



2010 Minerals Yearbook

ZIRCONIUM AND HAFNIUM

ZIRCONIUM AND HAFNIUM

By Joseph Gambogi

Domestic survey data and tables were prepared by Connie Lopez, statistical assistant, and the world production table was prepared by Lisa D. Miller, international data coordinator.

In 2010, the global economy began to recover, and consumption of zirconium ores and concentrates increased. In response to increased demand, producers revisited expansion and development programs. World production of zirconium mineral concentrates in 2010, excluding U.S. production, was about 1.25 million metric tons (Mt) compared with 1.18 Mt in 2009. The primary source of zirconium was the mineral zircon ($ZrSiO_4$), principally found in heavy-mineral sands. A relatively small quantity of zirconium was derived from the mineral baddeleyite, a natural form of zirconium oxide (ZrO_2) produced from a single source at Kovdor, Russia. In 2010, the leading producers of zircon were Australia and South Africa. Zircon was also the primary source of hafnium, where zirconium and hafnium are contained in zircon at a ratio of about 50 to 1. The leading producers of zirconium and hafnium metal were France, Russia, and the United States.

Because of improving economic conditions, U.S. production of milled zircon increased by 22% compared with that of 2009. The United States remained a net exporter of zirconium ore and concentrates. U.S. exports of zirconium ore and concentrate increased by 20%, and imports of zirconium ore and concentrates increased by 59% compared with those of 2009. 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

Zircon is a coproduct of the mining and processing of heavy-mineral sands for the titanium minerals ilmenite and rutile. In 2010, U.S. producers of zircon were DuPont Titanium Technologies (DuPont) (a subsidiary of E.I. du Pont de Nemours & Co.) and Iluka Resources, Inc. (a wholly owned subsidiary of Australian company Iluka Resources Ltd.). DuPont produced zircon from its heavy-mineral sands operation near Starke, FL. Iluka produced zircon from its heavy-mineral sands operations at Stony Creek, VA.

Data for zirconium and hafnium manufactured materials were developed by the U.S. Geological Survey (USGS) from a voluntary survey of domestic operations. Of the 39 operations surveyed, 15 responded, representing 85% of milled zircon production. Data for nonrespondents were estimated on the basis of prior-year levels adjusted for the effect of economic conditions. Domestic production of milled zircon was 46,900 metric tons (t). Domestic production of zircon concentrate in 2010 increased compared with that of 2009. Insufficient data were available to determine stocks of zircon and zirconium oxide as well as production of zirconium oxide (table 1).

Data for zircon concentrates were developed from a second voluntary survey of domestic mining operations. The two

domestic zircon producers responded. Data on domestic production and consumption of zircon concentrates were withheld to avoid disclosing company proprietary data. In February, Iluka's Stony Creek operations were brought to full production capacity after the company curtailed production in 2009 (Iluka Resources Ltd., 2011, p. 11). U.S. producers of zirconium and hafnium metal were ATI Wah Chang (an Allegheny Technologies, Inc. business unit) in Albany, OR, and Western Zirconium (a subsidiary of Westinghouse Electric Co.) in Ogden, UT.

Milled zircon (flour) was produced from zircon sand by at least five companies, and zirconium chemicals were produced by about a dozen companies. Wah Chang doubled its reactor-grade zirconium sponge production capacity to 3,630 metric tons per year (t/yr) (Allegheny Technologies Inc., 2011, p. 3).

Industrial Minerals Corp. Ltd. (IMC) continued the development of its Coos Bay, OR, heavy-minerals project. In 2010, IMC began construction of the processing plant and continued its permitting process. IMC expected to begin producing chromite, garnet, and zircon in 2012. Estimated proven ore reserves at Coos Bay were 7.9 Mt with a heavy-mineral grade of 21.5% and zircon grade of 0.4% (Industrial Minerals Corp. Ltd., 2010, p. 2, 14).

