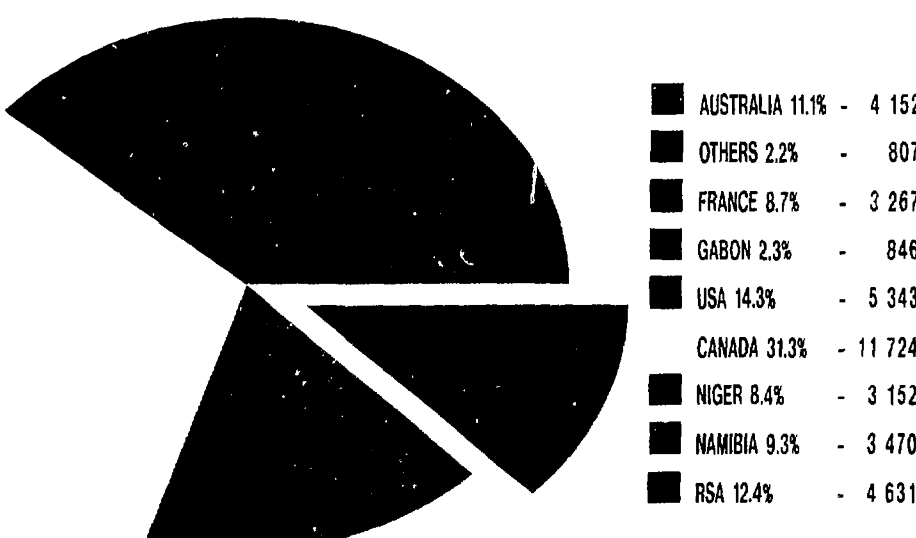
PRODUCER	URANIUM PLANT	
25 RANDFONTEIN ESTATES		
(a) COOKE SECTION	1	
(b) RANDFONTEIN SECTION	(1)	
(c) DOORNFONTEIN SECTION		
26 WEST WITWATERSRAND		
27 WEST RAND CONSOLIDATED	(1)	
28 SOUTH ROODEPOORT		
29 DURBAN DEEP		
30 ROODEPOORT		
31 RAND LEASES		
32 LANGLAAGTE		
33 CROWN MINES		◻
34 VILLAGE MAIN REEF		◻
35 STANHOPE		
36 PRIMROSE		
37 E.R.P.M.		
38 BALMORAL		
39 S.A. LANDS		◻
40 VLAKFONTEIN		◻
41 ERGO		
(a) ERGO DIVISION	1	◻
(b) SIMMERGO DIVISION		◻
(c) DAGGAFONTEIN DIVISION		◻
42 CONSOLIDATED MODDERFONTEIN		
43 MODDER B		
44 GROOTVLEI		
45 MARIEVALE		
46 SUB-NIGEL		
47 SOUTHGO		
48 WIT NIGEL		
49 LESLIE		
50 BRACKEN		
51 KINROSS		
52 WINKELHAAK		
TOTAL OPERATIVE URANIUM PLANTS	12	
TOTAL NUMBER OF PLANTS	18	

NOTE (1) = Uranium plant mothballed
△ Mostly reclaimed slimes from surface, but some current residues from gold plants
◻ Slimes reclamation operation

Fig. 4 Current gold and uranium producers in the Witwatersrand Basin, showing sites of uranium plants.



1986 WOCA URANIUM RESOURCES RAR + EAR-I<$130/kg U



1986 WOCA URANIUM PRODUCTION

Fig. 5 1987 WOCA production and resources pie-diagrams.

Uranium mineralization has been identified in other geological environments in South Africa, but possible resources in these environments are generally believed to fall in the higher cost categories. In order of decreasing importance these environments are the granitic and metamorphic terrains of Namaqualand and Natal, quartz-pebble conglomerates of the Mozaan Group and Black Reef Formation, the surficial deposits of the northwestern Cape and the marine phosphate deposits of the Agulhas Bank.

7 URANIUM PRODUCTION

All of South Africa's uranium is produced as a by-product; the majority from the Witwatersrand gold mines and a small proportion from the open-pit copper mine at Phalaborwa. As a result the level of production is not entirely dependent upon uranium market forces as is that from primary uranium producers. This can clearly be seen in the historical part of Fig 6, where there is no relationship between gold and uranium production, in spite of the fact that uranium is a by-product of gold. This, coupled with the fact that the bulk of production is committed to long-term contracts, cushions the South African uranium industry from short-term fluctuations in the uranium market.

