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World Supply and Demand for Zirconium Minerals: Current Position and Future Prospects

by

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SUMMARY

Indicated world reserves of zircon are about 28 million tons of which, for economic recovery, approximately 70 percent is dependent on the production of saleable ilmenite. Domestic reserves are indicated as 7.2 million tons, about 5.8 million tons of which are associated mainly with rutile and the balance with ilmenite.

Although modest increases in zircon production may be expected as the result of increased output of ilmenite in India and in some south-east Asian countries, the bulk of world production of zircon will continue to come from Australia and the United States. Domestic output of zircon concentrates should reach a peak of about 420,000 tons per annum in 1974 and thereafter fall to an annual level of about 250,000 tons in 1985. World production should reach a peak of 500,000 - 600,000 tons by the mid-1970's but will decline to about 300,000 tons per annum in the 1990's unless new, economic reserves are developed in the meantime.

World demand for zircon is likely to increase at an annual rate of 3-4 per cent, and should outstrip world supply by the mid-1970's. It is suggested that future supply and demand will be brought into balance by an upward pressure on prices. Increased prices for zircon, rutile and ilmenite will result in increased output of by-product zircon as ilmenite production is expanded to meet increased demand for titania, and as untapped sources e.g. off-shore deposits, are developed. Projected demand is likely to lead to changed patterns of zircon supply and consumption by increased selectivity in the use of zircon as a foundry sand, by the increased reclamation of zircon, and by the increased use of substitutes. While foundry applications will probably remain the main outlet for zircon there should be increased emphasis on the use of zircon in more processed forms such as zirconia and zirconium metal.

I. INTRODUCTION

One of the main functions of the Australian Atomic Energy Commission is the undertaking of research programmes aimed at fostering the advancement of atomic energy technology in Australia. An important aspect of this research concerns the effective utilisation of indigenous raw materials required for a modern nuclear industry. In particular, the Commission's Materials Division at Lucas Heights, N.S.W., is currently carrying out research on uranium dioxide (UO_2) and zirconium alloy both of which would be important in the installation of the types of nuclear power reactors that will be introduced into Australia in the not-too-distant future.

Uranium dioxide, the nuclear fuel, is used in the form of pellets, and Materials Division is investigating the production of these from Australian uranium concentrates to give a product which is economically competitive and which gives good performance. The uranium dioxide pellets are enclosed in tubular zirconium alloy cladding to form fuel pins which in turn are assembled into clusters to form fuel elements. Zirconium alloys are used not only for the fuel element cladding, but also for other structural applications in the reactor core e.g. pressure tubes, and support grids. Current research on zirconium and its alloys is confined to establishing technology for fabricating the nuclear plant components in Australia, and with the behaviour of the components in service. However, future investigations will possibly be directed towards the extraction of zirconium from its ores and in this connection a joint study is being undertaken by the Australian Atomic Energy Commission and the Bureau of Mineral Resources to establish the broad, economic feasibility of producing zirconium sponge in Australia.

Following meetings between officers of the two organizations at Canberra (29 July 1969) and at Lucas Heights (3 September 1969) it was decided that the initial study would be divided into three phases as follows:

Phase 1. Projection of zirconium requirements for nuclear reactors in Australia up to the year 2000; to be carried out by the A.A.E.C.

Phase 2. Compilation of data on present and future sources and markets for zirconium minerals to be undertaken by the BMR.

Phase 3. Assessment of world demand and production and future prices of zirconium sponge, billets and fabricated products as well as as a survey of processing methods and likely new developments to be undertaken by A.A.E.C. with assistance from BMR personnel where required.

This paper deals with Phase-2 of the investigation and as such attempts to assess current and future trends in the world supply-demand position of zirconium minerals. The future supply-demand position of zirconium sponge has been investigated in some detail by the A.A.E.C. and receives only passing mention in this paper.

II. SUPPLY OF ZIRCONIUM MINERALS

Although resources of zirconium minerals are both extensive and widespread, commercial sources over the years have been confined to the production of zircon concentrates as a by-product of the mining of titanium ores, and to a much lesser extent, to the mining of caldasite, a mixture of baddeleyite and zircon.

Trends in the pattern of world production of zirconium minerals during the thirty-five years 1934-1969 are shown graphically in Figure 1.

Australia became the world's leading producer of zirconium minerals soon after the inception of the mineral sands industry on the east coast in the early 1930's and has maintained that position, except in 1938, when Australian production almost ceased, and in 1942 when Brazilian production of baddeleyite exceeded Australian production of zircon. In 1969 Australia was responsible for approximately 84% of total non-communist world supply of zircon.

Apart from Australia, the United States is the only non-Communist zircon producer of any significance. Current and future output in the two countries will be emphasised, with reference made to other potential producers according to their potential importance as future suppliers of zirconium minerals.

A. AUSTRALIA.

Although some zircon concentrates were produced during the recovery of gold, platinum, and cassiterite at Tugun, Qld in 1932 by two small companies - Beach Sand Mining Co. and Black Lead Mineral Co., economic development of the Australian mineral sands industry did not begin until 1934 when Zircon Rutile Ltd began operations at Byron Bay, N.S.W. Zircon production in Queensland did not commence until 1941. Output of zircon as a by-product of ilmenite production at Capel, W.A. was first recorded in 1958. Zircon production on a small scale commenced on King Island, Tas. in early 1969.

Figure 1 traces the growth in domestic output of States up to the present. During the 1930's, domestic production of mineral sands was on a minor scale, and most of the zircon output was exported in the form of a mixed rutile-zircon-ilmenite concentrate. With the outbreak of World War II, output of rutile was stepped up to meet increased demand, and zircon production expanded concomitantly. In order to assure a maximum return to the domestic industry from the export of mineral sands products, the Commonwealth Government in 1943 banned the export of mixed concentrates except by producers already in production or who would be in production by 1944. The prohibition on the export of mixed concentrates was made absolute from 1 January, 1950.

1. Production and Capacity.

Details of equity shareholding, plant location, rated capacity and current production rates of domestic mineral sand producers are given in Table 1.

Domestic production of zircon falls into two distinct categories (i) production as a co-product of rutile; this category covers virtually all zircon output from the east coast, and (ii) production as a by-product of ilmenite mining which includes zircon production from the south-west corner of Western Australia and that from recently - commissioned plant on the central Queensland coast.*

Over the years, domestic production of zircon has in the main followed the pattern of rutile production. As a general statement it can be said that zircon production has paralleled that of rutile, and although there have been periods during which this balance has been upset by changing patterns in demand for one or other of these commodities e.g. domestic output of zircon in the period 1934-1949 of 158,000 tons was almost double that of rutile for the same period, it is interesting to note that the cumulative total production of each mineral for the thirty-five years 1934-1969 differ by less than 100,000 tons in a total of 2.7 million tons. Domestic output of zircon and rutile concentrates over the years is compared graphically in Figure 2.

Although output of zircon as a by-product of ilmenite is now assuming increasing importance, it should be kept in mind that zircon production as a co-product of rutile, has, over the years constituted the main source of supply, and what is more, mineral sand operators on the east coast will continue to be the main domestic supply, for that matter the chief world source of zircon, well into the 1980's, at least.

(a) East Coast.

The geographical pattern of mineral sand production on the east coast underwent a sharp change in the 1960's, and whereas, in the first 25 years of the industry's history, the bulk of production was from the Southport (including the beach deposits of North Stradbroke Is) - Byron Bay area of southern Queensland and northern New South Wales, during the 1960's, emphasis was switched to the deposits of the mid-New South Wales coast and the high-dune areas of the offshore islands of southern Queensland. During the late 1940's and throughout the 1950's the main production area was the Kingscliff - Cudgen - Norries Head section of the northern New South Wales coast where four of the major mineral sands companies - Associated Minerals Consolidated Ltd, Titanium Alloy Manufacturing Co Pty Ltd, Cudgen

* Operations of Murphyores' Gladstone plant were discontinued indefinitely as from early 1970.

R-Z, and N.S.W. Rutile Mining Co. Pty Ltd were in operation. However, by the mid-1960's high-grade reserves in this area had been exhausted and the main site of production swung to the extensive, relatively low - grade deposits of the Port Stephens - Wyong area of the mid-New South Wales coast, the high-dune area of North Stradbroke Is, the low-grade deposits of South Stradbroke Is. and the relatively ilmenite-rich coastal deposits north of Brisbane in the Tin Can Bay area. The change in venue of the main mineral sands mining operations on the east coast could have important implications for the future pattern of zircon - rutile production from this source. Although future output of zircon will undoubtedly increase in line with higher levels of rutile production, it appears likely that zircon production from the east coast will be at a somewhat lower level than that of rutile mainly because of the switch in production from the relatively zircon-rich areas of northern New South Wales, where zircon and rutile are roughly in the ratio 4:3, to those of the mid-coast deposits of New South Wales (Z:R : : 4:5) and of the high-dune deposits of the coastal islands such as North Stradbroke Island and the coastal deposits north of Brisbane (Z:R : : 1:1). Also, it is possible that there could be a time lag between production of rutile and zircon concentrates of marketable grade resulting from the increased demand for rutile in the past year which has not been matched by the market for standard-grade zircon. Such a position developed in the 1950's when following a sharp increase in demand for rutile in the period 1954-56 which coincided with a weakness in the zircon market, large dumps of partially concentrated zircon were built up from east-coast operations. In the late 1950's the world market for zircon firmed considerably and during the period 1958-1962 domestic zircon production from current mining operations was augmented significantly by the re-dressing of these stockpiles. Relative fluctuations in output of zircon and rutile concentrates in this period are presented graphically in Figure 2.

Future levels of zircon production as projected by east-coast rutile producers are detailed in Table 2.

No major expansion in zircon production is planned by established producers above and beyond the 1969 levels of output. The bulk of planned increase will be due mainly to new producers who have just commenced production or who are still in the planning stage, and of course, these producers have yet to prove the viability of their projects. By and large indicated production levels provide for the exhaustion of known reserves by 1985 and most of the larger producers appear to be gearing future production levels to a life expectancy of about 15 years. It seems likely that zircon production on the east coast will reach a peak in 1973, taper off until 1980 before dropping off sharply in the 1980-85 period. Present indications are that zircon production from the east coast after 1990 will be dependent on the discovery of additional economic reserves of mineral sands over the coming twenty years.

The above projections take no account of the possibility of future zircon production from off-shore heavy mineral deposits which by the 1980's could provide an important source of zircon and rutile. As yet, no firm plans have been announced for commercial production from this source, and in the absence of details on the reserves and extent of these deposits, costs of production and technological improvements necessary to make viable an operation based on such deposits, it would be useless at this stage to even hazard a guess as to potential levels of production of zircon from off-shore sources.

The potential of off-shore heavy mineral deposits is dealt with in more detail in the section on reserves [II A 3(d)].

(b) West Coast.

During the ten years since production of marketable zircon concentrates commenced in Western Australia, output has increased to an annual level of about 52,000 tons. Mining activity in this region is centred in the Geographe Bay area between Capel and Wonnerup where zircon comprises 4 - 9% of the heavy-mineral concentrates (Welch 1964) and the ratio of ilmenite to zircon averages about 13:1. It is reasonable to predict that production of ilmenite concentrates from the Geographe Bay area will reach 800,000 tpa by the mid-1970's at which stage the potential for by-product zircon output would be some 70,000 tons per annum. Company projections are given in Table 2.

In addition, considerable potential exists for production of zircon as a by-product of ilmenite-mining operations on the central Queensland coast. Extensive resources of relatively zircon-rich ilmenite deposits are known both on the mainland and on islands adjacent to the coast. Heavy mineral concentrates from Curtis Island average about 18 percent zircon, those from Fraser Is. between 15 and 25 percent. Production of say 200,000 t.p.a. of ilmenite from this area, would provide the base for the production of 40-50,000 t.p.a. of zircon if the market situation for zircon so warranted.

To sum up. On the basis of estimates tendered by individual producers, domestic output of zircon concentrates is seen rising to a maximum of 480,000 t.p.a. in 1974, easing to about 420,000 t.p.a. in 1980, and then falling off sharply to about 280,000 t.p.a. in 1985. However, it must be borne in mind that this type of projection will usually err on the optimistic side being the result of hopeful expectations rather than the product of systematic analysis. In particular, the future activity of Murphyores is in some doubt and future output of some companies e.g. Queensland Titanium Mines Pty Ltd, is dependent on the acquisition of leases, mining of which is opposed by various conservationist bodies. It seems more likely that domestic output of zircon concentrates will be confined to a maximum of about 420,000 t.p.a. and could fall to about 250,000 t.p.a. by 1985. Of course production of zircon from offshore deposits would alter this position considerably.

Installed production capacity for zircon on the east coast seems ample to meet projected levels of production for that region, but some increase in capacity, particularly in the dry separation sector, will be necessary in Western Australia, if projected levels of zircon output are to be realized from ilmenite-rich deposits.

2. Stocks.

The apparent level of zircon stocks in Australia over the period 1950-1969 is traced out in Figure 3. During the greater part of the history of the domestic mineral sands industry, output of saleable zircon concentrates have been matched largely by exports. With only a minor proportion of production directed to domestic consumers, the apparent level of stocks remained generally within the limits of 20,000-30,000 tons during the 1950s. However, following a sharp reduction in stock in the early 1960's an increasing divergence between production and exports of zircon concentrates has developed with a concomitant accumulation in the level of producer stocks. In late 1969 a comprehensive survey was carried out by the Bureau of Mineral Resources of marketable grade stocks held by zircon producers on both the east and west coasts, and by their respective sales organizations. According to information volunteered by producers, physical stocks of zircon held in Australia as at the end of November 1969 were about 140,000 tons of which some 27,000 tons were held in Western Australia. Although this level of stocks appears at first sight to be unduly high when viewed in the light of the pre - 1965 experience, it should be realized that such a level constitutes less than six month's export demand at current levels. Also, large-scale producers on the east coast now carry significant stocks to meet forward contracts and to provide some buffer against interruption in production resulting from the re-location of mining units; and, in addition, some stock accumulation is necessary to cover large-scale, bulk shipments, now a feature of the zircon export market. However, it is a fact that stocks of standard - grade zircon have built up over the last two years, and it seems likely that world demand for this grade of zircon will not overtake the recent increases in supply until 1972. Accordingly, a further build up in zircon stocks may be expected throughout 1970 and 1971.

