ZIRCONIUM AND HAFNIUM

By James B. Hedrick

Domestic survey data and tables were prepared by Mahbood Mahdavi, statistical assistant, and the world production table was prepared by Linder Roberts, international data coordinator.

Zirconium is produced from two ore minerals. The principal economic source of zirconium is the zirconium silicate mineral zircon ($ZrSiO_4$). The mineral baddeleyite, a natural form of zirconium oxide or zirconia (ZrO_2), is a distant second to zircon in its economic significance. Zircon is the primary source of all hafnium. Zirconium and hafnium are contained in zircon at a ratio of about 50 to 1. Zircon is a coproduct or byproduct of the mining and processing of heavy-mineral sands for the titanium minerals ilmenite and rutile or tin minerals. The major end uses of the mineral zircon are refractories, foundry sands (including investment casting), and ceramic opacification. Zircon is also marketed as a natural gemstone, and its oxide is processed to produce cubic zirconia, a diamond and colored gemstone simulant. Zirconium metal is used in nuclear fuel cladding, chemical piping in corrosive environments, heat exchangers, and various specialty alloys.

The principal uses of hafnium are in nuclear control rods, nickel-based superalloys, nozzles for plasma arc metal cutting, and high-temperature ceramics.

World production of zirconium mineral concentrates was estimated to have increased slightly in 2000. Data on U.S. production and consumption of zircon concentrates were withheld to avoid disclosing company proprietary data. Domestic production of zircon increased as a heavy-mineral sand mining operation in Virginia continued to improve recovery rates and scale-up production. In 2000, production of milled zircon was essentially unchanged from that of previous years. According to U.S. Census Bureau trade statistics, the United States was a net exporter of zirconium ore and concentrates. U.S. imports of zirconium ore and concentrates increased by 13%, and domestic exports of zirconium ore and concentrates increased by 5% compared with 1999.

With the exception of prices and referenced data, all survey data in this report have been rounded to no more than three significant digits. Totals and percentages were calculated from unrounded numbers.

Production

Data for zirconium and hafnium materials are developed by the U.S. Geological Survey from one voluntary survey of domestic operations. Of the 47 operations surveyed, 25 responded, and 2 were removed because they no longer used the material. Data for zircon concentrates are developed by a

Zirconium and Hafnium in the 20th Century

Just before the turn of the 20th century, zirconium oxide would change the world forever from nights dimly illuminated by candles and oil and gas lamps to the bright glow of incandescent lighting. The incandescent lamp mantle industry was established in 1884 with mantles of zirconium, lanthanum and yttrium oxides. By 1900, the zirconium oxide mantle mixture had been replaced with an improved, brighter oxide mixture of thorium and cerium. That same year, the Nernst lamp came into use which used rods or "glowers" made of 25 percent yttrium oxide and 75 percent zirconium oxide, essentially an yttria stabilized zirconia. In this lamp, it was necessary to heat the glowers with an auxiliary device to about 700° C, at which point it became conductive, and the resistance caused it to glow with a brilliant white incandescence. With the advent of the electric incandescent lamp around 1912, zirconia's use in Nernst glowers declined. Other commercial applications of zirconium oxide in 1900 were in opacification of enamels and enamelware, in paints, and in making x-ray images. The principal use of the zirconium minerals zircon and baddeleyite was in refractory materials. Domestic zircon production at the start of the 20th century was from mines centered around Zirconia, Henderson County, NC. All production was used in the United States.

In 1900, metallic zirconium had no commercial applications, although several uses had been tried or suggested. Ferrozirconium was developed prior to World War I and used as armor plate, bullet-proof metal, and armor-piercing projectiles. In 1930, the pure metal was first used commercially in the United States as a smokeless flashlight (flash powder) in photography, a use patented in Germany 9 years earlier. This use quickly waned with the development of the flash bulb which used only a thin coating of zirconium to ignite lower cost aluminum foil.

In 2000, the United States was a major producer of zircon and zirconium. Zircon was produced at mines in Florida and Virginia and was exported to many countries, the principal destinations being Italy and Mexico, where most of it was used in the opacification of ceramic tile and sanitaryware. To meet demand, zircon was imported from several countries, the principal producing sources being Australia and South Africa. Zirconium metal and alloys were produced in Oregon and Utah.

Zirconium's principal uses in 2000 were in nuclear reactor fuel cladding, heat exchangers, and corrosion resistant piping for chemical plants. Zirconium exports were shipped primarily to Canada, Japan, and the United Kingdom. The main sources of U.S. imports of zirconium were France, Germany, Japan, and Canada.

second voluntary survey of domestic operations. The two domestic zircon producers, which have three mining and processing operations, responded. Data for nonrespondents were estimated based on prior year levels. Data on domestic production and consumption of zircon concentrates were withheld to avoid disclosing company proprietary data.