The localities of the operating uranium plants in the Witwatersrand Basin are shown in Fig 4, and Table V summarizes the production capabilities of all the operating plants in the Republic of South Africa.

7.1 1986/87 production

The downward trend in the uranium market since the dramatic fall in the price triggered by the Three Mile Island incident appears to have been arrested with spot market prices hovering around \$17/lb U_3O_8 for most of 1986 and 1987. Trends in the contract price are less volatile and lag behind those of the spot market and the current trend is still downward. South Africa is highly committed to contract sales and its production levels are still declining in concert with the contract market. This price-related trend is compounded by political influences, labour unrest and the generally declining grades being mined as the mines become older. Thus, in South Africa, uranium production for 1987 was 3 963 t U, 13,9% lower than that of 1986 (Table VI).

In total, production for 1986 and 1987 was 8 565 t U, down 2 047 t U from the production for the preceding two-year period.

TABLE VI
SOUTH AFRICAN URANIUM PRODUCTION FOR 1986 AND 1987

PRODUCERS	1986 PRODUCTION		1987 PRODUCTION		% DIFFERENCE
	t U	% OF TOTAL	t U	% OF TOTAL	
Buffelsfontein	505,9	10,99	378,8	9,56	-25,13
Chemwes	245,4	5,33	358,6	9,05	46,10
Driefontein Cons	69,0	1,50	62,5	1,58	- 9,33
East Rand Gold and Uranium	132,0	2,87	132,6	3,35	0,43
Harmony	279,9	6,08	150,9	3,81	-46,10
Hartebeestfontein	394,1	8,56	351,9	8,88	-10,69
Joint Met Scheme	449,0	9,76	392,2	9,89	-12,65
Randfontein (Cooke)	508,9	11,06	391,4	9,88	-23,07
Vaal Reefs	1635,6	35,55	1421,0	35,85	-13,12
Western Areas	224,8	4,88	173,8	4,39	-22,66
Palabora	157,2	3,42	149,1	3,76	- 5,12
TOTAL	4601,8	100,00	3962,8	100,00	-13,88

The only South African producer to post an increase in output for 1987 was Chemwes, resulting from revised estimates of future sales figures after a period of operating at 60% capacity. Production from ERGO, Palabora and Driefontein Consolidated was unchanged or slightly lower. All other mines reported declines in production of between 42 and 216 t U, and from 10% to 46% relative to 1986. Labour unrest, causing reduced tonnes milled, was a common factor for all. The situation at Western Areas was aggravated by fires underground, and faulted ground at Buffelsfontein reduced the amount of ground available for mining. The largest drop in percentage terms was reported by Harmony where reduced demand on long-term sales contracts led to the decision to close the Virginia uranium plant. At the same time a drop in the recovery grade further affected the decline in production. This was another factor common to many South African uranium producers because the high gold price in rand terms permitted mining of lower-grade reserves. The uranium industry in South Africa has had a traumatic time since the beginning of the decade. This period has been marked by a general decline in production (with the notable exception of Vaal Reefs), plant closures, and lately, negative political influences and labour unrest. The remaining producers should be sufficiently strong and well-established as to be able to continue production at current, or slightly reduced levels, until the predicted upturn in the market early in the next decade.

7.2 Planned production capability projection

The Nuclear Geology Division of the AEC developed a computer program to forecast production capabilities of a given region using the available resources in specified cost categories. The program is sufficiently flexible to allow production forecasts for any sized region, from individual mines to the whole world, as long as the resources are known for the selected area. Various future scenarios are used to produce production capability forecasts, both for South Africa and the world, in order to study the possible effects of differing uranium market conditions.

This projection (Table VII) is of a short- to medium-term nature and covers the next 10 years, utilizing only those known resources associated with the 13 currently operating uranium plants. It is expected that the production of the new Oryx mine will be treated on a toll basis by one of the existing plants. The perceived outlook for the uranium market over this period is not encouraging, although indications are that conditions should start improving in the later half of the projection period. Given the lead time in responding to changes in the market it is considered improbable that any new plants will be brought on stream but producers, such as Chemwes, which are operating below capacity are likely to increase production towards the end of the period. The reopening of the expanded Beisa mine as the Oryx mine will also contribute to an increase in production.