3. Reserves.

No systematic testing compaign has been mounted on Australian mineral sands deposits since that conducted by the Bureau of Mineral Resources in 1947-1951. The results were published as BMR Bulletin 28. Gardner (1958) estimated that zircon reserves between Southport (Qld) and the mouth of the Clarence River, N.S.W. totalled 936,700 tons on the basis of a cut-off grade of 120 lb heavy mineral per cubic yard of sand, or approximately 4 percent by weight (The average grade of the deposits was considerably higher than this).

The concept of heavy mineral reserves along the east coast has undergone a radical change since then. With the exhaustion of high-grade deposits on the ocean beaches the industry moved both landwards and seawards (to off-shore islands) to work progressively lower and lower grade deposits, and because of increased efficiency, due in the main to improved methods of wet concentration, not only was the level of output maintained but in fact was substantially increased. To-day, mining operations are being conducted on head grades as little as one-tenth of that considered a payable level in the early 1950's. Up until as late as the mid-1960's deposits of mineral sand on the east coast, were estimated to contain four or five million tons of recoverable zircon on the basis of a cut-off grade of 0.25% rutile by weight. In addition, zircon reserves associated with the ilmenite deposits of Western Australia were estimated to be about one million tons (Welch, 1964). However, it was subsequently demonstrated that the wind - concentrated mineral sand deposits of the high-dune areas of islands along the eastern seaboard could be mined economically and that the economic exploitation of rutile and zircon in deposits carrying as much as 60% ilmenite in the heavy mineral concentrate was feasible, and that commercial development of relatively chrome-free ilmenite on the east coast, was possible. The result was the up-grading of overall zircon reserves by a factor of some 25 percent.

Reserves data have been collected from individual companies; the results are collated and evaluated in Table 3.

(a) Zircon reserves associated with rutile.

Zircon reserves in this category are those associated with the rutile-zircon-ilmenite deposits covered by leases from King Island in Bass Strait northwards to the Tin Can Bay area, Qld. Measured and indicated reserves of zircon associated with rutile total about 5.8 million tons based on a cut-off grade equivalent to about 0.15% rutile. These reserves are in the main low-grade by former standards, and seldom does the average grade in any particular area exceed the equivalent of 0.5% rutile, or roughly 1.5% heavy mineral. The bulk of reserves are concentrated in three main areas (1) the coastal section of New South Wales from Wyong in the south to Murwillumbah in the north (2) the off-shore islands of southern Queensland viz. Stradbroke and Moreton Islands (3) the southern Queensland coastal section between Noosa Heads and Double Island Point.

(b) Zircon reserves associated with Ilmenite.
Included in this category are

(i) Zircon reserves associated with the ilmenite deposits of the Geographe Bay area, W.A.

(ii) Zircon reserves contained in the heavy mineral deposits of the central Queensland coast and the offshore islands.

Zircon reserves associated with the ilmenite deposits of the Geographe Bay area, W.A. total about 1.2 million tons on the basis of a cut-off grade of 4-5 percent heavy mineral of which ilmenite comprises between 80 and 90 percent. However, in the case of the Yoganup deposits which contain about 300,000 tons of recoverable zircon, the cut-off grade has been increased to about 10 percent to allow for the increased costs of mining and treatment which result from the clayey and indurated nature of the deposit. The grade of ore is high and the bulk of reserves are contained in deposits which average at least 15 percent of heavy mineral.

(c) Possibility of new reserves.

(i) Zircon associated with ilmenite.

Ilmenite reserves in Western Australia are by no means confined to the Geographe Bay area. Ilmenite deposits have been recorded north of Bunbury and in the Albany and Geraldton areas. Up to date remoteness from a suitable port has precluded the exploitation of these deposits, and commercial production has been confined to the higher-grade deposits within 40 miles of the port of Bunbury. However, the development of new port facilities could result in the expansion of ilmenite reserves in more remote localities with concomitant increase in zircon reserves.

The large, high-dunal islands off the central Queensland coast e.g. Curtis and Fraser Is. also have the potential of extending domestic reserves of zircon. The dunes of these islands are known to be extensively mineralised and if the production of ilmenite from such sources becomes a viable reality, domestic zircon reserves will assume a new dimension. Considerable exploratory work has been undertaken on Fraser Island by Murphyores and Mineral Deposits Ltd. mainly on the north-east and south-east sections of the island. To date, mineral grades encountered have been disappointing. Testing of Murphyores leases is to be continued by Signal-Dillingham. A drilling campaign undertaken on behalf of Murphyores by Kenneth McMahon and Partners on the high dunes of Curtis Island indicated reserves of 11.3 million tons of heavy mineral containing 8.8 million tons of ilmenite, 1.5 million tons of zircon, and 0.2 million tons of rutile; average grade of ore was 1.5-2.0% heavy mineral approximately 0.2% rutile. Cut-off grade for similar high-dunal deposits on North Stradbroke Island is given as 0.3% rutile, and on present information, the successful economic exploitation of the Curtis Island deposits will be dependent on a market outlet for the contained ilmenite.

(ii) Zircon associated with Rutile.

Most of the likely areas held under lease along the New South Wales coast have been subject at least to exploratory drilling for heavy mineral over the years and it appears unlikely that any significant extension of the present reserve position will be realized, failing some drastic revision of the current concept of reserves. In contrast, the high dunal systems of North Stradbroke Island and of the coastal areas north of Brisbane offer considerable promise for additional reserves. On North Stradbroke Island current mining operations are confined to the upper 60-80 ft of the crest of the high dunes. However, deeper drilling to depths in excess of 200 feet have encountered promising mineralization and it is reasonable to suppose that known reserves will be increased considerably with depth.

A large, high dunal system exists as a westward extension of the beach deposits at present being developed between Tin Can Bay and Double Island Point, Qld. Superficial testing of the high dunes has indicated comparatively low-grade mineralization, too low to represent economic reserves even at to-day's rutile and zircon prices. However, the dunes represent such a large volume of sand that, given the right economic climate of increased demand and higher prices, the deposits of this area could represent an extensive low-grade reserve.

(d) Potential reserves contained in off-shore deposits.

Investigation of fossil strand lines offshore from productive beaches along the coast of northern New South Wales and southern Queensland is being continued, principally by one of the Planet group of companies. Earlier investigations by a number of groups gave indications of only low-grade concentrations of rutile and zircon along the shallowest of the fossil strand lines at a water depth of about 120 feet, but in the last year or so Planet have considerably refined their techniques in drilling, processing, location and seismic profiling, and have found deposits worthy of further investigations. They have not released any recent results, but reported earlier the drilling of deposits averaging 1.7 percent heavy minerals.

There seems little doubt that significant resources of rutile and zircon occur in this environment, particularly if additional strand lines in greater water depths be taken into consideration; but it cannot be said at this stage that any reserves with viable grades have been delineated. The continuing work of Planet, in particulr, may well resolve this situation; this offshore environment appears to promise a significant addition to present Australian resources of zircon, and it is to be hoped that some of these resources will become economically available in the future.

4. Costs of Production.

In the final analysis the cut-off grade of workable mineral sands deposits will depend on the prices offering for the individual minerals, and on the cost of production of the mineral concentrates. Possible price trends will be discussed further on in this paper; some general comments on costs of production follow.

In recent years the overall costs of mineral sands production have risen in line with the working of lower-grade deposits and the need for larger mining units and the concomitant increase in capital depreciation. The deposits worked have become notably lower in grade and have become less accessible involving further problems and cost of increased mobility of operations. Increased costs of restoration have added to this rising cost trend. In the face of these increases, unit costs to the f.o.b. stage have been held within reasonable limits by economies of scale, increased efficiency within the industry, and the swing to bulk-loading techniques which have resulted in a significant reduction in loading and transportation costs and which have achieved a quicker turn-round of vessels. However, these efficiencies can be taken only so far and it is reasonable to predict that future increases in mineral sand production will be achieved only with increased capital costs per ton of product.

As far as production on the east coast is concerned, costs of zircon production to the bagging stage have usually been marked up to rutile to give an overall production cost for a double ton of rutile and zircon.

As is the case with most mining operations, no standard unit cost can be applied to mineral sand production. Amongst other factors, costs vary according to the mining method selected e.g. dredging or dry mining methods, the type of terrain mined, and the nature of the deposit. On average, dredging and treatment costs (including a reasonable return on capital) on the east coast are estimated to be about 30-35 cents per cubic yard or 24-28 cents per ton. Allowing a 90% recovery rate of heavy mineral, operations based on an average grade of 0.15% rutile and a equivalent concentration of zircon, would need a double ton price of $180 ($140 per ton for rutile, $40 per ton for zircon) to break even. In fact, for 1969, rutile and zircon exports averaged about $125 per double ton ($85 for rutile, $40 for zircon). Assuming that contract prices for rutile will firm in the medium term and that zircon prices will ease, future export values could average about $150 per double ton ($115 for rutile, and $35 for zircon). In this case, mining of deposits averaging 0.2% each of rutile and zircon could be marginally profitable if mining and separation operations are conducted within say 50-80 miles of the port of shipment.

Mining costs of heavy mineral sand in Western Australia are on a par with those of the eastern states, but, because deposits being worked in Western Australia are so high in grade (usually 20-30 percent heavy mineral), and because of the comparative simplicity of recovering saleable-grade ilmenite, and because of the proximity of mining operations to port facilities, a ton of ilmenite concentrate can be delivered into ship's hold for roughly $5.00. Comparative costs would be increased to say $8.80 - 10.00 per ton if the grade of heavy mineral in the ground was reduced to the cut off level of 4-5%. Using as a basis grades currently mined and current costs of production, the separation and sale of zircon concentrates would (if all costs and receipts were marked to ilmenite) increase cost per ton of ilmenite from about $5 to

$6.80 and its f.o.b. value from about $10 to about $12.40.

B. OTHER WORLD SOURCES OF ZIRCONIUM MINERALS

In 1961, the U.S Bureau of Mines estimated "Free" World resources of zirconium minerals to be about 23.3 million short tons of which United States resources were estimated to be about 12.6 million short tons. In the light of the Australian experience these estimates have been modified and appear as Table 4 - Estimated World Reserves of Zirconium Minerals, by Country. World reserves of zircon (measured and indicated) total about 28 million tons of which about 70 percent are associated with ilmenite. Only three sources, eastern Australia, Brazil, and Sierra Leone are independent of ilmenite production. Zircon reserves in this category comprise about 28 percent of the world total. Australian reserves of zircon represent about 26 percent of total world reserves, 21 percent associated with the rutile deposits of the east coast, and the balance associated with the ilmenite deposits of the south - west corner of Western Australia.

Outside of Australia, the only significant producer of zircon concentrates is the United States where zircon production is entirely as a by-product of ilmenite production. Over the years, Australia and the United States have dominated the world supply of zirconium minerals, and present indications are that they will continue to do so up until 1990 at least.

1. United States.

Although placer deposits of zircon associated with ilmenite are known in California, Tennessee, Idaho, and South Carolina, and zircon was produced as a by-product of chromite production from Oregon beach sands in the mid-1950's, zircon production is now confined to the ancient - beach deposits of Florida and Georgia where reserves are estimated to be about 6.7 million tons.

Florida contains the largest known reserves of zircon in the United States (about 6.5 million tons proved and probable) principally in the Trail Ridge Deposit.

The Trail Ridge feature consists of a broad elevated ridge extending some 200 miles southward from southeastern Georgia deep into north-central Florida. The Trail Ridge deposit proper lies approximately 45 miles inland from the east coast of Florida along the western side of the main ridge feature. The deposit is about 19 miles long, is from one mile to two miles wide and is up to 30 feet thick. Elevation of the orebody base ranges from 145 feet to more than 200 feet above sea level. The zircon is associated with ilmenite, leucoxene and minor amounts of rutile; zircon comprises from 9-14 percent of the heavy mineral concentrate, although selected areas may contain up to about 30 percent zircon. The deposit is estimated to contain about 50 million tons of heavy mineral of which between 6 and 7 million tons is recoverable zircon.

E.I. du Pont de Nemours and Co. Inc. became the only producer of heavy mineral concentrates in Florida, following cessation of mining activities by the other two operators, National Lead Co. at Skinner and Florida Minerals Company at Vero Beach, in the 1960's. Du Pont developed the Trail Ridge deposits in the late 1940's. The Trail Ridge plant, near Starke, was built in 1948; the Highland plant near Lawtey, was commissioned in 1955. Each plant has an annual capacity of about 100,000 tons of titanium minerals; combined capacity for zircon production is some 60,000 tons per annum. Mining and separation methods are standard - dredging followed by concentration on spirals and dry separation by high-tension and electromagnetic methods. The non-conductors fraction consists principally of staurolite and zircon. The staurolite magnetic tailings are concentrated by gravity methods to give a zircon concentrate which is calcined at 1000°F in an oil-fired kiln.

The Humphrey Mining Company operates a small heavy-minerals plant on Du Pont leases at Folkston, Ga. about 40 miles north of Jacksonville. The deposit differs from that at Trail Ridge in that it is more recent, it is only 90 feet above sea level, the mineral is far less weathered, and the orebody is limited to a thickness of about 10 feet. Mining and plant operation is basically the same as used by Du Pont at Trail Ridge. The Folkston plant has a capacity of about 50,000 tons of titanium minerals a year, and produces approximately 12,000 tons of zircon concentrates a year and small amounts of monazite. Operations are expected to cease towards the latter part of the 1970's.

Data for production of zircon concentrates in the United States have not been available since 1958 but it is estimated that in the last fifteen years production has fluctuated between a low of 16,000 tons in 1954 to a high of 80,000 tons in 1965. Production in 1969 was an estimated 63,000 tons.

As zircon production is part and parcel of ilmenite production in the United States, any sustained increase in zircon production will depend on a significant increase in production of alluvial ilmenite from the Florida deposits. At the moment this appears to be unlikely. However, sporadic increases could result from the re-dressing of stockpiled non-magnetic tailings of which considerable tonnages have been accumulated over the years. Rather than forego depreciation allowance on plant and equipment Du Pont will, it is understood, augment current production of zircon with zircon from stockpile. This could have the effect of lifting U.S. zircon output to between 80,000 and 100,000 tons per annum over the next five years. In the latter half of the 1970's, output would probably revert to the more normal level of about 50,000-60,000 tons.

