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2018 Minerals Yearbook

THORIUM [ADVANCE RELEASE]

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Thorium

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Based on exports, about 500 metric tons (t) of monazite concentrates were produced in 2018 as a byproduct of heavy-mineral concentrates produced in the United States. Monazite is a source of rare earths and thorium (a naturally occurring radioactive element). Thorium alloys, compounds, and metal used by the domestic industry were derived from imports or stocks. Significant fluctuations in apparent consumption are caused by intermittent use, especially for applications that do not require annual replenishment of thorium supply.

In 2018, the United States imported about 1 t of thorium ore and concentrate from Canada and exported 521 t predominantly to China. Imports for consumption of thorium compounds increased by 6% compared with those in 2017. The United States imported 9 t of thorium compounds mainly from India (77%) and exported nearly 20.8 t; the value of thorium compounds imports was $567,000 (table 2). In 2016, 2017, and 2018, exports of compounds were unusually high relative to historical exports and may include misclassified materials (table 1).

Global mine production of thorium-bearing monazite concentrate was 26,800 t (table 3). In 2018, monazite-producing countries included Brazil, India, Madagascar, Malaysia, Nigeria, Thailand, the United States, and Vietnam. Other countries, such as China, produced monazite and thorium compounds, but data were inadequate to make reliable production estimates.

Thorium occurs widely but is concentrated in only a few geologic deposit types. Three principal sources of thorium are of commercial interest—monazite in heavy-mineral-sand placer deposits and in vein deposits, thorite ores in vein deposits, and thorium recovered as a byproduct of uranium mining. Thorium and its compounds were produced primarily from the mineral monazite, which was recovered as a byproduct of processing placer sands for zircon and titanium minerals (ilmenite and rutile), or from the tin mineral cassiterite. Monazite was recovered primarily for its rare-earth-element (REE) content, and only a small fraction of the byproduct thorium produced was consumed.

Issues associated with thorium's natural radioactivity were a significant deterrent to its commercial use. Excess thorium that was not designated for commercial use was either disposed of as low-level radioactive waste or stored. In the United States, typically only minor amounts of thorium are used annually. Although research into thorium-fueled nuclear reactors continued, no industrial-scale nuclear reactors used thorium in 2018. Principal uses include ceramics, catalysts, lighting, radiotherapy, and welding electrodes.

Production

The U.S. Geological Survey developed domestic mine production data for thorium-bearing minerals from a voluntary canvass of U.S. mining operations and information gathered from publicly available reports. In 2018, 500 t of monazite was recovered as a byproduct of processing heavy-mineral sands and exported as a salable product.

Monazite concentrates, which are produced from beach sands in Brazil, India, Malaysia, the Republic of Korea, and the United States, contain 3 weight percent (wt.%) to 14 wt.% thorium oxide (ThO_2) and 41 wt.% to 65 wt.% rare-earth oxides (REOs). However, monazites from some granitic rocks could contain up to 27 wt.% ThO_2 (René, 2017, p. 204). Beach sands containing monazite are also produced in Indonesia, Madagascar, Thailand, and Vietnam.

Consumption

Insufficient data were collected from thorium processors to determine the consumption of thorium during 2018. Thorium alloys and compounds used by the domestic industry were derived from imports or stockpiled inventory.

Thorium consumption worldwide was small compared with that of most other mineral commodities. Thorium is used in a variety of catalysts, ceramics, optics, nuclear medicine, and metal applications. In catalytic applications, ThO_2 is used in petroleum fluid catalytic cracking (converting crude oil into lighter fractions) and in the production of nitric and sulfuric acids. One of the major uses of thorium is in the form of thoriated tungsten metal. Thorium lowers the energy necessary for electrons to escape from a tungsten surface and enhances the thermionic emission. In welding and plasma cutting, thoriated tungsten electrodes improve ignition and arc stability. Thoriated tungsten filaments are used in high-intensity discharge lamps, vacuum tubes for radio transmitters and audio amplifiers, and cathode heaters. As a fluoride, thorium is used within antireflection materials in optical coatings. One of the oldest uses of thorium is in the manufacture of incandescent gas mantles. Gas mantles containing ThO_2 provide an intense white light but were not produced domestically owing to the availability of suitable substitutes. In the past, thorium has been used as an alloying agent in magnesium and nickel alloys for heat-resistant applications. Because of concerns about its naturally occurring radioactivity, thorium has been replaced by nonradioactive materials in many uses.