Consumption

After decreasing significantly in 2009, global consumption of zircon rebounded to close to that in 2008 and was estimated to be 1.3 Mt in 2010 (Roskill Information Services Ltd., 2011, p. 2). Globally, the leading end uses for zircon in 2010 in descending order were ceramics, zirconia and chemicals, refractory, and foundry and casting (Roskill Information Services Ltd., 2011, p. 4). Zircon is also used as a natural gemstone and may be processed to produce cubic zirconia, a synthetic gemstone and diamond simulant.

Zirconium metal is used in corrosive environments, nuclear fuel cladding, and various specialty alloys. The principal uses of hafnium were in high-temperature ceramics, nickel-base superalloys, nozzles for plasma arc metal cutting, and nuclear control rods.

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. Ytria-stabilized zirconia (YSZ) was used in the manufacture of oxygen sensors that control combustion in automobile engines and furnaces. YSZ was also used in the manufacture of a diverse array of products, including cubic zirconia, fiber optic connector components, refractory coatings, and engineering and structural ceramics. YSZ was used in dental applications, such as bridges, crowns, and inlays, because it

has two to three times the fracture resistance and 1.4 times the strength of similar alumina products.

Zircon, used for facings on foundry molds, increases resistance to metal penetration and gives a uniform finish to castings. Milled or ground zircon was used in refractory paints for coating the surfaces of molds. In the form of refractory bricks and blocks, zircon was 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.

Ammonium- and potassium-zirconium carbonates were used as paper and board coatings or insolubilizers for high-quality print performance. Zirconium chemicals were also used in inks to promote adhesion to metals and plastics and as crosslinkers in polymers and printing inks.

Because of its low thermal neutron absorption cross section, hafnium-free zirconium metal is used as cladding for nuclear fuel rod tubes. Hafnium is used in nuclear control rods because of its high thermal neutron absorption cross section. Commercial-grade zirconium, unlike nuclear grade, contains hafnium and is used in the chemical process industries because of its excellent corrosion resistance. Hafnium metal also is used as an alloy addition in superalloys.

Prices

Rising consumption caused prices of zirconium ores and concentrates to increase in 2010. At yearend, the published price range of standard grade, bulk, domestic zircon was \$830 to \$890 per metric ton, up from \$800 to \$860 per ton at yearend 2009 (table 2). The unit value of imports also increased slightly, and the import volume increased by 59%. The average unit value of imported zirconium ore and concentrates (primarily zircon sand) was \$1,200 per ton in 2010.

No published prices were available for zirconium metal. In 2010, the average unit value of imported unwrought powder from France was \$74.30 per kilogram, a 44% increase from that in 2009. The average duty-paid unit value of imported unwrought hafnium including sponge and powder from France was \$453 per kilogram, a 4% decrease from that in 2009.

Foreign Trade

In 2010, Australia (70%) and South Africa (24%) supplied most of the imports of ores and concentrates, and the United States remained a net exporter of zirconium ore and concentrates (table 4). Net exports of zirconium ore and concentrates increased by 3% (table 3). The majority of zirconium metal was exported in wrought products classified as "Other zirconium" in the Harmonized Tariff Schedule (HTS) category 8109.90.0000. Imports of zirconium and hafnium metal in the HTS categories 8109 and 8112 totaled 1,170 t and increased by 19% and 55%, respectively, compared with those of 2009. Imports of germanium and zirconium oxides increased by 4%, with China (38%) the leading import source of oxides. Domestic imports of ferrozirconium alloys increased to 45 t from 0.249 t in 2009. China (98%) was the leading import source of ferrozirconium.

World Review

Excluding U.S. production, world production of zirconium mineral concentrates in 2010 was about 1.25 Mt, a 4% increase compared with revised 2009 data (table 5). Australia and South Africa supplied about 76% of all production outside the United States. The leading zircon producers were Iluka, Richards Bay Minerals, and Exxaro Resources Ltd. China was the leading consuming country. Based on metal oxide content, world reserves of zirconium were estimated to be 56 Mt. After curtailing production in 2009, in 2010 producers were moving to increase production and renew exploration and development efforts.