2. India and Ceylon.

From the early 1920's to the late 1930's, the Indian heavy mineral-sand industry enjoyed a position of near monopoly on world ilmenite markets; during the 1930's about two-thirds of world requirements of ilmenite were supplied from the beach deposits of Travancore. However, by the early 1960's, India had lost virtually all of its export markets and ilmenite production fell from a high of 358,000 tons in 1958 to 12,000 tons in 1964. In 1965 Indian Rare Earths Ltd (I.R.E.) acquired the assets of Travancore Minerals Ltd, the only surviving mineral sands operator in India, when that company went into liquidation. In 1967 Indian Rare Earths commissioned a mineral sands plant at Manavalakurichi, a few miles north-east of the southern tip of India. Current zircon production capacity of the plant is rated at 3,600 t.p.a.

I.R.E. has recently concluded a long-term contract to supply a significant tonnage of ilmenite to Japanese pigment manufacturers. To meet this commitment and to cater for increased domestic requirements I.R.E. will double the capacity of its separation plant recently commissioned at Chavara near Quilon. When the expansion programme has been completed towards the end of 1972, the dry plant will have capacity for about 200,000 tons of ilmenite per annum and 11,000-12,000 tons of by-product zircon.

Production of beneficiated ilmenite from raw ilmenite of Travancore origin by Dharahgadrha Chemicals Company with technical help from the Wah Chang Corporation of United States will also call for increased tonnages of Indian ilmenite with a concomitant increase in the availability of by-product zircon.

Indian reserves of zircon are large-about 3 million tons of which approximately half are contained in the Quilon deposits. In addition, considerable tonnages of zircon-rich tailings from ilmenite operations, are available for further treatment. Production of by-product zircon in India could increase to 10,000-15,000 tons in the 1970's of which about one third to one half would be consumed domestically.

To date, mineral sand operations in Ceylon have resulted in the production of only limited quantities of zircon. Zircon reserves are estimated at about 0.9 million tons of which about 350,000 tons are contained in the ilmenite deposits near Pulmoddai. Mining operations are conducted by the Government-owned Ceylon Mineral Sands Corporation. Treatment plants are located at Pulmoddai and at China Bay near the Port of Trincomalee about 35 miles to the south. Overall production capacity for zircon is about 9,000 tons per annum.

3. Brazil.

Brazilian reserves of zirconium minerals are estimated at about 2.3 million tons. Commercial production of zirconium minerals is from two sources (a) zirconium associated with ilmenite sands, and (b) caldasite, a mixture of baddaleyite and zircon.

(a) Production of by-product zircon is controlled by National Commission of Nuclear Energy at two plants, one near the city of Barra de Itabapona in the State of Rio de Janeiro, and the other near the village of Cumuruxatiba in the State of Bahia. However, production from this source is less than 1,000 t.p.a. Reserves are put at about 0.5 million tons.

(b) The more important source of zirconium in Brazil is so-called baddeleyite which in fact is a mixture of baddeleyite and zircon (caldasite). This ore has been mined in Brazil since the early 1920's, and although complete production figures are not available, in 1961 and 1962 production was reported as 6,300 tons and 1,700 tons respectively. Exports have been banned since 1956 because of the fact that the ore carries a small concentration of uranium. The ore is mined near Pocos de Caldas in the State of Minas Gerais from both alluvial and eluvial deposits. Originally, concentrates of this material were produced assaying up to 95% ZrO_2; currently, concentrates are sold on the basis of a 70-75% ZrO_2 content. Reserves are put at about 1.5 million tons.

Although Brazil is an important source of zirconium minerals, it is unlikely that production will increase much above current levels. Future production will probably be geared to domestic demand because of the Government's export control policy and the comparatively high price of caldasite vis a vis standard zircon concentrates.

4. Africa

(a) Senegal

Heavy-mineral sands have been mined in Senegal since the mid-1920's. During the 1950's significant tonnages of zircon concentrates were produced as a by-product of ilmenite by Societe Miniere Gaziello et Cie. The bulk of production was exported to European foundries, reaching a maximum of 10,772 tons in 1960. However, the relatively high-chrome content of the ilmenite resulted in the cessation of mining activities in 1964. Major deposits are in the Kayar-Lompoul area south of Dakar, in the M'Bour-Joal area, and in the Casamanca delta south of Gambia. Zircon comprises about 10% of the heavy mineral concentrate; reserves of zircon are estimated at about 0.7 million tons.

(b) Sierra Leone

Sherbro Minerals Limited commenced full-scale dredging operations for rutile in the Gbangbama area about 170 miles southeast of Freetown towards the end of 1966. Despite mining difficulties (including the foundering of the dredge in late 1967), output of 100,000 tons of rutile per annum is planned for the early 1970's. The heavy mineral concentrate produced from these operations consists of about 80 percent rutile, 10-15 percent ilmenite, and about 5 percent zircon. Measured and indicated reserves of rutile are put at about 12 million tons, i.e. reserves of zircon are of the order of 0.6 million tons. Plant operations at capacity will result in the output of about 6000-7000 t.p.a. of zircon contained in a zircon-quartz-garnet tailing. The company has no plans for producing saleable zircon concentrates. At present design capacity it would not be economic to install secondary separation facilities (private communication)

(c) Republic of South Africa

During the period 1958-63, Umgababa Minerals Ltd produced concentrates of ilmenite, zircon, and rutile on the Natal coast about 22 miles from Durban. Plant capacity for production of zircon concentrares was about 8,000 t.p.a. Operations were discontinued in 1963 because of effluent problems which involved the pollution of nearby bathing beaches. Plant was subsequently acquired by Progress Minerals (PVT) Ltd and relocated at the mouth of the Kei River south of Morgan Bay. Production of ilmenite and zircon has commenced. Zircon reserves are put at about 0.2 million tons.

At Phalaborwa in the eastern Transvaal the Government-owned Phosphate Development Corporation (Foskor) has recently undertaken the recovery of baddeleyite concentrates from slime dumps resulting from the treatment of apatite concentrates, production of which commenced in 1955. Copper-mining operations by Palabora Mining Company in the same area could result in the output of 10,000-20,000 tons per annum by-product baddeleyite, as from 1971, from the treatment of the phoscorite phase (apatite-titano-magnetite-serpentinized olivine) of the carbonatite orebody.

(d) United Arab Republic

Ilmenite-rich sands have been worked in the Nile Delta since the 1930's. Operations are now concentrated near Rosetta and are under the control of the government-owned Egyptian Black Sands Company. Reserves of zircon which make up about 3% of the total heavy mineral fraction are put at between 1 and 1.5 million tons. Output of zircon which is consumed locally is limited to a couple of hundred tons per annum.

(e) Other

From time to time small tonnages of zircon have been produced along the southeast coast of Malagasy Republic as a co-product of monazite production. No production has been recorded since 1967. High hafnium zircon is produced in Nigeria as a by-product of tin mining. Production reached a maximum of 1,757 tons in 1960. Output has now been reduced to a couple of hundred tons per year, the bulk of which is shipped to the United States for the production of hafnium metal. Reserves are estimated to be about 0.15 million tons. Minor deposits of zircon have been recorded elsewhere in Africa, e.g. Republic of the Ivory Coast. Potential exists for the recovery of a mixed zircon-baddeleyite concentrate from the apatite flotation plant at Sukulu in eastern Uganda and baddeleyite could also be produced from residual deposits on the nearby Bukusu complex also in Uganda. However, the chance of significant production from these sources is remote.

5. South East Asia.

Deposits of mineral sand containing zircon have been identified in many areas in the south-east Asian region, but production and export have not been significant in the past, and judging by currently known potential, exports are not likely to become of world significance in the foreseeable future.

Potential production of zircon in India and Ceylon has been discussed in some detail in section II B2 of this report. In addition, investigations of mineral sands deposits in recent years, principally as part of Australian aid to developing countries have indicated deposits in Pakistan, Taiwan and Korea containing useful quantities of by-product zircon, and have also indicated the possibility of recovering more by-product zircon from tin mining in Thailand and Malaysia than has been effected previously. Mineral sand deposits in other south-east Asia countries like Japan, Indonesia and the Philippines appear to contain little zircon.

Although it is hoped that deposits will eventually be developed in Pakistan, Taiwan, Korea, and Thailand, and that additional production will result from current mining in India, Ceylon, and Malaysia, likely total production of zircon from all of these sources in hardly likely to exceed 20,000 tons per annum under the best of conditions. Moreover, a large part of any production from these countries could well be consumed by local foundry industries, although Pakistan appears to have good potential for some export.

In summary, present knowledge indicates no large-scale potential for the production and export of zircon in the south-east Asian region, and hence no promise of significant supplies for world markets in the foreseeable future.

Possible future trends in world production of zirconium minerals are summarized graphically in Figure 4.

Apart from minor tonnages of baddeleyite produced in Brazil and the Transvaal, zircon is the only commercial ore of zirconium, and its production will continue to be as a by-product or co-product of other heavy minerals, viz. ilmenite and rutile. Although world resources of zircon are extensive, approximately 70 percent of reserves are those associated with ilmenite. Zircon production from this source will depend on the production of saleable ilmenite. In this sense, zircon production is relatively inflexible.

Although modest increases in zircon production may be expected from increased ilmenite output in India and in some southeast Asian countries, the bulk of ilmenite-by-product zircon will continue to be that from the United States and Australia. Production from these two countries is unlikely to meet more than 30 percent of world demand in the long term and zircon production from Australian eastcoast rutile operations will be called on more and more to meet the deficit.

In summary, world zircon supplies are seen increasing to a peak of 500,000-600,000 tons in 1974, easing gradually in the late 1970's before declining sharply in the post1985 period. World output could decline to between 200,000-300,000 tons per annum in the 1990's unless new, economic reserves are brought into production in the meantime.

III. DEMAND FOR ZIRCONIUM MINERALS

In most studies of this nature, detailed empirical consumption data are lacking and conclusions regarding future demand must of necessity be less definite than those of future supplies. However, because of the dominant position enjoyed by Australia as a zircon supplier to world markets and the detailed data of Australian statistics available, it is possible at least to draw some reasonable conclusions as to the broad, overall consumption pattern of zircon in recent years. Figure 5 graphically illustrates the pattern of Australian exports of zircon concentrates to main countries of destination during the period 1954-1969, and apparent world consumption for the same period. As far as consumption goes, no allowance has been made for variations in the level of consumer stocks which could result in a significant divergence between apparent and actual consumption. Such was the case in the mid-1960's when, in early 1965, consumer stocks of zircon were reduced to a dangerously low level, following on the abnormally high level of activity in the world steel industry during 1964 and the reduction of stocks by many consumers in the mistaken belief that expansion programmes being undertaken by Australian mineral sand producers would result in an immediate increase in by-product zircon. In the event, achievement of increased zircon production predicted in some quarters was delayed and the short-term zircon shortage was further aggravated by some disruption in pipeline supplies, the result of a temporary build-up in producer stocks pending shipments in bulk. And so in 1964 the position of apparent consumption was well below the level of actual consumption because of liquidation of stocks, whereas in 1965 the position was reversed as consumers endeavoured to readjust stock inventories to normal levels. Nevertheless, the growth pattern indicated in Figure 5 for world consumption of zircon over the last 15 years is considered to be reasonably in line with actual consumption during this period.

A. PRINCIPAL OUTLETS FOR ZIRCON

1. Foundry Applications.

Its use as a foundry sand continues to provide the principal outlet of zircon. The chief inherent advantage of zircon in this role is its relatively high refractory value which combined with its high density and high thermal conductivity and low thermal expansion makes zircon a speciality material for use in precision foundry operations such as investment moulding and shell moulding, for complex shapes where large masses of metal must be cooled quickly, and for castings which require close tolerances and smooth finishes.

Zircon is used in the form of sand for moulds, facings, and cores; as milled flour for mould and core washes; as refractory shapes, ramming mixtures, and cement for furnace, crucible, and ladle linings; as ceramic pouring basins, strainer cores, runners, and gates; and as an abrasive for sandblasting precision castings.

Until the mid-1960's, approximately 60 percent of the world demand for zircon was provided by foundry applications, about 15 percent each going to the refractory and ceramic industries and the balance of 10 percent to abrasives, and miscellaneous uses. However, the pattern of consumption has changed significantly in recent years. There has been a marked increase in the use of zircon-type refractories, particularly in Japan, while the foundry use of zircon has levelled off under increasing pressure from lower-priced substitutes. World consumption of zircon is currently running at about 400,000 t.p.a. of which an estimated 48 percent is for foundry use, about 27 percent for refractories, and about 17 percent for ceramics.

2. Refractory Use of Zircon.

Unprocessed zircon and zirconia are used for fused-cast and conventionally fired refractories, and as ramming and other mixes. At least 90 percent of the fused-cast and zircon shapes and mixes produced are used in glass furnaces, primarily as liners for the glass tanks. The fused-cast shapes are also used to some extent in iron and steel mill furnaces where resistance to both high temperatures and severe abrasion is required. Some zircon shapes are used by the chemical industry in equipment such as sulphur burners and calcium phosphate furnaces. Zirconia shapes are used principally for metallurgical applications such as zirconia nozzles for continuous casting furnaces, where a heavy-duty refractory is required.

3. Zircon Use in Ceramics.

Zircon and zirconia are used in ceramics as an opacifier in glazes and enamels, to provide resistance to chemical corrosion in porcelains etc, to provide electrical resistance, as a component in piezoelectric devices of the lead zirconate-titanate type, and as a pigment in glazes.

4. Zirconium Metal.

The use of zirconium in metallic form has been comparatively restricted. Main outlet has been in nuclear reactors where because of its low, thermal-neutron capture cross-section and its advantages in strength and resistance to corrosion, zirconium is preferred to other metals acceptable on the ground of neutron economy viz. aluminium, magnesium, and beryllium. Zirconium is essential for water-cooled reactors which are the type being considered for construction in Australia. A single 500Mw reactor of the CANDU-PHW type being developed in Canada requires initially about 55 tons of zirconium plus a recurring requirement of 7.6 tons/year for the replacement of fuel rods i.e. the reactor will require some 200 tons of zirconium over its life of say 25 years. About 5 tons of zircon are required for the production of 1 ton of zirconium sponge, each ton of fabricated zirconium involves the consumption of about 9 tons of zircon. Translated into terms of zircon concentrate, zirconium requirements of a nuclear reactor of the type referred to above would be equivalent to about 2,000 tons of zircon concentrate.