Domestic production of milled zircon increased slightly and production of zirconium oxide increased by 34% from their 1999 levels (table 1).

Zircon is normally produced as a byproduct of the mining and processing of heavy-mineral sands containing the titanium minerals ilmenite and rutile. In 2000, U.S. mine producers of zircon were E.I. du Pont de Nemours and Co. (DuPont) and Iluka Resources, Inc. [previously RGC (USA) Mineral Sands, Inc.], a subsidiary of the Australian company Iluka Resources Limited. DuPont produced zircon from its Highland and Maxville heavy-mineral sands deposits near Starke, FL. Iluka produced zircon from its heavy-mineral sand operations at Green Cove Springs, FL, and Stony Creek, VA. U.S. producers of zirconium and hafnium metal were Wah Chang, an Allegheny Technologies company (prior to January 2000 named Oremet-Wah Chang, a subsidiary of Allegheny-Teledyne Corporation), Albany, OR; and Western Zirconium, a subsidiary of Westinghouse Electric Company, Ogden, UT. Primary zirconium chemicals were produced by Wah Chang and Magnesium Elektron Inc., Flemington, NJ. Secondary zirconium chemicals were produced by about 10 companies, and zirconia was produced from zircon sand at plants in Alabama, New Hampshire, New York, Ohio, and Oregon.

Iluka continued to improve production output from that of the previous year at its Old Hickory Mine in Stony Creek, VA. The original zircon production capacity at Stony Creek was 30,000 metric tons per year (t/yr). Phase one of a $100 million expansion announced in 1999 by Iluka Resources Limited will be at the Old Hickory Mine in Virginia, and phase two, at the Green Cove Springs Mine in Florida (Mineral Sands Report, 2000d). The feasibility study for phase one was completed in 2000.

Altair International Inc. announced that it had broken ground on the construction of a pilot plant at its two heavy-mineral sand deposits near Camden, TN. The deposits contain an estimated 490 million tons (Mt) grading 3.6% heavy minerals. The prime contractor for the site clearing and settling pond construction was Hubbs contractors of Camden. MD Mineral Technologies, which had been previously selected to design and engineer the plant, is expected to oversee the plant construction and startup (Altair International Inc., June 22, 2000, Altair announces groundbreaking at Camden, accessed March 13, 2001, at URL http://www.altairint.com/News/2000/2000.html).

Consumption

Approximately 95% of all zirconium consumed is in the form of zircon, zirconium oxide, or other zirconium chemicals. The remainder is consumed as zirconium metal and zirconium-containing alloys.

Zircon, used for facings on foundry molds, increases resistance to metal penetration and gives a uniform finish to castings. Milled or ground zircon is used in refractory paints for coating the surfaces of molds. Zircon in the form of refractory bricks and blocks is used in furnaces and hearths for containing molten metals. Glass tank furnaces use fused cast and bonded alumina-zirconia-silica-base refractories. Baddeleyite is used principally in the manufacture of alumina-zirconia abrasive and in ceramic colors and refractories.

Stabilized zirconium oxide exhibits high light reflectivity and good thermal stability and is primarily used as an opacifier and pigment in glazes and colors for pottery and other ceramic products. Yttria stabilized zirconia (YSZ) is used in the manufacture of oxygen sensors that control combustion in furnaces and automobile engines. YSZ is also used in the manufacture of a diverse array of products including high temperature, high strength structural ceramics, heat- and break-resistant shirt buttons, golf shoe cleats, golf putters, fiber optic connector components, coatings for the hot sections of jet engines, and cubic zirconia, a gemstone simulant for diamonds and colored gemstones.

Because of its low thermal neutron absorption cross section, hafnium-free zirconium is used as cladding for nuclear fuel rods. Commercial grade zirconium, unlike nuclear grade, contains hafnium and is used in the chemical process industries because of its excellent corrosion resistance.

Hafnium is used in nuclear control rods because of its high thermal neutron absorption cross section. However, the largest end use for hafnium metal is as an alloy addition in superalloys.

Prices

In 2000, the increased demand for zircon concentrates resulted in an increase in price. The average value of imported ore and concentrates increased by 27% to $396 per ton in 2000 from $311 per ton in 1999. Domestic prices of standard- and premium-grade zircon increased as a result of a tightening of supply, especially for premium grades. Published prices for imported grades of zircon were higher than those of 1999. Published prices for zirconium, hafnium, and zirconium oxide products were unchanged or slightly higher (table 2).

Foreign Trade

According to U.S. Census Bureau trade statistics, the United States was a net exporter of zirconium ore and concentrates in 2000. U.S. exports of zirconium ore and concentrates were 72,900 metric tons (t), a 5% increase from that of 1999 (table 3). The United States was a net exporter of zirconium and hafnium metal in 2000. U.S. exports of unwrought zirconium metal, waste, and scrap were 180 t, a 15% increase in tonnage compared with those of 1999. U.S. exports classified as "other zirconium metal, waste, and scrap" were 1,030 t, a 22% increase from the 1999 level.