7.3 Maximum production capability projections

The AEC, in arriving at its estimates, has taken into consideration known resources both within current mining lease areas and outside these areas. In total, 58 discrete resource

TABLE VII
SHORT-TERM URANIUM PRODUCTION CAPABILITY FROM EXISTING PLUS COMMITTED PRODUCTION CENTRES ON THE BASIS OF CURRENT URANIUM RESOURCES

(RAR + EAR-I) RECOVERABLE AT COSTS OF LESS THAN $130/kg U	
YEAR	TONNES U/YEAR
1988	4 128
1989	4 156
1990	4 186
1991	4 215
1992	4 375
1993	4 506
1994	4 637
1995	4 736
1996	4 997
1997	5 103
1998	5 143

areas were taken into account when compiling these projections. These included the resources tributary to the 13 currently operating plants, as well as those for the six mothballed plants, and two committed production centres. Preliminary feasibility studies have indicated that four further blocks of resources could be viably exploited, but commitments for the production of uranium have been deferred pending improvements in the market. The remaining 33 resource areas are prospective centres where future uranium production is dependent upon market and political trends.

The resources committed to them are judged as of sufficient size and quality to support a viable operation, but no feasibility studies have been undertaken as yet. In order to protect company confidentiality, details of the planned and prospective plants cannot be made available.

In arriving at these theoretical projections, it has been assumed that favourable market conditions will exist in the future and that production would be at optimum levels until 2030 or until the resources in the RAR and EAR-I categories at costs less than $130/kg U tributary to the centres are depleted or, in the case of by- or co-product sources, until production would be expected to cease (Table VIII).

It should be noted that many mines are currently not extracting uranium and are thus creating large low-cost resources in their tailings. Therefore it is likely that, under good market conditions, a number of mines would continue to produce uranium for some time after their underground operations have ceased.

Although production peaking at over 11 000 t U is theoretically attainable, it is considered, from market projections, that a production ceiling of 10 000 t U would be more realistic. South Africa's gold and uranium production since 1940 and 1952 respectively, and the uranium production capability projections until the year 2040 are also presented in Fig. 6.

TABLE VIII
MAXIMUM URANIUM PRODUCTION CAPABILITY PROJECTIONS FROM EXISTING, COMMITTED, PLANNED AND PROSPECTIVE PRODUCTION CENTRES ON THE BASIS OF THE URANIUM RESOURCES IN THE RAR AND EAR-I CATEGORIES RECOVERABLE AT COSTS OF LESS THAN $130/kg U *

YEAR	TONNES U/YEAR		TOTAL
	EXISTING AND COMMITTED CENTRES	PLANNED AND PROSPECTIVE CENTRES	
1988	4 128		4 128
1990	4 186	248	4 434
1995	4 736	1 707	6 443
2000	5 510	3 328	8 838
2005	5 479	4 582	10 061
2010	5 747	5 300	11 047
2015	3 607	6 802	10 409
2020	3 105	7 124	10 229
2025	2 892	6 999	9 891
2030	2 238	6 628	8 866