Zirconium applications, other than nuclear, require only minor amounts of the metal. Because of its resistance to corrosion, zirconium has limited specific areas of application in chemical processing equipment where dry chlorine, hydrochloric acid, and caustic alkalis are involved, and where the corrosion resistance of even titanium is not entirely satisfactory.

Reactor-grade, ductile zirconium is used as finely shredded foil in camera flash bulbs; zirconium-copper and zirconium-columbium alloys show promise in superconductive electromagnets. Zirconium is also used as a gas absorbent in vacuum tubes, and in surgical devices. However, metal requirements in these fields are not significant.

5. Miscellaneous Uses of Zircon.

Miscellaneous applications include the use of zircon as an abrasive, in core-wire and submerged-arc fluxes, in chemicals and in floor waxes. Of these applications only the abrasive use is of any significance. All zircon used by the abrasive industry is in the form of zirconia. Zirconia is usually mixed with 60-90 percent alumina, melted in electric furnaces, cooled and crushed. The abrasive grains are bonded into wheels or discs for use in conditioning ingots, billets, plates and castings. This outlet for zircon although small at present has considerable potential for expansion.

B. GEOGRAPHICAL DISTRIBUTION OF WORLD ZIRCON CONSUMPTION

By world standards, Australian domestic consumption of zircon is not significant, amounting as it does to about 4,000 tons per annum or slightly more than one percent of domestic production. About 75 percent of domestic demand is accounted for by the foundry industry, the balance going into ceramic applications. Micronised zircon is finding increased use in high-denisty insulators and in other high-grade ceramic ware, but zircon in this form probably comprises less than 10 percent of total domestic consumption. Domestic demand is expected to increase in line with expanded output of steel castings and increased industrial activity. No doubt, value added to zircon concentrates will be increased by the processing of raw concentrates by milling to flour and micronised zircon, and by the production of zirconia, culminating eventually in the production of zirconium sponge and fabricated shapes. However, Australian producers will continue to depend on overseas markets as an outlet for the bulk of their output of zircon and zirconium products; the United States, Europe, and Japan are responsible for approximately 90 percent of Free World consumption of zircon, and it is towards these major markets that this study is directed.

1. United States.

In 1969, United States' consumption of zircon accounted for about 36 percent of total world consumption estimated as 380,000 tons. Precise consumption data are not available, but the curves depicted in Figure 6 are considered to present a realistic picture of consumption trends in zircon over the last ten years.

(b) Foundry Use.

During the 1960's consumption of zircon in foundry applications in the United States has increased from about 42,000 tons to about 79,000 tons, an annual growth rate of about 6½ percent. Over the last ten years, increased use of zircon in foundry applications has been closely linked with increased production of steel castings. Zircon has proved itself a superior foundry sand for the production of steel castings particularly where precision operations are involved. The United States experience has been that in terms of pounds of zircon used per ton of steel casting produced zircon usage has increased from about 65 pounds per ton since the late 1950's to about 85 pounds per ton in the late 1960's. However, zircon's strong growth rate in foundry applications is unlikely to be sustained into the 1970's and 1980's. No significant growth in the volume of shipments of steel castings is predicted, and relatively high prices obtaining for zircon in recent years may be expected to result in some erosion in the foundry use of zircon by cheaper moulding sands.

(c) Refractories.

Refractory applications currently consume between 20,000-25,000 tons of zircon per annum in the United States. Of the zirconium-bearing refractories, zircon and zirconia bricks and shapes predominate. For statistical purposes, shipments of these refractories are expressed in terms of equivalent 9-inch bricks. In 1968 shipments totalled 1.722 million bricks compared with 1.44 million in the previous year. A growth rate of zircon in refractories of about 6-7 percent per annum in the 1960's compares favourably with an estimated annual growth rate of about only 2 percent in the 1950's. A swing to the use of zircon and zirconia brick in glass furnaces has been the major factor contributing to this significant consumption increase.

(d) Ceramics

No precise data are available of the consumption of zircon and zirconium compounds in ceramic applications. The U.S. Bureau of Mines estimates that the domestic ceramic industry consumed the equivalent of about 20,000 tons of zircon in 1968. This compares with an estimated consumption level of about 9,000 tons per annum in the mid-1950's and would indicate an annual growth rate of about 6 percent per annum in consumption. Of the zircon consumed in ceramics, it is estimated that zircon opacifiers and zirconia-based pigments each consume about 35 percent of the total; electrical and ceramic bodies consume about 20 percent, and the balance goes to miscellaneous ceramic applications, mainly piezoelectric devices.

(e) Miscellaneous Uses.

United States consumption of zircon for miscellaneous uses including abrasives, chemicals, metal and alloys is estimated to have been about 15,200 tons in 1968. Of this about 10,000 tons was consumed in the production of metals and alloys. The U.S. Bureau of Mines estimates that zirconium sponge requirements for domestic nuclear reactors in 1968 was 1.3 million pounds, equivalent to say 3,000 tons of zircon

2. Europe

In 1968 Western European countries consumed an estimated 39 percent of Free-World consumption of zircon concentrates. In 1968 and 1969 exports of zircon concentrates to non-Communist European destinations represented 47.8 percent and 47.0 percent respectively of total Australian zircon exports. Although these figures give a reasonably accurate picture of the importance of the European market on a global basis, the level of exports to individual European destinations, see Figure 5, does not necessarily represent the level of zircon consumption in those countries. In particular, a significant proportion of zircon concentrates shipped to Rotterdam is actually consumed in other European countries, mainly in Federal Germany. Because of the prevalence of trans-shipments of zircon between European countries, actual levels of consumption in individual countries are perhaps better represented by the import statistics collated by the Institute of Geological Sciences in the Statistical Summary of the Mineral Industry (SSMI). According to these statistics, total imports by the four main European consumers, United Kingdom, Federal Germany, France, and Italy, averaged about 97,000 tons of zircon per annum during the period 1962-1967. This would represent about 85 percent of total European consumption.

Detailed data regarding the pattern of zircon consumption in individual countries are not available, and only general observations can be made on the significance of special end uses in those areas.

(a) United Kingdom.

During the period 1962-1967 imports of zirconium ores into the United Kingdom averaged about 36,400 tons per annum although up to 2000 tons per annum of this amount is understood to have been trans-shipped to Spain. With estimated consumption currently put at about 35,000 tons per annum, the United Kingdom is the leading consumer of zircon in Europe. This pride of place is due mainly to the highly-developed ceramic industry which is responsible for about one half of total consumption of zircon in the United Kingdom. Significant inroads into foundry applications by other moulding sands have tended to erode this outlet for zircon, and foundry use now accounts for only about 40 percent of total zircon consumption in the United Kingdom. Refractories and miscellaneous applications consume about 3,500 tons of zircon per annum.

(b) Federal Germany.

Zircon imports have averaged about 25,000 tons per annum in recent years. Actual zircon consumption is currently between 25,000 and 30,000 tons per annum of which foundry applications account for about 65 percent. The next important outlet is the ceramics industry which consumes about 4,000 tons of zircon per annum.

(c) France.

French imports of zircon averaged 22,500 tons per annum during the period 1962-1967. Exports of Australian zircon to France averaged about 25,000 tons per year for 1968 and 1969, and this is considered to approximate the actual level of French consumption. France is the leading European producer of zircon and zirconia refractories which are responsible for about 50 percent of domestic consumption of zircon. The highly-developed and sophisticated French glass industry consitutes the main outlet for the domestic production of zircon refractories although French zircon refractories are shipped to other European countries. Foundry use of zircon consitutes only about 35 percent of total domestic consumption. Ceramic and abrasive outlets for zircon are relatively unimportant although consumption of zircon for metal production is assuming increased importance.

3. Japan.

Japanese consumption of zircon has risen spectacularly in recent years. Australian exports of zircon concentrates to Japan have increased from 20,000-25,000 tons per annum in the early 1960's to 71,000 tons in 1969 to make Japan the leading world importer of zircon concentrates. Actual consumption has been even more impressive increasing as it has from a level of 30,000 tons per annum to a current rate of about 100,000 t.p.a. This unprecedented growth rate has been due mainly to the unparalleled swing to zircon refractories in Japanese steel-making applications. From a level of about 8,000 t.p.a. in 1965, consumption of zircon for refractories has increased to about 40,000 tons in 1969 and is currently running at about 60,000 t.p.a. or approximately 60 percent of Japanese total demand for zircon. Both fired and electromoulded zircon and zirconia refractories are produced and used mainly in the form of fire-bricks for lining steel furnaces and in such applications as pouring ladles associated with continuous casting operations. Japan is largely dependent on imported supplies of raw materials for refractories and zirconia bricks are rapidly replacing high-alumina bricks. The higher cost of zirconia brick is apparently more than off-set by its longer life which in turn reduces the frequency of furnace dismantling for lining replacement. Further increases in consumption of zircon for refractories can be expected as Japanese current steel output of 90 million tons per annum is increased to a predicted 145 million tons by the mid-1970's.

The foundry use of zircon has kept pace with the increased output of steel castings in Japan which has more than trebled over the last five years. Currently, Japanese foundry use of zircon is estimated to be about 25,000 tons per annum, about 25 percent of total zircon consumption, about one-third of which is used in the form of flour for mould facings.

Ceramic applications, mainly for opacifiers, require about 10,000 tons of zircon per annum with miscellaneous applications, principally in abrasives, accounting for the balance of about 5000 tons a year.

C. SUBSTITUTION.

The strong growth pattern in zircon demand during the 1960's was achieved mainly in a climate of relatively low prices which enabled zircon to increase its share in foundry, refractory, and ceramic applications on the basis of performance which was high enough to outweigh the price disadvantage suffered by zircon. However, at the comparatively elevated price levels obtaining for zircon in recent years, the price differential between zircon and possible substitutes has become significant, and it is unlikely that the earlier growth rate of demand for zircon will be maintained. Forward projections of world consumption of zircon must take into account the possible erosion of zircon markets by the introduction of substitute materials. European prices of specific foundry sands are compared in Table 5.

TABLE 5 - COMPARATIVE UNITED KINGDOM PRICES OF FOUNDRY SANDS.

Zircon	£24½-25½	foundry grade, min 66% ZrO_2 bagged, c.i.f.
Ground silica	£ 6½-8½	99.5% + SiO_2 delivered United Kingdom.
Olivine	£14-16	sand, dry, bagged, 10 ton lots delivered United Kingdom.
Chromite	£ 21-22½	sand, moulding quality, 98% through 30 mesh, delivered United Kingdom.

Foundry applications although providing the main outlet for zircon are also the most vulnerable to substitution. Silica sand, chromite, and olivine are the three chief competitors for zircon's share of the foundry market. Silica remains the traditional foundry sand in general use, and although zircon has progressively replaced it in certain types of foundry operations, foundry use of zircon in the United States represents only about one percent of the foundry use of ground and unground silica. There seems little doubt that silica sand will remain the standard material, and that zircon will continue to be considered a superior, high-priced speciality item. It has been suggested that zircon (f.o.b.) prices would have to decrease to the range $A20-25 per ton to permit of its further substitution for silica in foundry applications.

High zircon prices in recent years have caused some erosion of zircon foundry markets by olivine and chromite, but no precise data are available as to what extent this has occurred. Olivine has found increasing use in Western Europe, the United States and Japan as a moulding sand particularly in the production of austenitic manganese steel castings where a basic foundry sand is required. Chromite sands are now being used in foundry applications where high resistance to metal penetration is required. However, this advantage is somewhat off-set by the difficulty of maintaining quality control in chromite sand and the accompanying danger of gashole damage to castings.

In the other main uses of zircon viz. refractories and ceramics, zircon is not at such a price disadvantage, and such a disadvantage which may exist is to a large extent offset by zircon's inherent qualities. Fused-cast alumina refractories can substitute for fused-cast zircon in glass and steel furnaces in specific areas, but zirconia refractories are used exclusively for continuous casting nozzles.

Although zircon is widely used in chemical porcelains, standard porcelains and alumina meet the main demand for electrical ceramic ware. Zircon's role as an opacifier in porcelain enamels has been to a large extent eroded by the use of titanium dioxide which provides greater opacification per unit weight and allows for the application of thinner enamel coats. On the other hand, the clarity and stability provided by zirconia stains in finished glazes enable zirconia to maintain its dominant position as a ceramic pigment against such substitutes as cobalt. vanadium, cadmium, and praseodymium.

D. PRICES

Perhaps the most critical factor determining the growth in demand for zircon, the question most important to producers and consumers in planning future operations, and yet the subject least amenable to definitive prediction, is the future levels of zircon prices. Although the historical pattern of zircon prices is now well established, only general observations can be made regarding possible future trends.

1. Historical Background and Current Position.

Average ex-mine and export values of zircon concentrates over the last fifteen years are compared graphically in Figure 7. In general, zircon prices have increased progressively since 1954 to reach a peak equivalent to £28½-30 3/8 per ton c.i.f. Europe in 1967 before easing in 1969 to the current level of £25 1/4-26½ for standard grade concentrates. Exports of domestic zircon concentrates are generally reported on an f.o.b. basis. Freight charges are the main component in the differential between f.o.b. and c.i.f. quotations. Conference rates for the shipment of bagged zircon are currently equivalent to $US19-21 per ton to Europe, $US17.40 to Japan (increased by 7½% in April 1970), and $US27.20 per ton to the United States. Charter rates when available are about $US7 per ton less to Europe $US9.50 per ton less to Japan and about $US15.00 per ton less to the United States. Insurance, the other significant component of c.i.f. charges amounts to about

1 percent of the value of the cargo or about 50 cents per ton of zircon.

Although Australian f.o.b. prices do in general reflect the going price of zircon concentrates on world markets, the average Australian export value has become increasingly contingent on the ratios of spot sales/contract sales, zircon sand/zircon flour, bulk/bagged material, standard/premium grade zircon, and east-coast/west-coast concentrates, in the overall shipments.

(a) Spot and Contract Prices.

Forward contracts written in connection with zircon sales are relatively short-term as compared with say those of rutile and ilmenite. Forward contracts for zircon are limited usually to one or two years and the small discounts offered in the contract price are a factor of the tonnage involved rather than an indication of a price backwardation.