Australia.—Owing to improved market conditions, Iluka significantly increased its global production of zircon (413,000 t in 2010 compared with 263,000 t in 2009). The increase was largely because of the startup of its operations in the Eucla Basin, South Australia (151,000 t), and its operations in the Murray Basin, Victoria (158,000 t). Production from the Perth Basin, Western Australia, contributed 46,200 t to the global total (Iluka Resources Ltd., 2011, p. 18–22).

In New South Wales, Alkane Resources Ltd. continued to develop its Dubbo Zirconia project. In 2010, the company operated a demonstration pilot plant to validate the process flowsheet, provide data for cost estimates, and generate product for market evaluation. A definitive feasibility study was scheduled for completion in 2011. Potential products from the project included zirconia, zirconium basic sulfate, zirconium carbonate, and zirconium hydroxide. Owing to high demand for rare earths, the company was also researching the recovery of rare-earth elements (Alkane Resources Ltd., 2011, p. 2).

In August, the mining license for Astron Ltd.'s Donald mining project was approved by the Department of Primary Industries, Victoria, and mine and plant designs were completed during the year. Ore reserves were estimated to be 305 Mt, with 6.2% heavy minerals containing 19% zircon (Astron Ltd., 2010a, b).

Gunson Resources Ltd. completed a definitive feasibility study for its Coburn heavy-minerals project in Western Australia. Reserves of zircon in the Coburn deposit were estimated to be 850,000 t supporting a mine life of 17 years, with a target production rate of 40,000 t/yr (Gunson Resources Ltd., 2010, p. 9).

Matilda Zircon Ltd. continued the development of zircon-rich heavy-minerals deposits in the Northern Territory and Western Australia. In 2010, Matilda Zircon formed an agreement with Chinese zircon consumer Tricoastal Minerals Co. to take all heavy-mineral concentrate from the Tiwi Islands operations and supply \$2.5 million in loans and share placements to assist in development of the Lethbridge Mine, which began production in June. At yearend, the company expected approval from the Western Australian Minister of the Environment to proceed with the development of the Keysbrook deposit, 70 kilometers south of Perth. Mining at Keysbrook was expected to begin in 2012, with an 8-year mine life (Matilda Zircon Ltd., 2010).

Canada.—Titanium Corp. continued its research into the recovery of bitumen, volatile organic compounds, and heavy minerals, including zircon, from mined oil sand tailings. In

2010, Titanium Corp. commissioned a demonstration pilot plant at the Canadian Government's Canmet testing facilities in Devon, Alberta. Pilot studies were conducted in June through September, with additional studies planned for 2011 (Titanium Corp., 2010, p. 4).

China.—As a leading producer of ceramic tiles, steel, and zirconium chemicals, China was the leading consumer of zircon, with about 40% of the total global zircon consumed (Porter, 2010, p. 7). China led the world in production of zirconium chemicals, with a total production capacity of 300,000 t/yr, including 170,000 t/yr of zirconium oxychloride (ZOC), an intermediate to many zirconium chemicals and zirconium metal. In 2010, the leading export destinations for China's ZOC were Japan (49%) and the United States (33%). China's production of ZOC was forecast to rise to 230,000 t by 2015 (Roskill Information Services, 2011, p. 97.)

Areva (50%) and China National Nuclear Corp. (50%) formed a joint venture called CNNC Areva Shanghai Tubing (CAST), which was expected to produce zirconium alloy tubes for fuel assemblies. The CAST facility was scheduled to begin production in 2020 near Shanghai (World Nuclear News, 2010a).

Indonesia.—In 2010, Matilda Zircon's Kalimantan heavy-mineral concentration plant exploration program was placed on care-and-maintenance status while focusing on its Australian projects. Matilda intended to reassess the Indonesian project in 2011 (Matilda Zircon Ltd., 2010, p. 4).

Kenya.—In July, Base Resources Ltd. acquired the Kwale Mineral Sands project from Vaaldiam Mining Inc. In 2010, an updated definitive feasibility study was underway and was scheduled for completion in 2011. The company expected the Kwale operation to be in production by 2013, with a production capacity of 35,000 t/yr of zircon (Base Resources Ltd., 2011).