U.S. imports of zirconium ore and concentrates were 65,200 t, an increase of 7,560 t from those of 1999 (table 4). Australia and South Africa supplied about 94% of the imports of ores and concentrates. Imports of unwrought zirconium metal and waste and scrap amounted to 1,040 t, a 22% increase compared with those of 1999. The leading import sources of unwrought zirconium were, in descending order of quantity, France, Germany, and Japan. Domestic imports of ferrozirconium alloys were 281 t in 2000, a 182% increase from the previous year. Imports originated primarily from Brazil, with a minor quantity from Germany. U.S. imports of unwrought hafnium metal and waste and scrap were 11.1 t, an 18% increase compared with those of 1999.

World Review

Excluding U.S. production, world production of zirconium mineral concentrates in 2000 is estimated to be 760,000 t, a minor increase compared with that of 1999 (table 5). Australia and South Africa supplied about 82% of all production outside the United States. World reserves of zircon are estimated to be 36 Mt of ZrO_2, while identified world resources of zircon were 65 Mt of ZrO_2. During 2000, the zirconium industry continued to be active in the exploration and development of mineral deposits on a global basis, particularly in Australia, Kenya, Mozambique, South Africa, and the United States. Iluka Resouces was the world's largest producer of zircon in 2000, with mines in Australia and the United States. Other major zircon producers in order of decreasing production were Richards Bay Minerals (RBM) of Australia, Namakwa Sands (Pty.) Ltd. of South Africa, DuPont of the United States, and Tiwest Joint Venture of Australia.

Australia.—Australia was one of the two largest producers of zircon concentrates in the world (table 5). In 2000, major producers of zircon concentrates, in order of estimated zircon production, were Iluka Resources (formerly RGC Ltd. and Westralian Sands Ltd.), Tiwest, Consolidated Rutile Ltd. (CRL), and Cable Sands Ltd. (CSL). Australian zircon production for 2000 was as follows: Iluka, 194,000 t; Tiwest, 91,000 t; CRL, 46,000 t; CSL, 30,000 t; and New South Wales producers, 4,000 t (Mineral Sands Report, 2001b). Total Australian production in 2000 was reported to be 353,000 t, a decrease from the 1999 level.

Worldwide production from Australian-based Iluka was 315,000 t of zircon in 2000, a decrease from the 331,000 t in 1999 (Iluka Resources Limited, 2001, p. 9). The company operated eight mines in Australia and two in the United States. Iluka's Australian subsidiary, WA Titanium Minerals, operated six mines in Western Australia, two of which opened in 2000. The company commissioned the Capel North West Mine in January, near Capel, Western Australia. In October, WA Titanium brought online its second operation, the North Mine and Newman concentrator near Eneabba, Western Australia. Other mining operations were the South Mine near Eneabba and the Yoganup, Yoganup extended, and Busselton mines in the southwestern region. Iluka's two east coast mines, in which it has a 43% interest, were operated by CRL on North Stradbroke Island, New South Wales.

Iluka upgraded the ore grade at its Ouyen deposit in northwestern Victoria by 28%. The inferred resource at Ouyen was increased by 1.7 Mt to 7.7 Mt grading 11.4% heavy minerals and containing 40% ilmenite, 15% rutile, and 9% zircon (Iluka Resources Limited, 2000).

Iluka calculated resources for two of its heavy-mineral sands deposits in the Perth Basin of Western Australia. The Red Gully deposit to the north and the Dandalup deposit to the south of Perth displayed resources of 942,000 t of heavy minerals (Iluka Resources Limited, 2000).

Australian Zirconia Ltd., a wholly owned subsidiary of Alkane Exploration Ltd., announced it had produced a 99.3% zirconium oxide and hafnium oxide product from its Dubbo hard-rock zirconium-bearing deposit in New South Wales. DEMA Pty. Ltd. was the feasibility study manager and consultant for the project. The multimineral deposit is located on the Toongi alkaline intrusive that contains hafnium, lanthanides, niobium, tantalum, yttrium, and zirconium in the igneous rock trachyte. Based on a planned 200,000 t/yr sulfuric acid leach process, the plant was expected to produce 3,500 t/yr zirconium oxide (and hafnium oxide), 500 to 1,500 t/yr yttrium-lanthanide concentrate, and 900 t/yr tantalum-niobium pentoxide concentrate (Australian Zirconia Ltd., Dubbo zirconia project, accessed May 8, 2001, at URL http://www.alkane.com.au/zirconia.html).