(b) Price of standard and premium grade zircon.

The European c.i.f. price of premium (ceramic) grade zircon, max 0.1% TiO_2 is at a premium of about £2½ per ton on the standard or foundry grade max 0.3% TiO_2 i.e. £28-29 compared with £25 1/4-26½ per ton. Australian f.o.b. spot prices indicate a premium of about \$3-4 per ton. This premium might be expected to increase with a tighter supply position.

(c) Prices of Zircon Sand and Flour.

The price of zircon flour is largely dependent on the cost of milling and the mark-up added by the producer. Zircon sand is milled locally by Associated Minerals Consolidated Ltd at both Southport and Hexham, and by Rutile and Zircon Mines (Newcastle) Ltd at Newcastle. Custom grinding is carried out by Commercial Minerals of Sydney. In general, zircon flour commands a premium of up to \$20 per ton over the equivalent grade of zircon sand.

(d) Bulk and Bagged Zircon.

Export statistics for bulk and bagged zircon have been available as separate, statistical items only since July, 1969. For the eight months July 1969 - February 1970, the latest figures available at the time of writing, exports of bagged zircon (94,986 tons) averaged \$45.8 per ton f.o.b. compared with exports of zircon in bulk (118,898 tons) at an average of \$35.1 per ton. Of course, the item for bulk zircon contains a high proportion of contract material and is made up wholly of zircon sand; the bagged material contains a higher proportion of zircon for spot sale and includes all zircon flour exported. In fact, the margin between the export f.o.b. value of zircon bagged and in bulk is roughly about \$3 per ton.

(e) Price Difference Of Domestic Concentrates.

Zircon concentrates produced as a by-product of ilmenite in Western Australia have traditionally been sold at a discount on concentrates produced on the east coast reportedly because of the darker colouration and higher iron content of zircon of Western Australian origin. The price difference has been accentuated in recent months as requirements of Japanese importers have been met increasingly by relatively low-priced concentrates shipped through Bunbury. For the period July 1969 - February 1970 exports of zircon sand from Western Australia averaged $26.3 per ton f.o.b. for bulk material and $29 per ton for bagged zircon. There seems little evidence to justify such a wide margin in price between east and west coast zircon. Quality-wise there is little if any difference between the foundry grades from the two sources although producers in Western Australia are at a disadvantage with regard to freighting opportunities. Neither ceramic-grade zircon nor zircon flour is produced by mineral sand operators in Western Australia. In connection with a zircon stockpiling plan proposed by domestic mineral sand producers, minimum export prices for bulk, standard grade zircon have been suggested as $34 per ton f.o.b. for east coast material, and $30 per ton for west coast concentrates.

(f) Price Sensitivity of Supply and Demand.

Mine output of zircon is relatively inflexible, being as it is a function of the level of production of rutile, and to a lesser extent the production of ilmenite. Production costs of zircon are generally marked to those of the titanium mineral with which the zircon is associated. Changes in zircon prices would influence the level of zircon mine production if the exploitation of mineral sand deposits, particularly those worked for rutile, became uneconomic because of low zircon prices or if marginal deposits became viable because of high zircon prices. However, substantial prices changes for zircon would be necessary to effect such production levels. Production of saleable zircon concentrates is somewhat more sensitive to price changes. Above say $40 per ton, it might be expected that virtually all mine production of zircon will be processed to saleable-grade concentrates. Below say $30 per ton, an increasing proportion of mine production will be stockpiled in the form of "uncleaned" zircon containing garnet, ilmenite, tourmaline and other impurities.

In contrast to supply, zircon demand, particularly for foundry application, is relatively elastic. It is suggested that the growth rate of foundry demand for zircon will be reduced to about 2% p.a. at current price levels and would actually decline above $40 per ton f.o.b. No additional inroads by zircon into foundry requirements supplied by silica sand can be expected unless zircon prices were reduced to the range of $20-25 per ton.

As might be expected, the demand for more-highly processed forms of zircon is less sensitive to changes in the price of zircon concentrates.

In this area, moderate price changes for the raw materials are easily absorbed in the value of the finished product, e.g. zirconia, and consumption of zircon in the ceramic and refractory industries is expected to increase in line with industrial activity, say 4-5% p.a., notwithstanding increases in the price of zircon in the long term. The extreme case is in the production of nuclear-grade zirconium metal, fabricated products of which represent a gross value increase of many times the value of the raw material. It is obvious that the price of zircon concentrates will have little if any bearing on deciding the use of zirconium for nuclear applications.

2. Future Price Trends

Indications are that a sustained upward pressure on zircon prices will develop by the mid-1970's as demand outstrips supply. It is becoming more and more apparent that the zircon market is settling into a two-tier price system where zircon for use in foundries will remain priced at or below present levels, and zircon for use in ceramic, refractory and miscellaneous applications will be priced higher in line with zircon's price quality competitiveness in these fields. Prices of zircon for use in these latter applications are seen increasing to $60 per ton in the 1970's and even higher to the range $60-80 per ton in the 1980's.

IV. CONCLUSIONS.

Known world reserves of zircon associated with rutile are limited and at projected rates of production, such reserves will be virtually exhausted by 1990. Although reserves of zircon contained in ilmenite deposits are more extensive, any worthwhile increase in zircon production from this source will be dependent on large-scale expansion in ilmenite production.

Under current conditions of the cost-price structure the future pattern of supply of and demand for zircon might be expected to be that illustrated in Figure 8 where demand outstrips supply in the mid-1970's, and this imbalance increases progressively through to 1990. In fact, it is suggested that supply and demand will be brought into equilibrium by an upward pressure on prices. Increase prices for both zircon and rutile will increase the output of by-product zircon as ilmenite production is expanded to meet increased demand for titania in the form of beneficiated ilmenite, and as untapped resources e.g. off-shore deposits, are exploited. The projected, high level of demand will be translated into a reduced level of actual consumption by increased selectivity of the use of zircon in foundries, by the increased reclamation of zircon foundry sands, and by the increased use of substitutes for zircon moulding sands. While foundry applications may be expected to continue as the main outlet for zircon, there will be increased emphasis on the use of zircon in more processed form e.g. zirconia and metal.

V. REFERENCES

EILERTSEN, Donald E., 1965 - Zirconium. Mineral Facts and Problems, 1965. U.S. Bureau of Mines Bull. 630.

EMERY, K.O., and L.C. NOAKES, 1968 - Economic Placer Deposits of the Continental Shelf. Technical Bull., Ecafe, Vol. 1, 1968.

GARDNER, D.E., 1965 - Beach sand heavy mineral deposits of Eastern Australia. Bur. Min. Resour. Aust. Bull. 28.

INSTITUTE OF GEOLOGICAL SCIENCES, MINERAL RESOURCES DIVISION, 1969 - Statistical Summary of the Mineral Industry 1962-1967, London H.M.S.O.

KALIX, Z., FRASER, L.M., RAWSON, R.I. 1966 - Australian Mineral Industry Production and Trade 1842-1964. Bur. Min. Resour. Aust. Bull. 81.

MOORE, JOHN A., 1969 - Zirconium. American Metal Market June 16, 1969.

PARKER, JOHN G., 1970 - Zirconium and Hafnium in 1969. Mineral Industry Surveys, U.S. Bur. of Mines.

TAUBER, E., 1964 - Zircon and its use in ceramics. Aust. Natn. Clay Vol. 5., No. 6.

TAUBER, E., 1965 - The milling of zircon concentrates for use as an opacifier in ceramic glazes ibid Vol. 6, No. 9.

TAUBER, E., and O'BRIEN R.J., 1967 - Metallurgical Application of a Zircon Castable. Australian Mining 15 June, 1967.

VON BACKSTROM, J.W., 1969 - Nuclear Reactor Materials in South Africa. Minerals Sci. Engng. 1969.

WARD, J., 1963 - Prospects for Australian Rutile. Australian Mineral Industry Quarterly Review, 16(2).

WARD, J., 1966 - Prospects for Australian Zircon, ibid. 19(1).

WARD, J., 1967 - Australian Ilmenite Industry: Current Position and Future Prospects, ibid. 19(4).

WELCH, B.K., 1964 - The ilmenite deposits of Geographe Bay. Aust. Instit. Min & Metall. Proceedings, No. 211.

WRIGHT, W.J. and ALDER, K.F. 1970 - The requirements for manufacture of nuclear fuel in Australia. A.I.M.M. Annual Conference 1970 Victoria.

YIH, STEPHEN, W.H., 1969 - The special metals. Mining Congress Journal, Feb, 1969.

TABLE 1. AUSTRALIAN ZIRCON PRODUCERS

COMPANY	EQUITY SHAREHOLDING	LOCATION OF SEPARATION PLANTS WET PLANTS	LOCATION OF SEPARATION PLANTS DRY PLANTS	RATED CAPACITY OF DRY PLANT (TONS OF ZIRCON PER ANNUM)	PRODUCTION OF ZIRCON CONCENTRATES IN 1969 (TONS)
Associated Minerals Consolidated Ltd (includes Wyong Minerals Ltd a wholly-owned subsidiary since mid 1967 and Titanium and Zirconium Industries Pty. Ltd (TAZI) formerly a wholly-owned subsidiary of C.R.A. which became a wholly-owned subsidiary of Associated Minerals in March 1969	60% Consolidated Gold Fields (Australia) Ltd (C.G.F.A.) 40% local residual	Two wet plants on east coast of North Stradbroke Island, Qld, Laurieton, N.S.W. Wooyung, N.S.W. Seven Mile Beach, N.S.W. Swan Bay, N.S.W. Lake Munmorah, N.S.W. Tuggerah Lake, N.S.W.	Dunwich North Stradbroke Is., Qld Southport, Qld Hexham, N.S.W. Wyong, N.S.W. to close in June 1970	110,000	106,600
(a) Coastal Rutile Ltd	public-controlled company	Noosa area, Qld	Meeandah, Brisbane	8,500	
Consolidated Rutile Ltd	51% Cudgen R-Z Ltd 49% local residual	North Stradbroke Is.,	Meeandah, Brisbane	30,000 (to be increased to 62,000 t.p.a. by the end of 1970	23,000
Cudgen R-Z Ltd	63% Mineral Securities Aust. Pty Ltd. 37% local residual	Woodburn, N.S.W. Iluka, N.S.W. Brooms Head, South of Maclean, N.S.W.	Kingscliff, N.S.W.	40,000	46,500
Mineral Deposits Ltd	85% National Lead Company 15% local residual	Forster, N.S.W. Crescent Head, N.S.W. Myall River, N.S.W. Woolgoola, N.S.W. Tuncurry, N.S.W.	Crescent Head, N.S.W. Hawks Nest/near Port Stephens) N.S.W.	30,000 45,000 Dry plant of 25,000 t.p.a. to be commissioned at Pinkenba, Brisbane in September 1971. Crescent Head plant to be phased out over next 3-4 years.	51,400
Naracoopa Rutile Ltd	68.4% Costigan Mining Australia Pty Ltd, a wholly-owned subsidiary of Ontario based, New Mount Costigan Mines Ltd 31.6% Kenneth McMahon and Partners	East Coast, King Is., Tas.	East Coast, King Is., Tas.	10,000	6,100
(b) N.S.W. Rutile Mining Co. Pty Ltd	subsidiary of Murphyores Holdings Ltd, public-controlled company	Tugun, Qld, Cudgen, N.S.W. Yamba, N.S.W.	Cudgen, N.S.W.	35,000	23,400
(c) Northern Rivers Rutile Pty Ltd	privately-owned company	Budgewoi, N.S.W.	Kincumber, N.S.W.	12,000	

COMPANY	EQUITY SHAREHOLDING	LOCATION OF SEPARATION PLANTS: WET PLANTS	LOCATION OF SEPARATION PLANTS: DRY PLANTS	RATED CAPACITY OF DRY PLANT (TONS OF ZIRCON PER ANNUM)	PRODUCTION OF ZIRCON CONCENTRATES IN 1969 (TONS)
Queensland Titanium Mines Pty Ltd	50% National Lead Company 50% Titanium Metals Corporation of America	Inskip Peninsula, Qld	Rainbow Beach (Inskip Peninsula), Qld	17,000	11,400
Rutile and Zircon Mines (Newcastle) Ltd	50% Peko-Wallsend Investments Ltd 50% Coffs Harbour Rutile N.L. which is 94.5% owned by Kathleen Investments (Aust.) Ltd.	Tomago area (north of Hunter River), N.S.W.	Salamander Bay-Crowdy Head (near Port Stephens), N.S.W.	50,000	40,200
Signal-Dillingham Corporation	joint overseas control	Evans Head, N.S.W.	Woodburn, N.S.W.	19,000	500
Sub-Total				361,500	309,100
Cable (1956) Ltd Ilmenite Minerals Pty Ltd	100% Kathleen Investments (Aust) Ltd	Strahan, W.A. Wonnerup, W.A.	Bunbury, W.A.	17,000	10,000
(d) Murphyores Inc. Ltd	subsidiary of Murphyores Holdings Ltd	Rods Peninsula (south of Gladstone) Qld	Barney Point, Gladstone, Qld	30,000	4,900
Western Minerals Sands Pty Ltd	66 2/3% Australian Titan Products Pty Ltd 33 1/3% Westralian Sands Ltd	North Capel, W.A.	North Capel, W.A.	Nil	
Western Titanium N.L.	85% Consolidated Gold Fields (Australia) Ltd 24% local residual.	South Capel, W.A.	South Capel, W.A.	22,000	23,200
Westralian Sands Ltd	public controlled company	Yoganup, W.A.	Capel, W.A	20,000	16,900
Sub-Total				98,000	57,000
TOTAL				450,500	366,100

(a) to commission plant in mid-1970.
(b) plant sold to Signal-Dillingham Corp.
(c) ceased operations in 1969.
(d) operations suspended indefinitely.