* Assuming most favourable market conditions

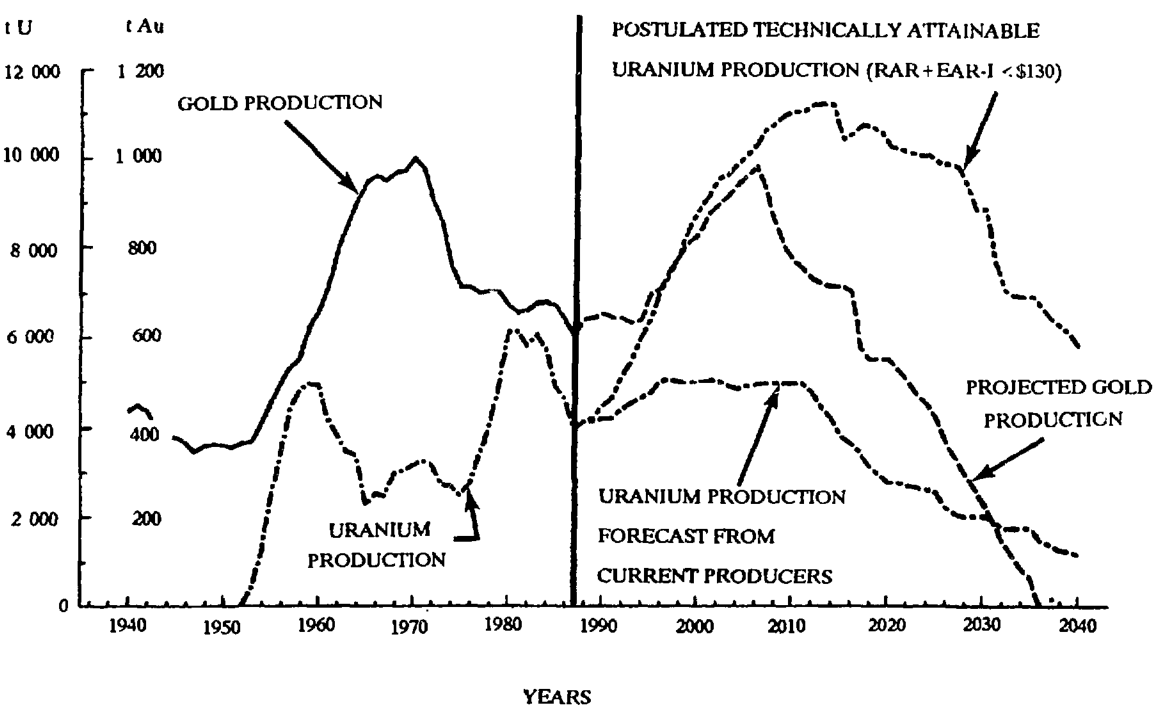


Fig. 6 South Africa's historical gold and uranium production, and uranium production capability projections to the year 2040.

8 SOUTH AFRICA'S INTERNATIONAL POSITION

Fig 5 shows South Africa's position diagrammatically.

TABLE IX
WOCA'S URANIUM RESOURCES IN THE RAR + EAR-1 CATEGORIES EXPLOITABLE AT COSTS OF LESS THAN $130/kg U AS AT 1 JANUARY 1987

COUNTRY	TONNES U x 1000			%
	RAR	EAR-1	TOTAL	
Australia	518	384	902	24
South Africa	426	110	536	14
Niger	176	300	476	13
Canada	249	211	460	12
USA	398	0	398	11
Brazil	163	92	255	7
Namibia	183	20	203	5
France	65	38	103	3
Rest	268	133	401	11
TOTAL	2 446	1 288	3 734	100

SOURCE: NEA/IAEA (1988)

TABLE X
SUMMARY OF WOCA'S 1986 URANIUM PRODUCTION TONNES U

COUNTRY	PRODUCTION	SHARE OF WORLD %
Canada	11 724	32
South Africa	4 631	13
USA	5 343	14
Australia	4 152	11
Namibia	3 470	9
Niger	3 152	8
France	3 267	9
Gabon	846	2
Rest	807	2
TOTAL	37 392	100

SOURCE: NUEXCO 3/88

9 NATIONAL POLICIES

South Africa's national policies affecting the production and export of uranium are embodied in the Nuclear Energy Act 1982, as amended. No person may prospect or mine for uranium without the permission of the Minister of Mineral and Energy Affairs, but such permission may be withheld only if the Minister is satisfied that the security of the State could be endangered if the applicant were given permission to proceed.

There are no restrictions on foreign participation in uranium prospecting and mining, and foreign-based operations are subject to the same legal requirements as domestic companies. In a practical sense, uranium prospecting and mining are subject to the mining laws and regulations generally applicable.

The State does not actively undertake prospecting operations, but limits its activities to regional geological mapping and airborne surveys and hydrological, geochemical and geophysical investigations.

The Nuclear Energy Act also provides that no person may dispose of uranium or export it from South Africa, except under the authority of the Minister. In exercising this control, the Minister is required to consult the AEC, the members of which represent various national interests, including the uranium mining industry. In practice these functions have been delegated to and are exercised by the chief executive of the AEC.

10 THE NUCLEAR FUEL CYCLE IN SOUTH AFRICA

The nuclear fuel cycle (Fig. 7) is an open cycle with a partial closure resulting from the reprocessing of spent fuel to recover unconsumed uranium and plutonium generated in the reactor. Both the front and back ends of the open part of the cycle are rooted in the earth, comprising both the source of uranium and the final repository for the radioactive waste materials of the cycle.

South Africa has played a part in the world nuclear fuel cycle since its earliest days, having been a major producer of uranium even before its use in the peaceful generation of power was commercially demonstrated. The first yellow cake was produced in 1952 and since then South Africa has been a consistent and reliable major supplier of uranium to the Western World.

The large known resources which South Africa possesses will ensure that it will maintain its position and reputation in the uranium market for the foreseeable future.