Basin Minerals Ltd. announced the completion of a prefeasibility study of its Douglas heavy-mineral sands deposit discovered in the Murray Basin in western Victoria. The Douglas deposit covers an area of 5,860 square kilometers and has a resource of 22.4 Mt of heavy minerals. The area contains the Acapulco, Bondi, Bondi East, and Echo strandline deposits containing 11.3 Mt of ilmenite (including leucoxene), 1.26 Mt of rutile, and 1.62 Mt of zircon. The project has a projected startup date for 2003 (Basin Minerals, [undated], Mineral sands exploration overview—Douglas project, accessed May 2, 2001, at URL http://www.basinminerals.com.au/projects.html).

Basin Minerals explored five heavy-mineral sands deposits in the Murray Basin area of South Australia, Victoria, and New South Wales. The principal deposits were the Douglas project in Victoria, the Culgoa project in northern Victoria, the Baranald-Swan Hill in New South Wales and Victoria, the Oakville in northern South Australia, and the Pooncarie in western New South Wales. Total resources of the Douglas and Culgoa deposits were 24.4 Mt of heavy mineral concentrates contained in 393 Mt of ore grading 6.2% heavy minerals (Basin Minerals, [undated], Mineral sands exploration overview—Table 1, accessed May 2, 2001, at URL http://www.basinminerals.com.au/projects.html).

Basin Minerals acquired additional land adjacent to its Douglas deposit in Victoria. The State of Victoria awarded successful bids to Basin Minerals for block 2 in the Murray Basin which includes the former CRL WIM 100 deposit with 860 Mt of ore grading 5.9% heavy minerals (Mineral Sands Report, 2000c).

BeMaX Resouces NL announced the results of its pilot plant at its Ginkgo mineral sands joint venture (MSJV). The MSJV partners are BeMaX (50%), Imperial Mining (Aust) NL (25%), and Probo Mining Pty. Ltd. (25%). Located 120 kilometers (km) north of Mildura, Victoria, the Ginkgo deposit has an inferred resource of 260 Mt grading 2.6% heavy minerals. Initial tests showed product suitable for market including ilmenite, rutile, leucoxene, and zircon (BeMaX Resources NL, April 3, 2000, Update—Ginkgo mineral sands deposit, accessed March, 13, 2001, via URL http://www.bemax.com.au/Announcements00.html).

BeMaX purchased Imperial Mining's 25% share of the MSJV, raising BeMaX's holdings to 75%. Imperial Mining was a wholly owned subsidiary of Imperial One Limited (BeMaX Resources NL, October 10, 2000, Completion of purchase of Imperial Mining (Aust) NL, accessed March 13, 2001, via URL http://www.bemax.com.au/Announcements00.html).

BeMaX released information on a heavy mineral strandline discovery that straddles BeMaX's BIP joint-venture property and the property of Iluka Resouces in the Murray Basin. The adjacent Snapper (BeMaX) and Trelega (Iluka) deposits straddle the mining exploration claims at the southwest edge of the BIP joint venture EL5474 property in Victoria (BeMaX Resources NL, October 10, 2000, Mineral Sands discovery straddles boundary of BeMaX's and Iluka's properties, accessed

March 13, 2001, via URL http://www.bemax.com.au/Announcements00.html).

Mineral Deposits Limited (MDL) stated that it would restart its Viney Creek dredge mine in New South Wales in 2001 because of increased demand for heavy minerals and a weak Australian dollar against the U.S. dollar. The 2,500-ton-per-hour dredge was placed on standby in April 1999 because of weak demand for rutile and zircon. The dredge will be refurbished in the last quarter of 2000. MDL's Hawks Nest dry mill continued to operate with feed from its smaller dredge operation at Fullerton, New South Wales (Mineral Sands Report, 2000e).

Tiwest, an Australian collaboration of U.S.-based Kerr McGee Chemical's LLC subsidiary KMCC Western Australia Pty. Ltd. and Australian-based Ticor Resources Pty. Ltd., produced zircon from its Cooljarloo Mine in Western Australia. In 2000, Tiwest processed 918,000 t of heavy-mineral concentrates to produce 91,000 t of zircon, compared with 548,498 t of heavy-mineral concentrates and 60,188 t of zircon produced in 1999 (Minerals Sands Report, 2001c). The large increase in production was the result of the Cooljarloo Mine upgrade project in 2000. The capacity of heavy-mineral concentrates was increased to 675,000 t/yr from 535,000 t/yr, a 20% gain. Tiwest's expansion cost was 20 million Australian dollars ($A) and was designed and implemented by contractor HBH Consultants (The Institution of Engineers, Australia, 2001, Australian engineering awards 2000—Cooljarloo mine upgrade project for the Tiwest joint venture, accessed March 22, 2001, at URL http://www.ieaust.org.au/events/aeea_entrants/aeea_entrantdetails8.html).