TABLE 2. PROJECTED AUSTRALIAN PRODUCTION OF ZIRCON 1970-1985 ('000 tons)

Company	Projected Levels of Production of Zircon Concentrates (tons)																Planned Increases in Capacity
	1970	71	72	73	74	75	76	77	78	79	1980	81	82	83	84	1985	
Associated Minerals Consolidated Ltd	108	110	110	110	110	110	110	110	110	100	100	90	90	90	90	90	No plan for increase in production capacity (110,000 t.p.a.) planned in foreseeable future.
Mineral Deposits Ltd	50	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
Queensland Titanium Mines Pty Ltd	15	15	20	20	20	20	20	20	20	20	20	20	20	20	20	20	Plan to increase capacity from 17,000 to 20,000 tons.
Rutile and Zircon Mines	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	
Consolidated Rutile Cudgen R-Z Ltd	60	80	90	90	90	90	90	90	80	70	60	-	-	-	-	-	Capacity of Consolidated Rutile Ltd at Meeandah to be increased from current 30,000 t.p.a. to 60,000 t.p.a. in Dec. 1970.
N.S.W. Rutile Mining Co. P/L	20	20	20	20	20	-	-	-	-	-	-	-	-	-	-	-	
Naracoopa Rutile Ltd	6	6	8	8	8	8	8	8	8	2	-	-	-	-	-	-	No increase in production capacity of dry plant (10,000 t.p.a.) is planned.
Coastal Rutile Ltd	3	8	8	12	12	12	12	12	12	12	12	12	12	12	12	12	
Signal-Dillingham	8	10	12	16	18	18	18	18	18	15	10	-	-	-	-	-	
SUB-TOTAL	32	359	378	386	388	368	368	368	358	332	317	242	232	232	232	220	
Western Titanium N.L.	22	22	22	30	30	30	30	30	30	30	30	30	30	30	30	30	Capacity to be increased from current (22,000 t.p.a.) level to 30,000-35,000 t.p.a. in 1973.
Westralian Sands Ltd	20	22	25	25	25	25	25	25	25	25	25	20	15	-	-	-	Capacity to be increased to 25,000 t.p.a. in 1971.
Western Mineral Sands Pty Ltd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cable (1956) Ltd Ilmenite Minerals Pty Ltd	13	17	17	17	17	17	17	17	17	17	17	17	17	-	-	-	Production capacity to be increased from 17,000 to 23,000 tons per annum in 1973 if additional reserves proved.
Murphyores Inc. Ltd	-	-	-	-	20	30	30	30	30	30	30	30	30	30	30	30	Production at Gladstone dependent on development of Fraser Is.-Curtis deposits as feed for upgrading ilmenite.
SUB-TOTAL	55	61	64	72	92	102	102	102	102	102	102	102	92	60	60	60	
TOTAL	375	420	442	458	480	470	470	470	460	434	419	344	324	292	292	280	

TABLE 3. AUSTRALIAN RESERVES OF ZIRCON

Company	Location of Reserves	Recoverable zircon ('000s tons) measured	indicated	inferred	Average grade	Cut-off grade	Sub-marginal reserves
Associated Minerals Consolidated Ltd	From Wyong (NSW) in south to Gympie (Qld) in north	1,670	details not available		0.37% rutile	0.15% rutile	a reduction of 0.1% rutile cut-of^ would increase zircon reserves by 150,000 tons.
Coastal Rutile Ltd	From north of Noosa River to entrance of Tin Can Bay, Qld.	55 80 (in areas under option)	18	30	measured reserves average 2.1% heavy mineral H.M. contains 17% rutile 21% zircon	0.15% rutile	no details available
Consolidated Rutile Ltd.	high-dunal area, North Stradbroke Is., Qld	547	-	-	2.5% H.M. (o.5% rutile)	0.3% rutile	no details available
Cudgen R-Z Ltd	Murwillumbah, Mullumbimby, Ballina, Woodburn, Maclean, Grafton, Coffs Harbour, Bellingen, Port Macquarie, Taree, Bulahdelah, Taree and Dungog Mining Division in New South Wales, and Double Island Point, Qld	642	-	-	3.7% H.M. (0.8% rutile)	0.3% rutile	no details available
Mineral Deposits Ltd	In vicinity of Hawks Nest, N.S.W., Crescent Head, N.S.W Brisbane, Qld. includes reserves on Moreton and Bribie Islands Central Queensland (coastal area) includes deposits in Gladstone-Rockhampton area.	549	586	95	0.49% rutile 0.24% rutile 0.15% rutile	0.15% rutile	no details available
Naracoopa Rutile Ltd	Naracoopa King Is., Tas Cowper Point	45 25	- -	- -	11.7% H.M. (10.5% zircon) 3.2% H.M. (7.6% zircon)	1.5% H.M. (1.5% rutile)	no details available
N.S.W. Rutile Mining Co Pty Ltd	(a) Tugun, Qld, Cudgen and Yamba, N.S.W.	80	-	-	1.0% H.M. (0.3% rutile)	0.2% rutile	no details available
Queensland Titanium Mines	Double Island Point, Qld Fraser	400 (mostly in leases under application)	-	-	0.2% rutile	0.10% rutile	not determined
Rutile and Zircon Mines (Newcastle) Ltd	In New South Wales in Hunter River - Port Stephens - Manning River areas	551	346	-	1.4% H.M. 0.5% rutile)	0.15% rutile	not determined

Company	Location of Reserves	Recoverable zircon ('000s tons) measured	indicated	inferred	Average grade	Cut-off grade	Sub-marginal reserves
Signal-Dillingham Corporation.	In vicinity of Evans Head, N.S.W.	190	-	-	1.0% H.M. Z - 31% R - 29%	0.5% H.M. (0.15% rutile)	not determined
	(a) leases being acquired by Signal-Dillingham Corp.						
Sub-Total		4,834	948	125			
Cable (1956) Ltd Ilmenite Minerals Pty Ltd	Capel - Wonnerup area, W.A.	200	-	-	8-10% H.M.	5-7% ilmenite	Deposit north of Perth containing approximately 400,000 tons of zircon currently being tested. Could represent large, low-grade deposit.
Murphyores Inc. Ltd	Richards Point area, south of Gladstone, Qld Curtis Island, Qld	- -	200 -	- -	not available 2% H.M.	not available not available	not determined, drilling on Curtis Island indicates 8.6 million tons of ilmenite, 1.5 million tons of zircon and 200,000 tons of rutile in deposits averaging about 1.5% heavy mineral.
Western Mineral Sands Pty Ltd	North Capel, W.A.	120	-	-	20% H.M. Z-4% of H.M.)	4% H.M.	not determined
Western Titanium N.L.	Capel-Bunbury area, W.A.	560	-	250	15% H.M. (Z-5-6% H.M.)	4-5% H.M.	not determined
Westralian Sands Ltd	Yoganup-Capel area, W.A.	300	-	-	18-20% H.M. (Z-10% H.M.)	10% H.M.	not determined
Sub-Total		1,180	200	250			
TOTAL		6,014	1,148	375			

TABLE 4. ESTIMATED WORLD RESERVES OF ZIRCONIUM MINERALS, BY COUNTRY

Type or Reserve	Country and area	Estimated Reserves (Measured and indicated) (million of tons)
Not dependent on production of ilmenite	Australia	
	East Coast	5.8
	Brazil	
	Minas Gerais	1.5
	Sierra Leone	
	Gbangbama	0.6
	Sub-Total	7.9
Dependent on production of ilmenite	Australia	
	West coast	1.2
	Central Queensland coast	0.2
	United States	
	Florida and Georgia	6.7
	Other	4.6
	India	
	Quilon	1.5
	Other	1.5
	Ceylon	
	Pulmoddai area	0.4
	Other	0.5
	Brazil	
	States of Rio de Janeiro and Bahia	0.8
	Africa	
	Senegal	0.7
	United Arab Republic	1.3
	Republic of South Africa, Natal Coast.	0.2
	South-East Asia	minor
	Sub-Total	19.6
By-product of minerals other than rutile and ilmenite.	Africa	
	Nigeria	0.1
	Transvaal	n.a.
	Uganda	0.1
	Sub-Total	0.2 +
	TOTAL	27.7 +

n.a. not available but believed to be extensive.