Early on it was recognized that self-sufficiency in the nuclear fuel cycle was imperative for South Africa and to this end the construction of Pelindaba, the National Nuclear Research Centre, was commenced in 1961. This heralded the start of large-scale and intensive investigations into all aspects of the nuclear fuel cycle, and in the same year the first ingot of uranium metal was produced. The production of uranium hexafluoride (UF_6) is a key step in the fabrication of fuel elements for a nuclear reactor and research into this aspect led to the commissioning of a pilot UF_6 plant in 1975. Parallel research into enrichment of uranium saw the demonstration of the feasibility of the locally developed enrichment process in 1967 and the completion of a pilot plant in 1977. A new cascade design - the Helikon process - will be used in the semi-commercial enrichment plant.

The Safari-I research reactor went critical in 1965, and for the first time in 1981 was re-fuelled with locally manufactured fuel elements. The pilot UF_6 plant has been expanded to a commercial size to provide feed-stock for the full-scale enrichment plant, construction of which commenced in 1978, and which is expected to be fully operational in 1988.

Construction of the Koeberg nuclear power station by Eskom was started in 1976 and its first unit was synchronized into the national electricity grid in 1984, followed by the second unit in 1985. Currently about 7% of South Africa's electricity is generated by Koeberg. No commitment has been made for the construction of further nuclear stations, but investigations are being conducted in various areas along the South African coast with a view to defining suitable sites for probable future stations.