RZM Pty. Ltd. purchased Western Metals Limited's 30% stake in the Wemen heavy-mineral sands project in the Murray Basin, Victoria, for $A5 million. Following the buyout, RZM entered into a 50-50 joint venture with the Australian company Sons of Gwalia for its Murray Basin mineral resource tenements and freehold land and a 50% share of RZM's heavy-mineral sands processing equipment and operations at Tomago, New South Wales. Production from the deposit is scheduled for 2001. Wemen is forecast to produce 10,000 t/yr of zircon over the mine's 6-year life (Industrial Minerals, 2000a).

Brazil.—Millennium Inorgânica Chemicals do Brazil S/A announced it would invest $31 million to upgrade its heavy-mineral sands output at its Mataraca Mine at Guaju, Paraiba State. The installation of a new dredging operation is expected to improve recoveries and lower overall operating costs. The upgrade was expected to be completed by yearend 2001 (Industrial Minerals, 2000f). In 1999, the mine produced about 110,000 t of ilmenite, 2,000 t of rutile, and 16,000 t of zircon (Titanium Minerals Outlook, 2000b). Millennium Inorgânica Chemicals do Brasil S/A produced 61.5% of the zircon concentrate mined in Brazil in 1999. Total Brazilian production of zircon in 1999, the latest available preliminary data, was 29,448 t (Esteves dos Reis, 2001).

Other zircon producers in Brazil are operated by Industrias Nucleares do Brasil S/A (INB), a wholly owned subsidiary of Comissa Nacional de Energia Nuclear. INB produces up to 9,800 t/yr of zircon from its mines in Buena and Delta Paraíba in Rio de Janeiro, Cumuruxatiba in Joacema, and Alcobaça in Bahia.

China.—Production of zircon is estimated to be 20,000 t or less in 1999, which were the latest available data. China was a net importer of zirconium materials in 1999, importing 131,000 t with 73% as zircon concentrates, 18% as bagged zircon or flour, 8% as opacifiers, and 1% other. The principal market for zircon in China is ceramics with an estimated 60% share of the market. Milling capacity is estimated to be 74,000 t/yr and is located mainly in Guangzhou Province, the center of China's ceramic industry. Nanhai is the largest producer of zircon flour with a capacity of 15,000 t/yr out of an estimated 50,000 t/yr capacity. The principal producers of opacifiers are Atofina Chemicals, Inc., and China Glaze Co. Ltd. Total opacifier capacity is estimated to be 24,000 t/yr (Mineral Sands Report, 2000a).

CRL announced the sale of its Chinese-based milling plant, Changzhou Dongao Zirconium Products Ltd., to Johnson Matthey plc in November. The mill has a capacity of 5,000 t/yr. Johnson Matthey plans to upgrade the facility, raise capacity, and install equipment for tile products (Mineral Sands Report, 2000b)

Deqing Biochemistry General Company (DBGC) announced it was producing zirconium chemicals, including zirconium oxychloride, carbonate, sulfate, acetate, and dioxide, from its plant in Deqing, Zhejiang Province. Capacities for DBGC's zirconium products were 750 t/yr for zirconium oxychloride, 300 t/yr for zirconium carbonate, and 300 t/yr for zirconium sulfate. An expansion in 2001 is expected to increase DBGC's zirconium compound capacity to 15,000 t/yr (Jiang Dongming, Deqing Biochemistry General Corporation, written commun., 2001).

India.—Indian Rare Earths Ltd. (IRE) was the eighth largest producer of zircon in the world from its mine at Chavara. IRE produced 22,000 t of zircon in 2000 (Mineral Sands Report, 2001c).

MDL and Iscor Ltd. have signed a memorandum of understanding to form an alliance to develop two heavy-mineral sands deposits in Tamil Nadu State. The Tamil Nadu deposits at Kudiraimozhi and Navaladi-Sattankulam contain 1 billion metric tons of ore grading 6.2% ilmenite, 0.4% rutile, and 0.7% zircon (Mineral Deposits Limited, November 1, 2000, Announcements—Indian mineral sands project, accessed June 14, 2001, via URL http://www.mineraldeposits.com.au/Announcements2000.html).

Kerala Minerals and Metals Ltd. (KMML) is planning an expansion of its operations at Chavara. KMML has reserves of 18 Mt grading up to 50% heavy minerals. The heavy minerals contain 65% to 75% ilmenite, 5% to 7% rutile, and 4% to 8% zircon (Titanium Minerals Outlook, 2000a).