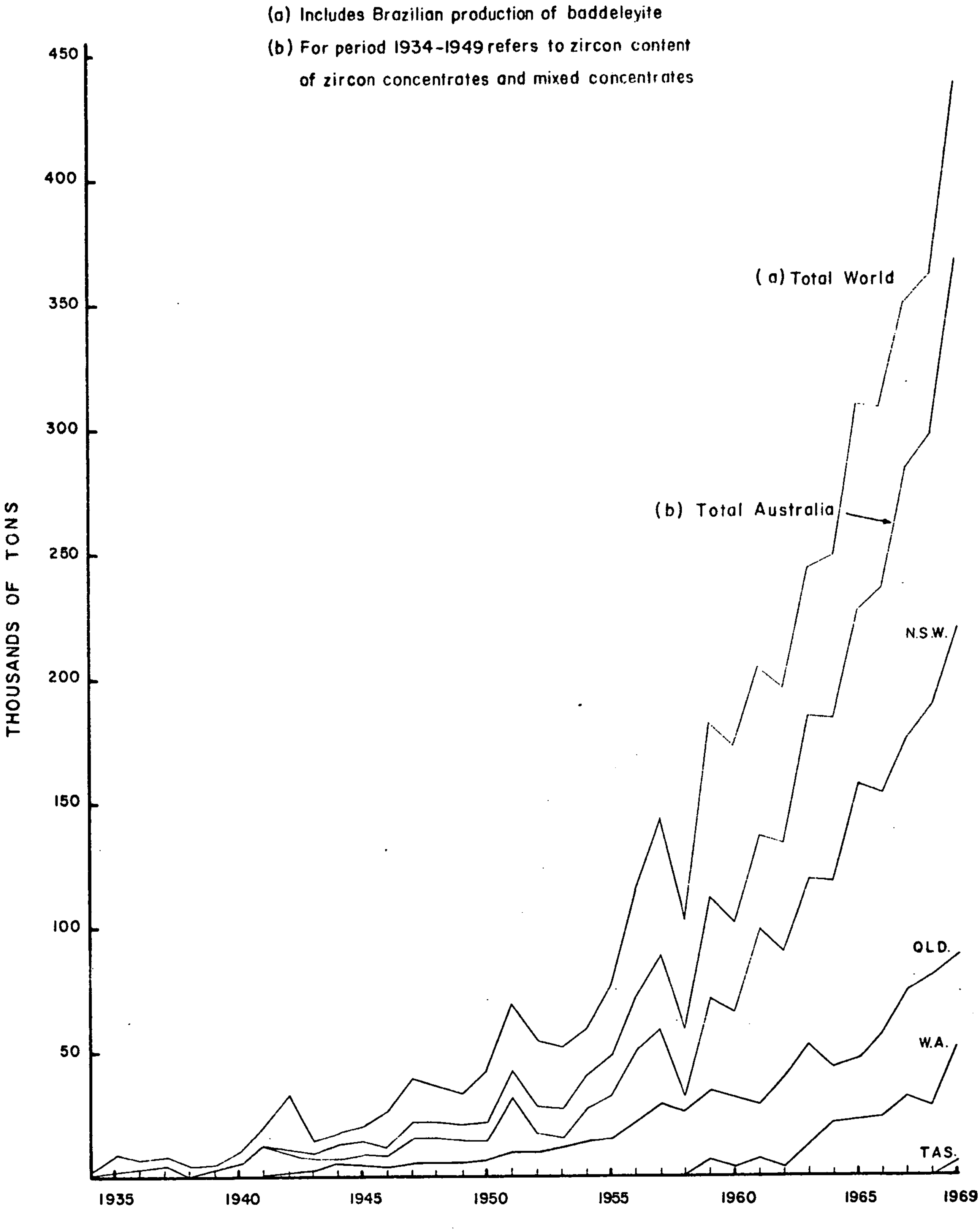

FIG. 1 WORLD PRODUCTION OF ZIRCONIUM MINERALS, 1934-1969

To accompany Record 1970/33 M(M)91

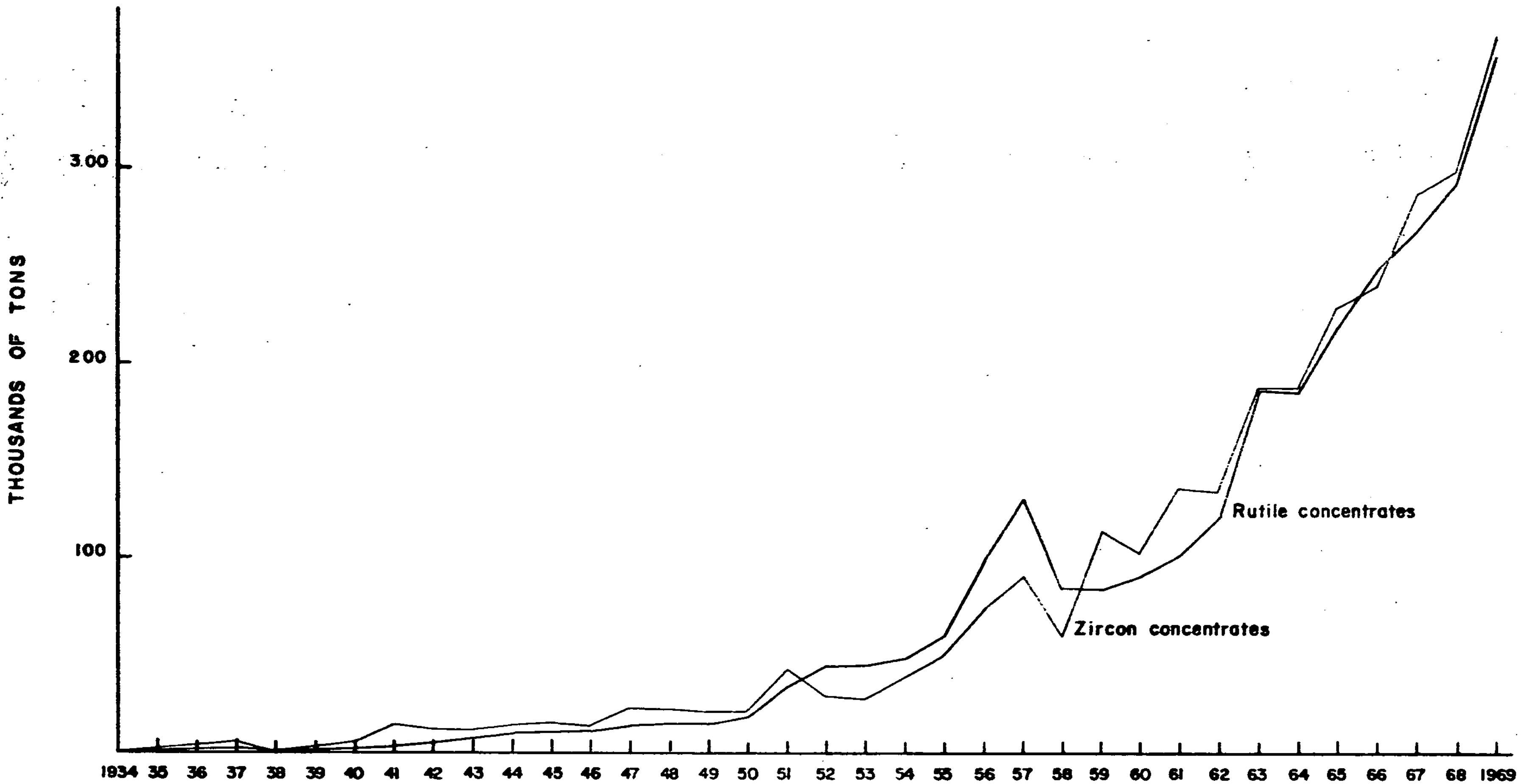

FIG. 2 AUSTRALIAN PRODUCTION OF RUTILE AND ZIRCON CONCENTRATES 1934-1969

To accompany Record 1970/33

M(M)92

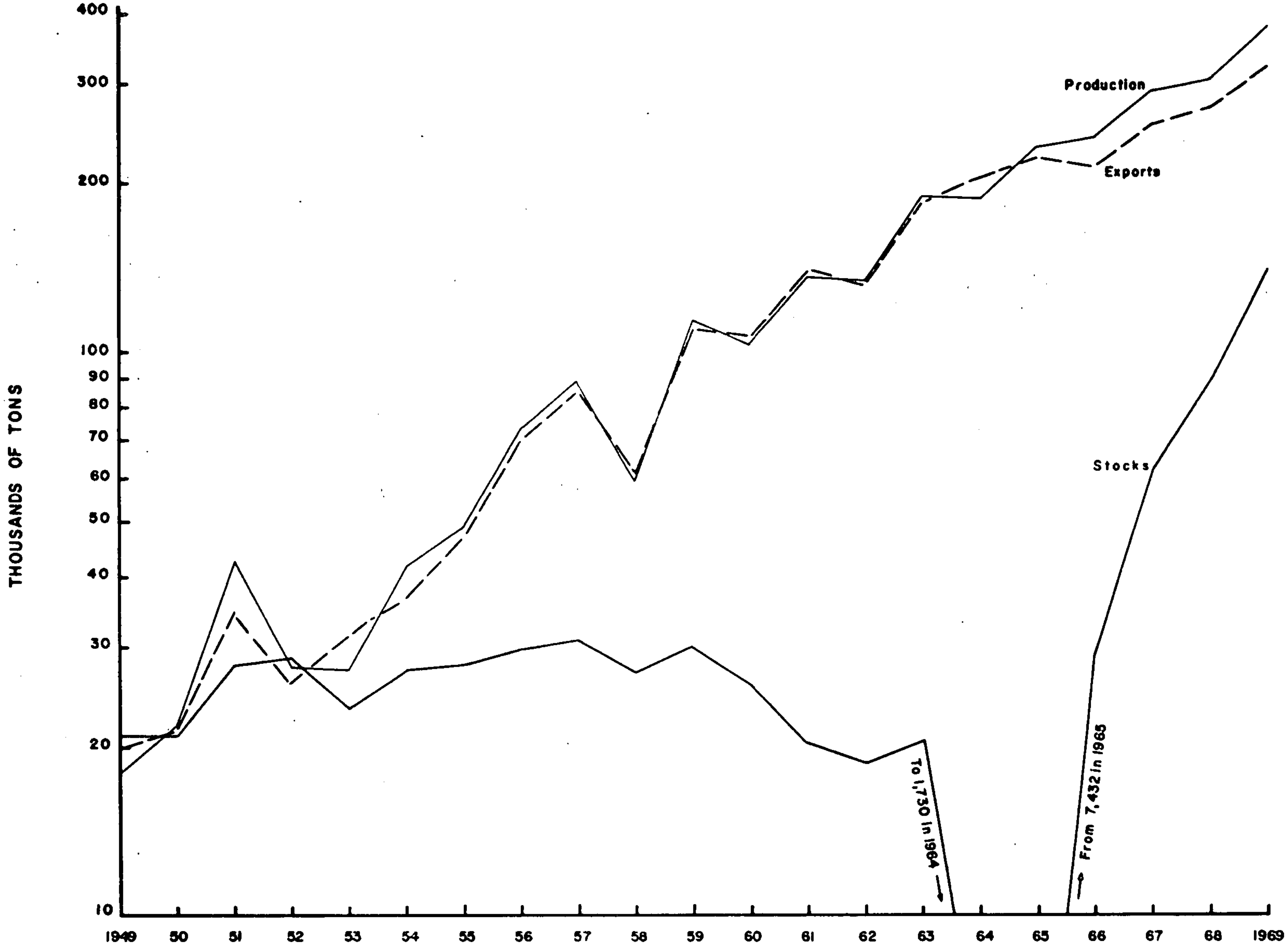

FIG. 3 DOMESTIC PRODUCTION, EXPORTS AND STOCKS OF ZIRCON CONCENTRATES 1949-1969

To accompany Record 1970/33 M(M)93

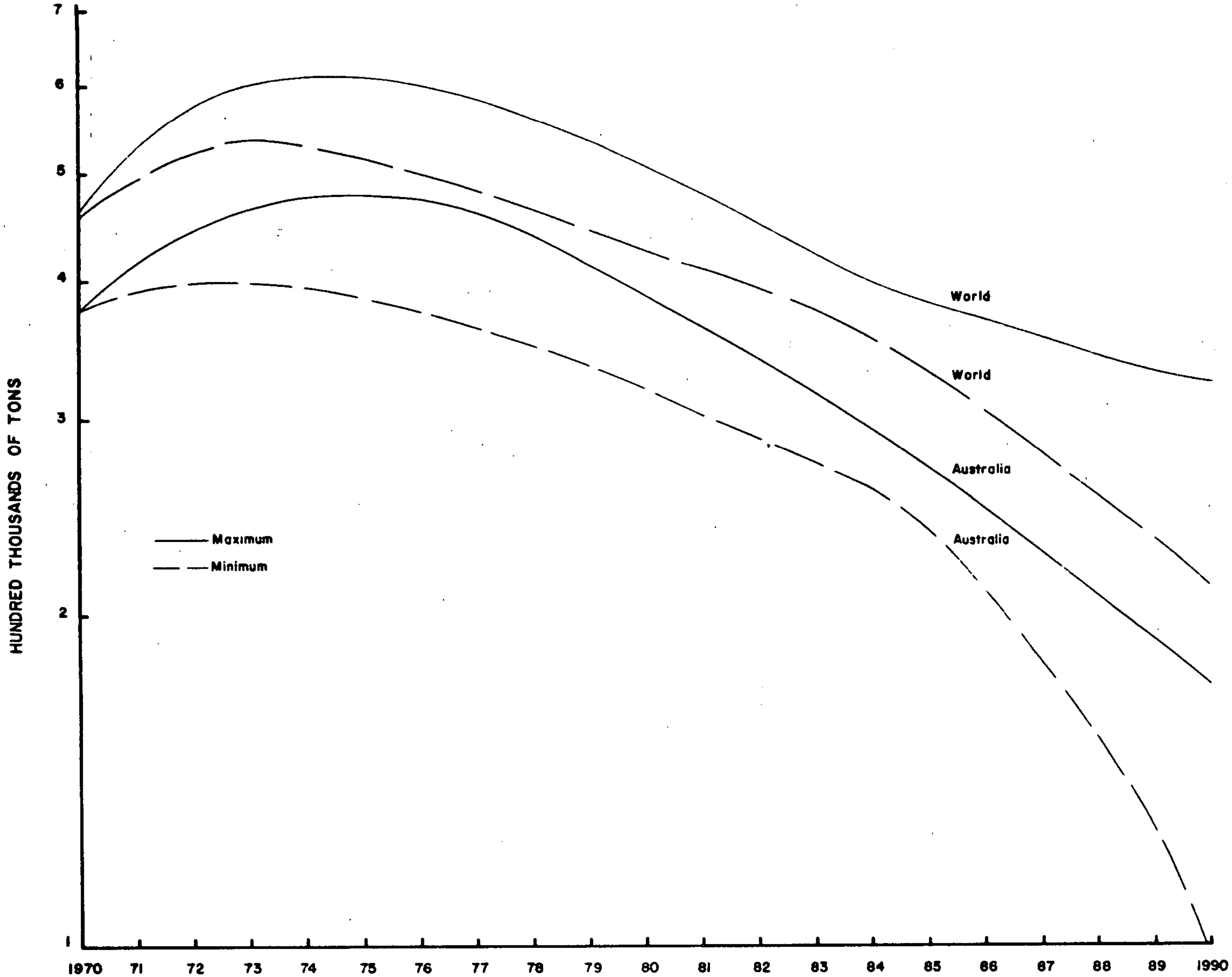

FIG.4 PROJECTED TRENDS IN WORLD PRODUCTION OF ZIRCONIUM MINERALS

To accompany Record 1970/33

M(M)94

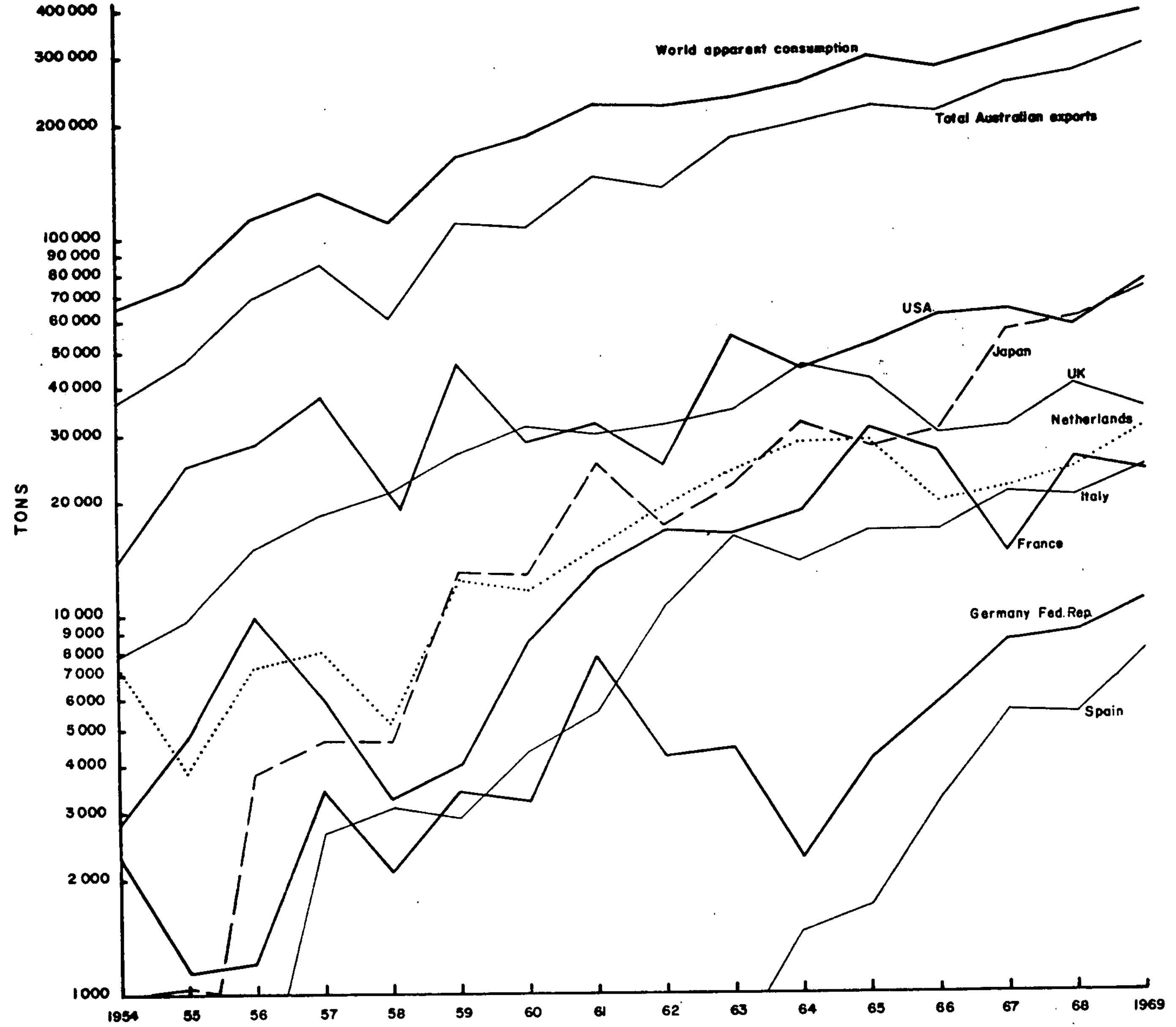

FIG. 5 AUSTRALIAN EXPORTS AND WORLD APPARENT CONSUMPTION OF ZIRCON 1954-1969

To accompany Record 1970/33

M(M)95

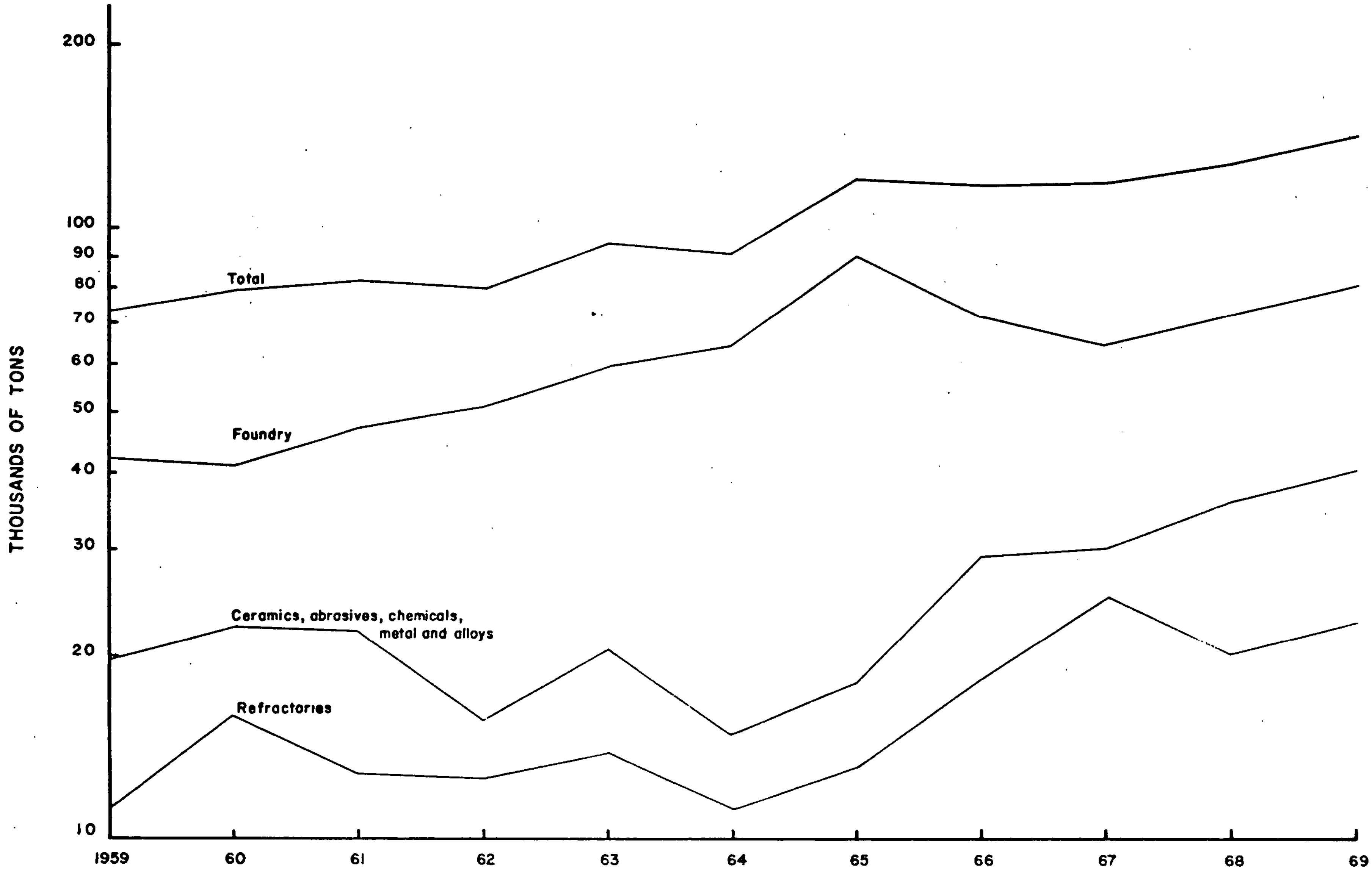

FIG. 6 ESTIMATED UNITED STATES CONSUMPTION OF ZIRCON BY END-USE 1959-1969

To accompany Record 1970/33 M(M)96

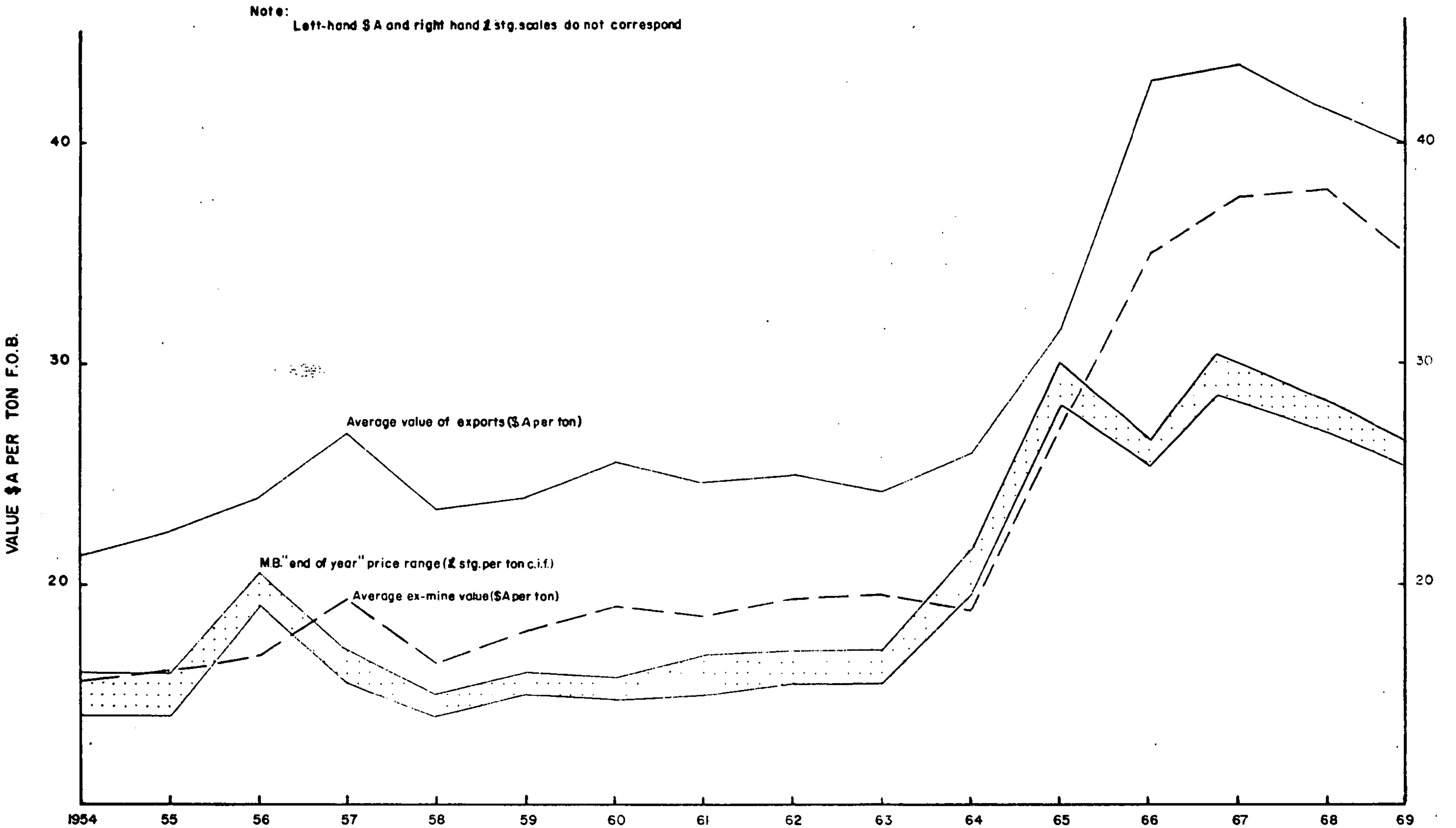

FIG. 7 AVERAGE VALUES OF AUSTRALIAN ZIRCON CONCENTRATES 1954-1969

To accompany Record 1970/33

M(M)97

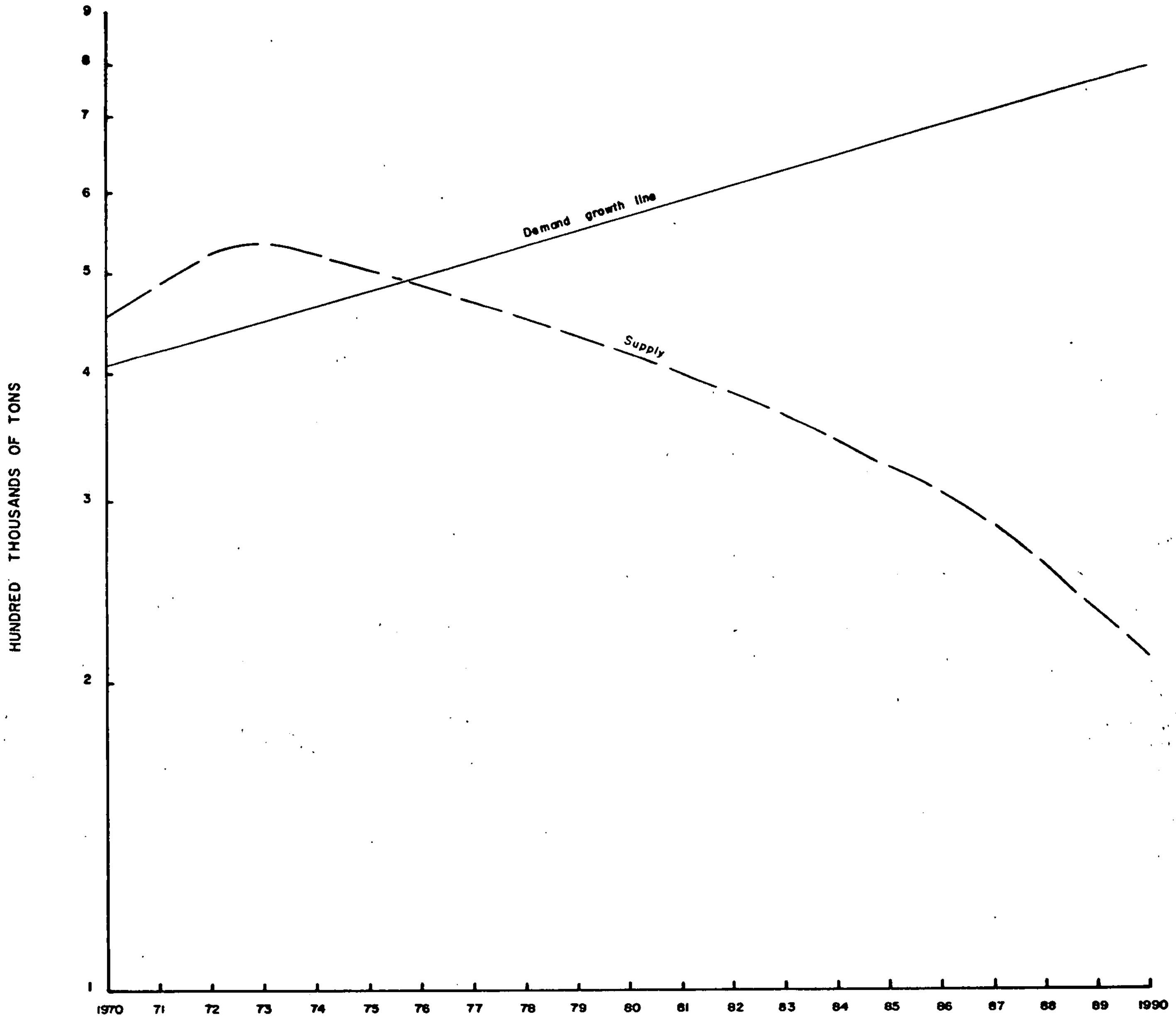

FIG. 8 PROJECTED WORLD SUPPLY / DEMAND POSITION OF ZIRCON 1970-1990

To accompany Record 1970/33

M(M)98

VII APPENDIX

Analysis of selected zircon concentrates

by

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Samples of zircon concentrates selected from areas from King Island in the south to North Stradbroke Island in the north and from Capel in the west, were analysed quantitatively for trace elements.

Trace element determinations were made by atomic absorbtion spectrophtometry following digestion of the sample with hydrofluoric and sulphuric acids. Phosphate was determined colorimetrically by the phosphatovanadomolybdate method. The rare earths were determined gravimetrically by the oxalate method. Titanium was determined colorimetrically after complexing with hydrogen peroxide.