Interest in thorium as a nuclear fuel continues in part owing to its higher abundance relative to uranium. Basic research on thorium fuel cycles has been undertaken in Australia, Brazil, Canada, China, France, Germany, India, Italy, Japan, Norway, Romania, Russia, the United States, and some other countries. However, there are several challenges when working with thorium fuel cycles. Irradiated ThO_2 and spent ThO_2-based fuels are difficult to dissolve in nitric acid (HNO_3) because of the inertness of ThO_2. The high gamma radiation associated with the short-lived daughter products of ^{232}U, which is always associated with ^{233}U, requires remote reprocessing and refabricating of fuel. The protactinium formed in the thorium fuel cycle also introduces complications which need a solution. As of yearend 2018, experimental nuclear reactors based on a thorium fuel cycle were operated only in India (René, 2017, p. 210). In India, an advanced heavy water 300-megawatt electrical (MWe) reactor has been developed to use thorium fuel. The reactor operates with Th-MOX (thorium-plutonium or thorium ^{233}U fuel in mixed mode) as seed but is capable of eventually self-sustaining ^{233}U production. About 39% to 75% of the power in this reactor comes from thorium depending on the fuel mixture used (World Nuclear Association, 2017, p. 5).

Thorium-based nuclear research and development programs have been underway in the United States. The U.S. Department of Energy is supporting the development of innovative nuclear energy technologies, including the use of thorium fuels, through its Office of Advanced Reactor Technologies (U.S. Department of Energy, undated). Companies known to be involved in these efforts included Alpha Tech Research Corp. (Salt Lake City, UT), Flibe Energy Inc. (Huntsville, AL), Lightbridge Corp. (Reston, VA), Southern Co. (Atlanta, GA), TerraPower, LLC (Bellevue, WA), ThorCon USA Inc. (Stevenson, WA), Transatomic Power Corp. (Cambridge, MA), and X-energy, LLC (Greenbelt, MD).

Prices

Published prices for ThO_2 and thorium nitrate were not available. In 2018, the unit value of thorium nitrate exports from India was $64 per kilogram, a 10% increase compared with the unit value in 2017 (Zen Innovations, 2019). In the United States, the average unit value of imported thorium compounds was $63 per kilogram, a 27% decrease compared with $86 per kilogram in 2017. The average unit value of exported thorium compounds increased to $55 per kilogram from $15 per kilogram in 2017. For imports and exports, the data are often composed of a mix of high-volume, low-unit-value shipments and low-volume, high-unit-value shipments. For example, the monthly unit value for imports by country in 2018 ranged from about $29 per kilogram (shipped from France to New York in August and Chicago in December) to $3,411 per kilogram (shipped from Germany to New Orleans).

Foreign Trade

Owing to limited consumption, thorium mineral concentrates and compounds are imported and exported sporadically. In 2014 and 2015, no thorium ores and concentrates were imported into the United States. In 2016, imports of thorium ores and concentrates rose to 16 t, fell to zero in 2017, and then were about 1 t in 2018, all from Canada. India continued to be the leading supplier of thorium compound imports in 2018. United States imports of thorium compounds were primarily in the form of thorium compounds from India and France (table 2). Imports of thorium compounds in 2018 totaled 9 t valued at $567,000, an increase in quantity from 8.5 t valued at $731,000 in 2017 (table 2). The United States did not report exports of thorium ores and concentrates from 2010 through 2017. In 2018, exports of thorium ores and concentrates were 521 t. Exports of thorium compounds from the United States were 20.8 t, a 77% decrease from 88.6 t in 2017. The principal destinations were Brazil (47%) and Uruguay (34%) (table 2).

World Review

Thorium consumption worldwide was limited by concerns about its naturally occurring radioactivity. In 2018, exploration and development of several rare-earth projects associated with thorium were underway, but progress on most projects slowed because of declining prices.

Brazil.—In 2018, Brazil exported 1,990 t of thorium-bearing monazite concentrates to China to produce rare-earth materials, a 31% decrease compared with that in 2017 (Zen Innovations, 2019). An estimated 2,000 t of monazite was produced in 2018. According to the Departamento Nacional de Produção Mineral (2019; now called Agência Nacional de Mineração), Brazil's prior shipments were derived from Indústrias Nucleares do Brasil S.A.'s (INB) inventories in Sao Francisco do Itabapoana.

Canada.—Medallion Resources Ltd. continued to pursue plans to develop a processing facility to produce mixed rare-earth compounds from monazite. Medallion's proposed facility would purchase monazite byproduct from heavy-mineral-sand operations and produce rare-earth compounds. The company engaged an Australian company, Simulus Engineers, to develop a chemical process to extract rare-earth concentrates from byproduct monazite sand (Medallion Resources Ltd., 2019).