Korea, Republic of.—The Atomic Energy of Canada Ltd. (AECL) was contracted by Korea Hydro and Nuclear Power to refurbish the CANDU 6 reactor at the Republic of Korea's Wolsong 1 nuclear powerplant. Under the terms of the contract, AECL completed the removal and replacement of 380 calandria tubes, pressure tubes, and end fittings. A calandria is constructed like a shell-and-tube heat exchanger. Fuel channels consist of an inner pressure tube, which contains the fuel bundle and the heavy water primary coolant, and an outer calandria tube. Each calandria tube is made of zirconium alloy and is approximately 6 meters long and 13 centimeters in diameter. CANDU reactors were designed to undergo refurbishment after approximately 25 years of operation (World Nuclear News, 2010b).

Mozambique.—Kenmare Resources plc was ramping up production at its Moma heavy-minerals operation. Zircon production at Moma in 2010 was 37,100 t, a 76% increase compared with that in 2009. In October, a breach of a settling pond allowed water to flood into a nearby village, causing one fatality. The mine was idled for 4 weeks while repairs and new safety measures were implemented. At yearend, Kenmare was proceeding with an expansion that would increase production capacity by about 50% (Kenmare Resources plc, 2011).

Russia.—ARZM Uranium Holding Co. continued to develop the Lukoyanovskoye heavy-minerals sands deposit near Nizhny

Novgorod. By 2014, the company planned to begin production of heavy-mineral concentrates including up to 35,000 t/yr of zircon. ARZM planned to supply mineral concentrates to OJSC TVEL (ARZM Uranium Holding Co., 2010, p. 40).

Senegal.—A feasibility study of Mineral Deposits Ltd.'s Grande Cote heavy-minerals deposit was completed in 2010 enabling the company to secure financing to develop the project. Construction of the mine and separation plants was expected to begin in 2011, and initial production was scheduled for 2013. Once the mine and separation plants are fully commissioned, the company expected to produce an average of 575,000 t/yr of ilmenite, 80,000 t/yr of zircon, 11,000 t/yr of leucoxene, and 6,000 t/yr of rutile (Mineral Deposits Ltd., 2010, p. 16).

South Africa.—Exxaro Resources Ltd. increased zircon production in South Africa to 161,000 t in 2010 from 152,000 t in 2009 through improved recovery of zircon at its Namakwa Sands operation. In 2010, Exxaro's Hillendale Mine neared the end of its life; however, plans were underway to develop the Fairbreeze deposit as a substitute for the waning production from the Hillendale Mine (Exxaro Resources Ltd., 2011, p. 53).

Rio Tinto Plc invested \$158 million in a tailings treatment facility at its Richards Bay Minerals heavy-minerals operation. At yearend, the treatment facility neared completion and was scheduled to begin production in the first quarter of 2011. Heavy-mineral concentrates, including zircon, were to be recovered from about 30 years accumulation of mine tailings (Industrial Minerals, 2010).

Vietnam.—In an effort to assist the domestic mining industry, the Government of Vietnam continued to suspend a ban on exports of titanium and zirconium mineral concentrates designed to encourage the production of value-added products. Producers were permitted to export through the end of 2010 (Mineral Sands Report, 2009).

Outlook

The consumption of zirconium mineral concentrates was expected to increase with demand from consumers such as the ceramics, metals, and chemicals industries. Because the use of these materials is pervasive in the general economy, economic growth may be used to estimate trends in zirconium consumption. The International Monetary Fund projected that world economic growth would be about 4.3% in 2011 and 4.5% in 2012. China was expected to lead global economic growth with 9.6% in 2011 and 9.5% growth expected in 2012. China's continued growth was expected to significantly increase in zircon consumption during the long term. The U.S. economy was projected to increase by 2.2% in 2011 and 2.6% in 2012 (International Monetary Fund, 2011). During the long term, the U.S. Congressional Budget Office projected the U.S. gross domestic product growth annually to average 3.6% from 2013 to 2016 (U.S. Congressional Budget Office, 2011).

In recent years, new mines were bought online in Australia, Mozambique, and South Africa; however, the global financial crisis curtailed production and delayed the development of several mining projects. This constricted supply together with rising demand are likely to create a scarcity of zircon through 2013.