Hafnium determinations were carried out on the powdered sample by X-ray fluorescence using the $HfLB_2$ line to avoid interference from zirconium.

Table 1 details the samples analysed.

Table 2 tabulates the trace element determinations.

Chemical composition of zirconium alloys specified by the United Kingdom Atomic Energy Agency is presented in Table 3.

Table 4 illustrates typical spectrographic analyses of the maximum impurities in nuclear - reactor - grade and commercial - grade zirconium sponge produced by The Wah Chang Corporation.

Table 1. Details of samples analysed

Sample No.	Company	Locality	Grade of concentrate
1	Western Titanium N.L.	Capel, W.A.	foundry
2	Naracoopa Rutile Ltd	King Island, Bass Strait, Tas.	foundry
3	Titanium and Zirconium Industries Pty Ltd	North Stradbroke Is, Qld	high-grade
4	Associated Minerals Consolidated Ltd	South Stradbroke Is, Qld	ceramic
5	"	"	standard
6	"	Big Swan Bay, N.S.W.	ceramic
7	"	"	standard
8	"	Lake Munmorah, N.S.W.	ceramic
9	"	"	standard
10	Rutile and Zircon Mines (Newcastle) Ltd	Tomago, N.S.W.	standard

Table 2. Trace Element Determinations

Sample No.	Ti	Al	P205	Rare Earth	Fe	Na	Ca	Mg	Zn	Cu	Mn	Co	Ni	Cd	Pb	Cr	Hf as % HfO_2
	parts per million																
1	240	540	445	<100	335	20	25	62	6.0	3.8	3.8	2.5	<2	<0.3	<2.5	<2.5	1.52
2	1,080	450	225	<100	185	20	23	19	3.1	3.8	3.8	<2	<2	<0.3	<2.5	<2.5	1.52
3	725	415	260	<100	160	15	20	11	3.4	3.8	3.8	<2	<2	<0.3	<2.5	<2.5	1.55
4	400	145	140	<100	95	18	15	8.3	1.4	2.5	<2	2.5	2.5	<0.3	<2.5	<2.5	1.55
5	740	200	315	<100	140	53	20	16	2.1	2.5	<2	2.5	<2	<0.3	<2.5	<2.5	1.53
6	460	145	160	<100	35	24	13	13	1.9	2.5	<2	<2	<2	<0.3	<2.5	<2.5	1.55
7	635	295	215	<100	50	47	13	19	2.4	2.5	<2	<2	<2	<0.3	<2.5	<2.5	1.57
8	280	145	215	<100	80	23	13	9.3	1.6	2.5	<2	<2	<2	<0.3	<2.5	<2.5	1.58
9	475	200	305	<100	140	42	20	14	2.8	2.5	2.5	<2	2.5	<0.3	<2.5	<2.5	1.57
10	930	200	480	<100	150	37	13	7.5	1.6	3.8	<2	<2	<2	<0.3	<2.5	<2.5	1.55