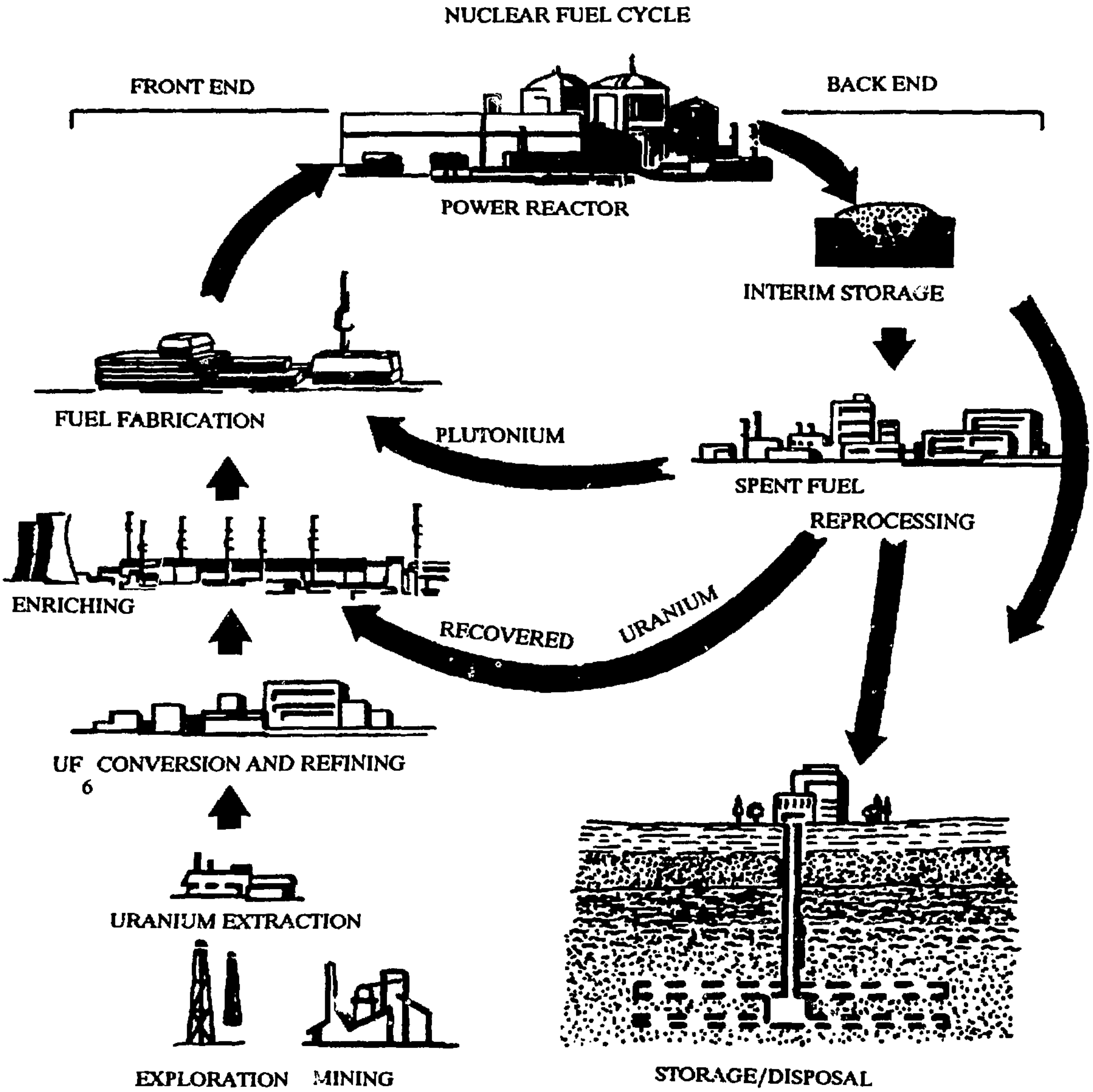


Fig. 7 Generalized concept of the nuclear fuel cycle

South Africa, unlike many other countries with nuclear programmes, gave serious consideration to the back end of the nuclear fuel cycle well before the completion of its first nuclear station. In 1978 intensive and wide-ranging investigations were initiated by the AEC for the identification of a site for the safe long-term disposal of low- and intermediate-level radioactive wastes. The first phase involved the compilation and analysis of a variety of data from various disciplines, including geology, geophysics, seismology, sociology, argriculture, ecology, economics and politics. This identified certain regions as being favourable, with a certain part of the northwestern Cape being particularly attractive. Detailed investigations of this area constituted the second phase, which culminated in 1983 in the purchase of some 10 000 ha of land located about 100 km southeast of Springbok (Fig. 8).

Following further detailed studies conducted on this land, construction of the Vaalputs National Radioactive Waste Facility was commenced in 1986 and the first consignment of low- and intermediate-level radioactive waste was received in November 1986. The necessity for the off-site storage and subsequent disposal of high-level waste will not arise before the early part of the next century. Studies have been initiated to determine safe and cost-effective methods of handling this waste and for assessing the suitability of the Vaalputs site for this purpose.

South Africa may not have a large nuclear programme, but most aspects of the nuclear fuel cycle, with the exception of spent-fuel reprocessing, have been addressed, and could be successfully developed to operational status.