Kenya.—Tiomin Resources Inc. of Toronto, Canada, raised 5 million Canadian dollars (Can$) through the private offering of warrants for investments in its Kwale heavy-mineral sands deposit. The cash was expected to be used to acquire surface mining rights at its Kwale deposit and to finalize detailed engineering plans for the heavy-mineral sands mine (Mineral Sands Report, 2000g). The Kwale deposit is divided into three economic zones of Pliocene age: the north, the central, and the south dunes. Zircon and other heavy minerals are contained in the Magarini Formation sands, which form a belt of low hills believed to be aeolian in origin. Resources of the Kwale deposit are 200 Mt of ore containing 0.6 Mt of zircon (Tiomin Resources Inc., [undated], Kwale—Rutilite, ilmenite, and zircon, accessed May 16, 2001, via URL http://www.tiomin.com/s/Properties.asp?PropertyInfoID=316&PropertyMapID=1034).

Based on the results of a feasibility study by LTA Process

Engineering Pty. Ltd. of South Africa and Ausenco of Australia, Tiomin planned to start construction at Kwale in 2001. During its first 6 years, the mine is expected to produce 37,000 t/yr of zircon. Kwale has a mine life of 14 years (Industrial Minerals, 2000e).

Mozambique.—Kenmare Resources plc of Dublin, Ireland, bought the heavy-mineral sands dry separation plant from BHP Limited's Beenup Mine in Western Australia, which closed in 1999 after being in operation less than a year (Industrial Minerals, 2000d). The 650,000 t/yr plant was purchased for $4.7 million and is expected to be installed at the Moma titanium minerals project in Mozambique (Kenmare Resources plc, 2000a).

Kenmare had previously purchased BHP's wet concentrator in January for $1.4 million (Industrial Minerals, 2000c). The aquisition of both plants from the Beenup minesands project is expected to save Kenmare in excess of $60 million in capital expenditures. The Moma titanium project is scheduled to begin production in late 2002 (Kenmare Resources plc, 2000b)

South Africa.—Iscor Ltd. announced it would begin development of its Hillendale Mine in Kwazulu Natal Province in the second quarter of 2001. The initial production capacity of the mine will be 50,000 t/yr of zircon but will increase to 100,000 t/yr by 2003. Other heavy mineral capacities, at full production, are 550,000 t/yr for ilmenite, 40,000 t/yr for rutile, and 10,000 t/yr for leucoxene. Reserves at the Hillendale deposit are 73 Mt grading 5.6% valuable heavy minerals, excluding magnetite (Iscor Ltd., [undated], Heavy minerals—Hillendale, accessed April 22, 2001, via URL http://www.iscor.com/mainframe.asp?imgname=01). Construction of the Hillendale mine and wet concentrator plant began in April at a cost of $137 million. Construction also began on a central mineral separation plant at Empangeni, 20 km from the mine site. The separation plant was expected to come onstream in the third quarter (Industrial Minerals, 2000b).

Ticor Ltd. announced in October that it has begun a review of Iscor's heavy-mineral sands deposits in South Africa. Ticor is interested in acquiring a 50% share of the project, which has reserves of 16 Mt of heavy minerals. The project consists of three deposits: the Hillendale, the Fairbreeze, and the Gravelotte. The Hillendale is scheduled to be the first mine developed. The combined mine life of the three deposits is at least 20 years (Mineral Sands Report, 2000f).

Foskor Ltd. commissioned a third zircon smelting furnace for the production of zirconia with a capacity of 1,500 t/yr. Total zirconia capacity of the three operations is 5,000 t/yr. In addition to producing synthetic zirconia from zircon, Foskor produced an estimated 2,000 to 3,000 t of baddeleyite (natural zirconia) from its Palabora Mine at Phalaborwa in 1998, which were the latest available data. The company ceased production of baddeleyite in June 1999 as a result of declining ore grades (Industrial Minerals, 2000g).

Namakwa Sands, a wholly owned subsidiary of Anglo American plc, increased its heavy-mineral sands production as a result of the completion of its phase two expansion. Construction of the project, which was funded at 1.2 billion rand (R) in 1997, was completed in 1999. Zircon was produced from its mine at Brand-se-Baai. Zircon concentrate produced from its dry mill at Koekenaap increased to 106,800 t in 2000 from 91,900 t in 1999 (Mineral Sands Report, 2001a). The phase two expansion increased ore capacity to 12 million metric tons per year (Mt/yr) from 4 Mt/yr. Zircon capacity increased to 133,000 t/yr with a mine life of 35 years.

Amagamet Canada, a division of Premetalco Inc., was the North American sales agent for Namakwa Sands of South Africa. Amagamet reported the purity of the Namakwa South Africa zircon to be 66% minimum, ($ZrO_2 + HfO_2$), 0.06% maximum (Fe_2O_3), and 0.12% maximum (TiO_2) (Amagamet Canada, [undated], Zircon, accessed June 14, 2001, at URL http://www.amalgamet.com/busmizi.htm).