Construction and operation of new nuclear powerplants throughout the world were expected to increase future demand for zirconium and hafnium metal. The International Atomic Energy Agency projection of world nuclear generating capacity was more than 73 gigawatts (GW) in net new capacity by 2020, with 546 to 803 GW in place by 2030. Total capacity at yearend 2010 was 377 GW (World Nuclear Association, 2011). Although the amount of zirconium metal varies by reactor, boiling water reactors were estimated to contain on average about 44 t of zirconium, and pressurized heavy-water reactors required about 12.5 t. Global zirconium metal consumption was projected to reach 6,500 t by 2015 (Desai, 2009).

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TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS¹

(Metric tons)

	2006	2007	2008	2009	2010
Zircon:					
Production:					
Concentrates	W	W	W	W	W
Milled zircon	50,800	64,600	61,500	38,400	46,900
Exports	76,300	66,200	42,100	39,600	47,400
Imports for consumption ²	36,200	20,000	34,400	14,400	22,900
Consumption, apparent ³	W	W	W	W	W
Stocks, December 31, dealers and consumers ⁴	17,600	18,000	26,600	NA	NA
Zirconium oxide:					
Production ⁵	21,700	25,600	18,100	NA	NA
Exports ⁶	3,340	2,400	2,970	3,050	5,630
Imports for consumption ⁶	2,820	3,740	5,060	2,810	2,920
Consumption, apparent ³	24,200	26,900	20,400	NA	NA
Stocks, December 31, dealers and consumers ⁴	1,560	1,880	1,670	NA	NA
Zirconium, unwrought, waste and scrap, other:					
Exports	1,880	2,160	2,670	2,300	2,060
Imports	748	784	1,030	977	1,160
Ferrozirconium:					
Exports	491	259	316	566	569
Imports	196	400	129	(7)	45
Hafnium, unwrought, waste and scrap, other, imports	4	4	12	5	8

NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Data are rounded to no more than three significant digits.

²Includes insignificant amounts of baddeleyite.

³Defined as production plus imports for consumption minus exports plus or minus Government shipments.

⁴Excludes foundries.

⁵Excludes intermediate oxides associated with metal production.

⁶Includes germanium oxides and zirconium dioxides.

⁷Less than ½ unit.

TABLE 2
PUBLISHED YEAREND PRICES OF ZIRCONIUM MATERIALS

(Dollars per metric ton)

Material	2009	2010
Baddeleyite, contract price, cost, insurance, and freight main European port:		
Refractories/abrasive grade	2,500–3,100	2,500–3,100
Ceramic grade (98% zirconium oxide and hafnium oxide)	3,000–3,300	3,000–3,300
Zircon:		
Domestic, standard-grade, bulk	800–860	830–890
Australian, standard-grade, free on board, bulk	880–900	850–890
Zirconia, fused, monoclinic, refractory/abrasive	4,100–4,900	4,400–5,200

Source: Industrial Minerals.

TABLE 3
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY¹

Class and country	HTS ²	2009		2010	
		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates:	2615.10.0000				
Belgium		6,580	\$6,850	657	\$1,000
Canada		1,770	2,090	2,340	3,350
China		2,630	1,430	359	223
El Salvador		--	--	3,210	898
Germany		870	1,240	1,970	4,500
Italy		156	232	18,200	15,800
Japan		11,600	6,520	1,470	3,080
Korea, Republic of		2,320	2,060	2,080	1,870
Mexico		4,010	4,140	3,560	3,970
Netherlands		9	53	5,280	4,610
Spain		4,430	3,900	2,000	1,660
United Kingdom		1,540	2,470	1,660	3,350
Other		3,650 ^r	5,360 ^r	4,580	6,760
Total		39,600	36,300	47,400	51,100
Ferrozirconium:	7202.99.1000				
Canada		54	122	109	276
Mexico		490	983	395	791
Other		21 ^r	35 ^r	65	128
Total		566	1,140	569	1,200
Unwrought zirconium, including powder:	8109.20.0000				
China		5	158	61	2,570
France		37	1,730	75	3,260
Germany		11	356	52	1,670
Mexico		(³)	12	35	1,270
Russia		73	4,000	65	3,230
United Kingdom		24	730	109	2,650
Other		15 ^r	673 ^r	41	1,800
Total		165	7,660	438	16,400
Zirconium waste and scrap:	8109.30.0000				
Canada		27	1,590	42	2,570
France		12	208	5	45
Japan		--	--	7	192
Netherlands		--	--	10	107
Sweden		16	266	10	118
Other		2 ^r	41 ^r	8	198
Total		58	2,110	82	3,230
Other zirconium:	8109.90.0000				
Canada		442	37,200	420	33,600
China		680	62,700	328	33,800
France		149	11,600	41	3,220
Japan		205	17,500	62	5,490
Korea, Republic of		287	26,100	276	23,500
Spain		83	14,300	89	14,400
Sweden		109	9,280	143	13,000
Other		122	11,100	180	16,300
Total		2,080	190,000	1,540	143,000