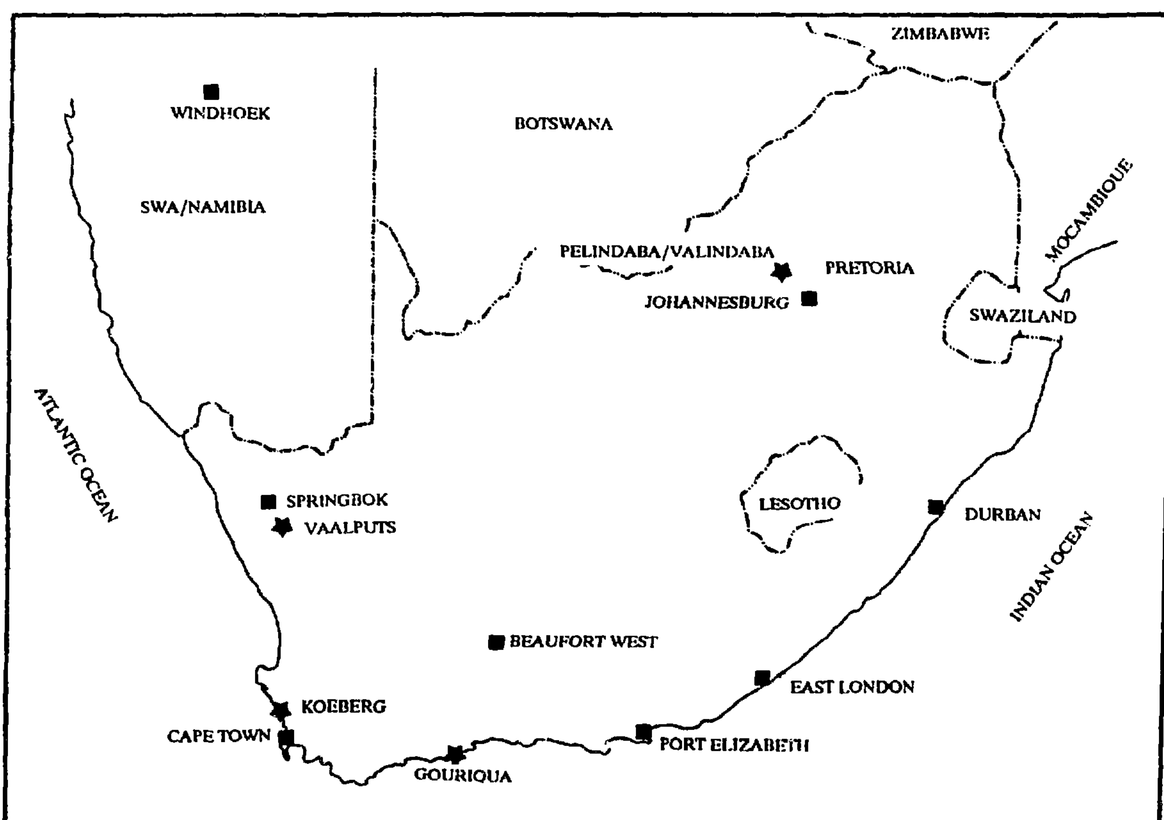


Fig. 8 Locality map of nuclear related centres in South Africa

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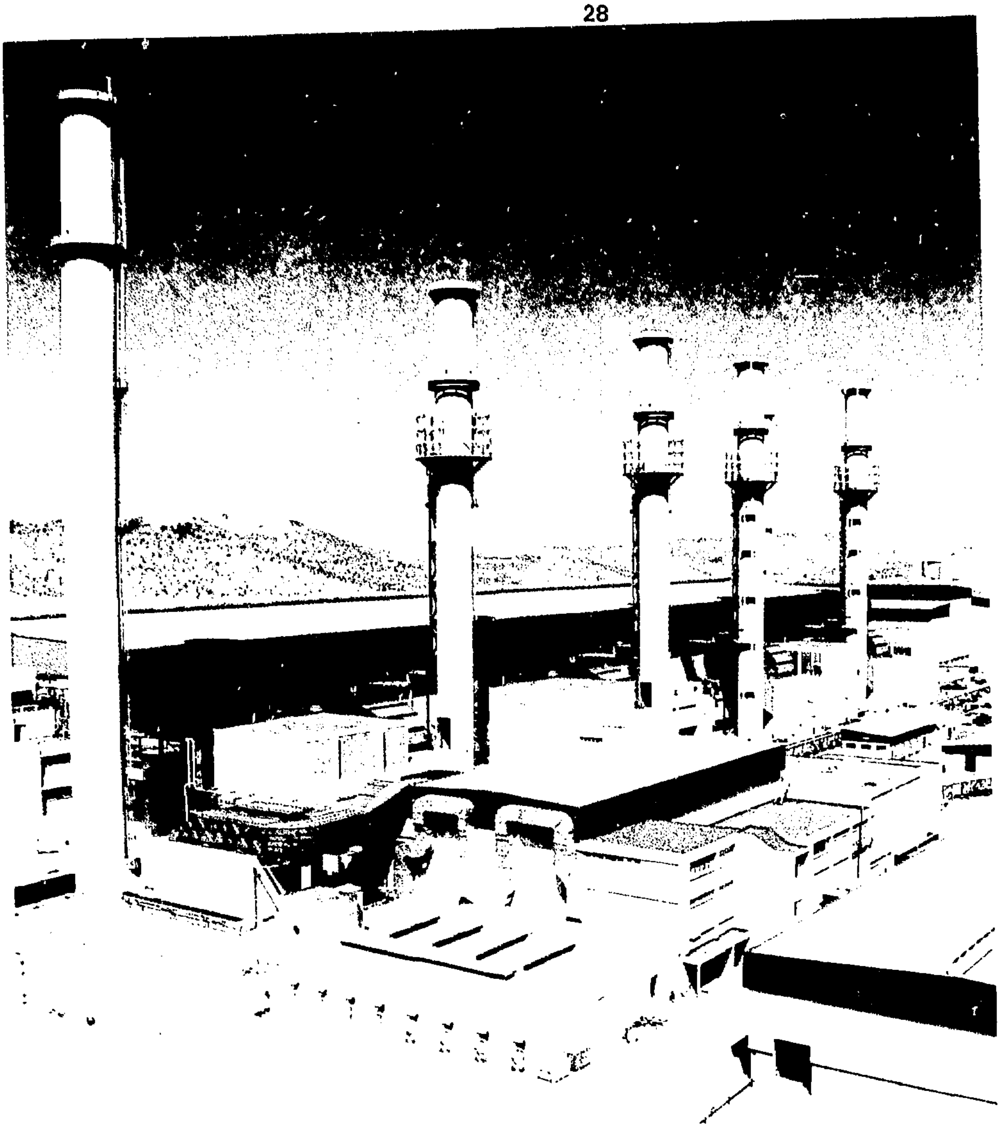
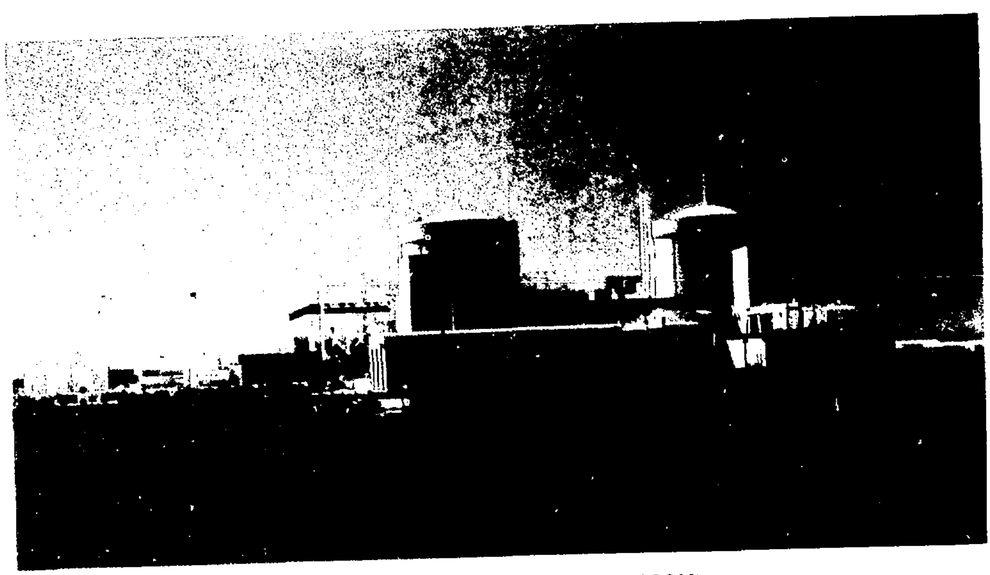
The open pit at Palabora mine (Palabora Mining Co.).