Palabora Mining Co. Ltd. continued to produce baddeleyite from its open pit mine. Open pit mining at the Palabora Mine is scheduled to cease in 2002, and the company will begin recovering ore by underground mining methods. In 1999, the latest available data, Palabora produced 7,486 t of baddeleyite, an 8% decrease from 1998. The decreased production was attributed to a decline in ore grade with increasing depth of the pit. Palabora also produced zirconium sulfate tetrahydrate and milled baddeleyite (Palabora Mining Co. Ltd., 2000, p. 9).

RBM completed construction of a new heavy-mineral sands processing plant. Completed in October 1999, the plant is designated mining plant E (Joseph, 2001).

Outlook

The global demand for zirconium materials was largely in balance in 2000. Growth was expected to increase by 3% per year over the next few years, and new deposits are expected to come online. Prices were forecast to rise in the near term in response to higher energy costs. During the next few years, however, the supply and demand of zircon is expected to be in closer balance as new deposits and plant expansions come online, especially in the United States and Australia. Expansions in supply are expected in Mozambique and South Africa, and further exploration and development efforts are underway in Australia, Canada, India, Kenya, South Africa, Ukraine, and the United States. Production of zircon in the United States was expected to increase during the first decade of the 21st century.

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TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS 1/

(Metric tons)

	1996	1997	1998	1999	2000
Zircon:					
Production:					
Concentrates	W	W	W	W	W
Milled zircon	55,300	55,700	55,700	55,600	56,200
Exports	35,000	44,300	41,000	69,500	72,900
Imports for consumption 2/	92,500	62,400	89,500	57,600	65,200
Consumption, apparent 2/	W	W	W	W	W
Stocks, December 31: Dealers and consumers 3/	34,300	29,300	32,000	24,700	25,100
Zirconium oxide:					
Production 4/	15,000	15,900	17,300	17,100	22,900
Exports 5/	1,480	1,970	1,540	1,680	2,220
Imports for consumption 5/	5,240	4,220	3,900	3,140	3,950
Consumption, apparent	W	W	W	W	W
Stocks, December 31: Producer 4/	822	982	985	W	818 e/

e/ Estimated. W Withheld to avoid disclosing company proprietary data.
1/ Data are rounded to no more than three significant digits.
2/ Includes insignificant amounts of baddeleyite.
3/ Excludes foundries.
4/ Excludes intermediate oxides associated with metal production.
5/ Includes germanium oxides and zirconium dioxides.

TABLE 2
PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1999	2000
Zircon:		
Domestic, standard-grade, bulk, per short ton 1/	$300.00 r/	$340.00
Domestic, 75% minimum quantity zircon and aluminum silicates, bulk, per short ton 1/	267.00	267.00
Domestic, premium-grade zircon, bulk, per short ton 1/	490.00	497.00
Imported sand, ceramic application, f.o.b., bulk, per metric ton 2/	320.00-360.00	345.00-375.00
Imported sand, refractory application, f.o.b., bulk, per metric ton 2/	320.00-360.00	340.00-370.00
Imported sand, foundry sand application, f.o.b., bulk, per metric ton 2/	320.00-360.00	340.00-370.00
Baddeleyite, imported concentrate: 3/		
98% to 99% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	1.23	--
Over 99% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	1.36	0.98
Zirconium oxide: 4/		
Powder, commercial-grade, drums, 2,000-pound minimum, per pound	3.00-6.60	3.00-6.60
Electronic, same basis, per pound	3.66-7.50	3.66-7.50
Insulating, stabilized, 325° F, same basis, per pound	4.00	4.00
Insulating, unstabilized, 325° F, same basis, per pound	4.00	4.00
Dense, stabilized, 300° F, same basis, per pound	4.20	4.20
Zirconium: 5/		
Powder, per pound	75.00-150.00	75.00-150.00
Sponge, per pound	9.00-12.00	9.00-12.00
Sheets, strip, bars, per pound	20.00-50.00	20.00-50.00
Hafnium, sponge, per pound 5/	75.00-95.00	75.00-95.00

r/ Revised. -- Zero.
1/ Domestic average price.
2/ Industrial Minerals (London), no. 387, December 1999, p. 71; no. 399, December 2000, p. 75.
3/ American Vermiculite Corp. baddeleyite price lists.
4/ Chemical Marketing Reporter, v. 256, no. 26, December 27, 1999, p. 25; v. 258, no. 25, December 18, 2000, p. 29.
5/ American Metal Market, v. 107, no. 251, December 31, 1999, p. 6; v. 108, no. 250, December 29, 2000, p. 9.