Commerce Resources Corp. continued work on prefeasibility studies on its Ashram REE project located in Nunavik, Quebec, and planned for fluorspar recovery. A preliminary economic assessment indicated positive cash flow with a 4,000-metric-ton-per-day open pit operation and a 25-year mine life. The host mineralogy (monazite, bastnaesite, and xenotime) was amenable to recovery with processing using conventional and proven techniques, but there were no plans to recover thorium from the deposit (Gagnon and others, 2015).

China.—China was thought to have produced substantial but unknown quantities of thorium byproducts during the processing of domestic and imported mineral concentrates to produce rare-earth compounds. In 2018, China's imports of thorium ores and concentrates were 13,600 t (gross weight), a 127% increase compared with those in 2017. The leading import sources were Madagascar (8,000 t), Brazil (1,990 t), Thailand (1,920 t), Vietnam (1,540 t), the United States (500 t), Malaysia (91 t), Nigeria (50 t), and Indonesia (42 t). Thorium also may be present in imports of mixed heavy-mineral concentrates not explicitly classified as thorium bearing (Zen Innovations, 2018).

Greenland.—Greenland Minerals Ltd. (GML) continued to advance its Kvanefjeld project for production of fluorspar, rare earths, uranium, zinc concentrates, and refined compounds. Unspecified quantities of thorium byproduct contained in the concentrates were expected to be removed during the processing of the mineral concentrates. In 2016, Shenghe Resources Holding Ltd., a China-based company engaged in the mining and processing of rare earths, acquired a minor interest in GML, but by 2018 it was a major shareholder. Changes were made to the project to make it more economical. In August 2018, GML and Shenghe entered a nonbinding memorandum of understanding regarding commercialization of the Kvanefjeld project (Greenland Minerals Ltd., 2019). Shenghe formed a joint-venture (JV) company with subsidiaries of China National Nuclear Corporation, called the China Nuclear Hua Sheng Mining Ltd., for the trading of rare-earth minerals. This JV would support the development of the Kvanefjeld project (World Nuclear News, 2019).

India.—India's producers of monazite concentrate included Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. (KMML). Government regulations govern the mining, processing, and storage of radioactive minerals in India, and a stockpile of monazite-rich tailings from heavy-mineral-sand operations has been produced. The tailings were reported by India's Atomic Energy Regulatory Board to fall into two categories—(1) large quantities containing less than 5% monazite mixed with silica sand, and (2) smaller amounts of greater than 5% monazite stored in trenches and topped with silica sand (for safety reasons). The stockpiled tailings were not quantified (Bhattacharya, 2015, p. 8, 10, 41). The installed capacity of the monazite (96% pure) separation plant at Manavalakurichi (IREL) is 6,000 metric tons per year (t/yr), and the capacity at Chavara (KMML) is 240 t/yr (Indian Bureau of Mines, 2019, p. 24–3).

IREL's plant at Udyogmandal, Aluva, in Ernakulam district, Kerala State, was capable of processing 10,000 t/yr of monazite into various rare-earth compounds and thorium hydroxide. Uranium present in the monazite is recovered as ammonium diuranate, which supplements the local uranium supply. In Odisha State, IREL's production capacity included 2,000 t/yr of thorium oxalate and 150 t/yr of thorium nitrate (Singh, 2018). A small part of the purified thorium nitrate was converted to nuclear-grade thorium oxide powder for supply to the Bhabha Atomic Research Centre and Nuclear Fuel Complex for developing thorium-based fuel for nuclear reactors. IREL has a monazite-processing plant in Odisha State producing 11,000 t/yr of rare-earth chloride and other compounds (Indian Bureau of Mines, 2019, p. 24–3). According to India's Department of Atomic Energy (DAE), IREL's production of thorium oxalate and thorium nitrate was 248 t and 82 t, respectively, for the fiscal year April 1, 2016, to March 31, 2017.

DAE's estimate of monazite resources for 128 deposits totaled 12.5 million metric tons (Mt) containing about 1.1 Mt of ThO_2. The leading States for these resources were Andhra Pradesh (3.7 Mt), Odisha (3.1 Mt), Tamil Nadu (2.5 Mt), Kerala (1.8 Mt), and West Bengal (1.2 Mt) (Indian Bureau of Mines, 2019, p. 24–2).

Malaysia.—Reserves of thorium were estimated to be about 185 t (Al-Areqi and others, 2015, p. 1), and production in 2018 was about 91 t. Lynas Corp. Ltd. mined monazite and performed initial concentration for REEs at its Mt. Weld plant in Australia. These materials were then shipped to the Lynas Advanced Materials Plant in Gebeng, Malaysia. The company has experienced opposition from local environmental groups, claiming unsafe disposal of the waste from the plant (Al-Areqi and others, 2015). Lynas was the only reliable supplier of REEs outside China, and there was concern that closing the Lynas operation in Malaysia might make Chinese production more dominant.