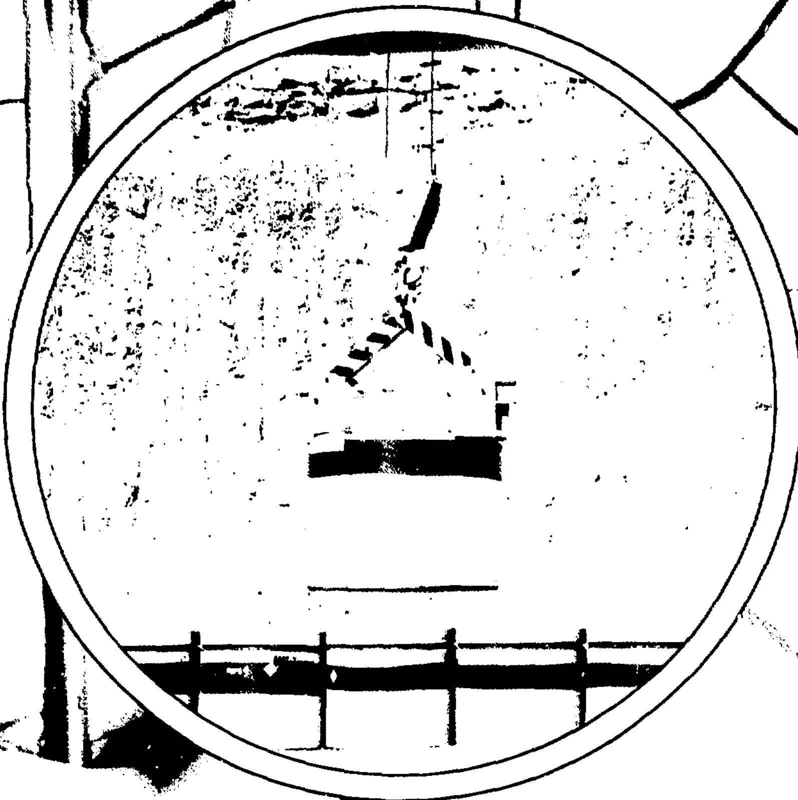


A section of the uranium enrichment plant at Valindaba (AEC).



Koeberg Nuclear Power Station (ESCOM)

Banks of belt filters for collecting yellow cake for the Chemwes uranium plant near Klerksdorp (GENCOR).



Disposal of intermediate-level waste at Vaalputs

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