^rRevised. -- Zero.

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

²Harmonized Tariff Schedule of the United States.

³Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY¹

Class and country	HTS ²	2009		2010	
		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Zirconium ore and concentrates:	2615.10.0000				
Australia		8,090	\$6,910	16,100	\$16,000
South Africa		5,080	7,390	5,550	7,730
Other		1,250	2,810	1,220	3,790
Total		14,400	17,100	22,900	27,500
Ferrozirconium:	7202.99.1000				
China		--	--	43	232
Other		(3)	7	2	14
Total		(3)	7	45	246
Unwrought zirconium, including powder:	8109.20.0000				
France		3	166	1	75
Germany		9	1,540	13	2,050
Japan		7	16	--	--
Kazakhstan		--	--	15	168
Other		3 ^r	174 ^r	2	36
Total		22	1,890	31	2,330
Zirconium waste and scrap:	8109.30.0000				
France		83	807	83	710
United Kingdom		313	842	578	1,270
Other		33 ^r	247 ^r	35	405
Total		429	1,900	695	2,390
Other zirconium:	8109.90.0000				
Canada		34	3,810	8	974
France		347	48,600	397	64,600
South Africa		86	112	--	--
Other		59 ^r	4,000 ^r	29	2,700
Total		526	56,500	435	68,300
Unwrought hafnium, including powder:	8112.92.2000				
France		4	1,910	7	3,120
Russia		(3)	31	--	--
Other		(3) ^r	145 ^r	(3)	272
Total		5	2,080	8	3,390

^rRevised. -- Zero.

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

²Harmonized Tariff Schedule of the United States.

³Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 5
ZIRCONIUM MINERAL CONCENTRATES: ESTIMATED WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons)

Country ³	2006	2007	2008	2009	2010
Australia ⁴	492,000	601,000	550,000	476,000	518,000
Brazil ^{4,5}	25,120	26,739	17,682	18,134	18,150 ^P
China	135,000	140,000	140,000	130,000	140,000
India	28,000	29,000	30,000	37,000 ^r	38,000
Indonesia	65,000	111,000	65,000	63,000	50,000
Malaysia	1,690 ⁴	7,393 ⁴	948 ^{r,4}	1,145 ^{r,4}	1,300
Mozambique	--	26,347	32,985	19,101	37,100
Russia ⁶	7,500	7,136 ⁴	7,000 ⁴	5,000 ⁴	6,000
South Africa	435,000 ^{r,4}	405,000 ^{r,4}	405,000 ^{r,4}	390,000 ^r	400,000
Ukraine	27,000 ^r	37,000 ^r	36,000 ^r	31,000 ^r	30,000
United States	W	W	W	W	W
Vietnam	26,100	22,000	22,000	7,000	7,000
Total	1,240,000 ^r	1,410,000 ^r	1,310,000	1,180,000	1,250,000

^PPreliminary. ^rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

¹World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Includes data available through May 16, 2011.

³Small amounts of zirconium concentrates were produced in various countries; however, information is not sufficient to estimate output.

⁴Reported figure.

⁵Includes production of baddeleyite-caldasite.

⁶Production of baddeleyite concentrate averaging 98% ZrO₂.