South Africa.—Steenkampskraal Thorium Ltd. (STL) continued work to support the recommissioning of the idled Steenkampskraal (SKK) Mine in the Western Cape Province. The SKK Mine produced monazite concentrates from 1952 to 1963. STL reported significant efforts to restart the SKK Mine and planned to produce mixed rare-earth nitrates and thorium compounds through hydrometallurgical treatment of monazite concentrates (Blench and Slabber, 2016, p. 9–11). Steenkampskraal Thorium (Pty) Ltd. (STL Nuclear) commenced a project to produce energy for a wide range of energy consumers, called the Thorium-100 Nuclear Power Plant (HTMR-100 NPP). This concept offered the potential for modularity and security of fuel supply (thorium is four times more abundant than uranium). The construction of the first plant was planned for 2018 [Steenkampskraal Thorium (Pty) Ltd., 2018].

Outlook

During the next decade, concerns related to thorium's natural radioactivity are expected to continue to limit its use in nonenergy applications. At the same time, the potential supply of thorium from rare-earths production is projected to increase.

In the long term, consumption of thorium will increase substantially if its use as a nuclear fuel becomes commercialized. Many countries are researching nuclear reactor designs that incorporate thorium-bearing fuels.

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TABLE 1
SALIENT U.S. THORIUM STATISTICS[1]

		2014	2015	2016	2017	2018
Production, gross weight, thorium ores and concentrates, including monazite	metric tons	--	--	--	--	500
Exports, gross weight:						
Thorium ores and concentrates, including monazite	do.	--	--	--	--	521
Thorium compounds	do.	14.8	2.16	63.9	88.6	20.8
Imports for consumption, gross weight:						
Thorium ores and concentrates, including monazite	do.	--	--	16	--	1
Thorium compounds	do.	11.0	2.74	3.12	8.51	9.00
Price, yearend, thorium compounds, gross weight,[2] India	dollars per kilogram	65	63	65	73 r	72

[r]Revised. do. Ditto. -- Zero.
[1]Table includes data available through July 7, 2020. Data are rounded to no more than three significant digits.
[2]Source: U.S. Census Bureau.

TABLE 2
U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS[1]

	2017		2018	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Exports:				
Thorium ore, monazite concentrate (2612.20.0000):				
China	--	--	520	$206,000
United Kingdom	--	--	1	7,580
Total	--	--	521	214,000
Thorium compounds (2844.30.1000):				
Brazil	20.0	$229,000	9.83	142,000
El Salvador	5.09	160,000	--	--
Peru	3.78	53,900	0.08	2,750
United Arab Emirates	7.40	47,200	--	--
Uruguay	--	--	7.04	102,000
Vietnam	48.2	119,000	--	--
Other	4.25 r	690,000 r	3.85	903,000
Total	88.6	1,340,000	20.8	1,150,000
Imports for consumption:				
Thorium ore, monazite concentrate (2612.20.0000), Canada	--	--	1	4,260
Thorium compounds (2844.30.1000):				
France	(2)	15,000	2.07	59,700
India	8.30	607,000	6.90	497,000
United Kingdom	0.14	109,000	--	--
Other	--	--	(2)	10,500
Total	8.51	731,000	9.00	567,000

[r]Revised. -- Zero.
[1]Table includes data available through July 7, 2020. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 3

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1]

(Metric tons, gross weight)

Country or locality[2]	2014	2015	2016	2017	2018
Brazil	-- e	1,625 r	4,525 r	2,900 e	2,000 e
India[e]	3,000	3,000	2,500	3,000	5,000
Madagascar	--	--	--	--	16,000
Malaysia	372	499	230 e	130 e	91 e
Nigeria	104	80 r, e	--	55 e	50 e
Thailand[e, 3]	3,200	1,300	2,600	2,200 r	1,700
United States	--	--	--	--	500 e
Vietnam[e, 4]	--	460	400	360	1,500
Total	6,680	6,960 r	10,300 r	8,650 r	26,800

[e]Estimated. [r]Revised. -- Zero.

[1]Table includes data available through May 13, 2020. All data are reported unless otherwise noted. Totals and estimated data are rounded to three significant digits; may not add to totals shown.

[2]In addition to the countries and (or) localities listed, China, Indonesia, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may have produced monazite, but available information was inadequate to make reliable estimates of output.

[3]China's imports from Thailand.

[4]China's imports from Vietnam.