TABLE 3
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY 1/

Class and country	1999 Quantity (metric tons)	1999 Value (thousands)	2000 Quantity (metric tons)	2000 Value (thousands)
Ore and concentrates:				
Afghanistan	--	--	137	$61
Argentina	652	$412	507	281
Australia	40	23	73	43
Belgium	3,390	1,020	6,190	2,400
Brazil	1,030	542	910	417
Canada	4,240	1,980	6,420	2,920
Chile	221	147	431	257
China	2,960	1,240	872	390
Colombia	2,240	1,440	2,430	1,480
Costa Rica	97	85	--	--
Dominican Republic	254	209	215	162
Ecuador	532	336	957	495
France	2,100	1,210	1,000	657
Germany	4,370	1,730	993	1,210
Guatemala	98	82	78	59
Hong Kong	104	65	60	37
Hungary	15	4	--	--
India	3	3	49	24
Indonesia	117	65	215	108
Ireland	427	306	124	118
Israel	37	54	329	467
Italy	16,900	5,140	23,000	7,600
Japan	993	400	1,510	778
Korea, Republic of	16	12	562	208
Malaysia	59	32	--	--
Mexico	3,920	1,520	14,800	3,710
Netherlands	16,500	4,830	5,130	1,710
Pakistan	670	422	551	333
Panama	--	--	31	6
Philippines	276	164	178	103
Portugal	44	48	36	44
Singapore	19	10	--	--
Sri Lanka	19	13	--	--
Sweden	34	22	34	22
Switzerland	57	32	34	22
Taiwan	187	115	133	106
Thailand	119	67	40	24
United Arab Emirates	176	99	--	--
United Kingdom	5,160	2,570	3,790	7,040
Venezuela	1,350	849	900	543
Vietnam	59	37	179	138
Other	6 r/	10 r/	5	20
Total	69,500	27,300	72,900	34,000
Unwrought zirconium and waste and scrap:				
Canada	11	544	5	190
Japan	56	959	48	1,010
United Kingdom	64	1,020	111	1,550
Other	25 r/	635 r/	16	872
Total	156	3,160	180	3,620

r/ Revised. -- Zero.

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY 1/

Class, harmonized code, and country	1999 Quantity (metric tons)	1999 Value (thousands)	2000 Quantity (metric tons)	2000 Value (thousands)
Zirconium ore and concentrates: (2615.10.0000)				
Australia	23,800	$6,770	31,600	$9,020
Austria	38	13	--	--
Belgium	--	--	20	43
Canada	27	42	50	58
China	--	--	41	136
Germany	107	143	391	510
Italy	3,560	2,540	2,330	1,390
Japan	38	28	553	3,420
Mexico	--	--	240	189
Netherlands	448	403	120	82
Russia	26	66	42	105
South Africa	29,400	7,440	29,400	9,410
Ukraine	80	38	--	--
United Kingdom	102	416	394	1,320
Other	(2/)	8	18	119
Total	57,600	17,900	65,200	25,800
Zirconium, unwrought and waste and scrap: (8109.10.3000, 8109.10.6000, 8109.90.0000)				
Argentina	--	--	21	333
Canada	53	1,990	56	4,030
China	31	510 r/	17	314
France	596	25,100	665	26,600
Germany	118	18,000	179	20,200
Japan	32	479	79	458
Other	29	610	24	664
Total	859	46,700	1,040	52,700
Hafnium, unwrought and waste and scrap: (8112.91.2000)				
Belgium	1	191	--	--
Canada	1	245	1	340
France	6	1,060	8	1,440
Germany	(2/)	238	1	415
Japan	--	--	1	38
Russia	1	30	(2/)	11
Total	9	1,770	11	2,240

r/ Revised. -- Zero.
1/ Data are rounded to no more than three significant digits; may not add to totals shown.
2/ Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 5
ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country	1996	1997	1998	1999	2000 e/
Australia	502,000	424,000	404,000	400,000	353,000 3/
Brazil 4/	15,560	19,252	19,300	19,500	19,500
China e/	15,000	15,000	15,000	15,000	15,000
India e/	19,000	19,000	19,000	19,000	19,000
Indonesia	2,000 e/	105	231	250	250
Malaysia	4,511	4,050	3,057 r/	1,763 r/	2,000
Russia 5/	5,080	5,745	6,293	6,800	6,500
South Africa e/ 6/	260,000	265,300 3/	265,000 r/	219,000 3/	270,000
Sri Lanka	15,863	12,450	8,814 r/	-- r/	--
Thailand	5	--	-- e/	-- r/	--
Ukraine e/	55,000	65,000	65,000	69,000 r/	75,000
United States	W	W	W	W	W
Total	894,000	830,000	806,000 r/	750,000 r/	760,000

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; not included in total. -- Zero.

1/ World totals and estimated data are rounded to no more than three significant digits.

2/ Includes data available through May 11, 2001.

3/ Reported figure.

4/ Includes production of baddeleyite-caldasite.

5/ Production of baddeleyite concentrate averaging 98% ZrO_2.

6/ Includes production of byproduct zircon from titanium sands mining and 15,000 to 20,000 tons per year baddeleyite from Palabora Mining Co. Ltd.