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# 2016 Minerals Yearbook

## THORIUM [ADVANCE RELEASE]

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# Thorium

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There was no reported domestic production of thorium ores and concentrates in 2016; however, some heavy-mineral concentrates produced in the United States may contain thorium from their naturally occurring source. Thorium alloys, compounds, and metal used by the domestic industry were derived from imports or stocks. Large fluctuations in apparent consumption are caused by intermittent use, especially for applications that do not require annual replenishment of thorium supply.

In 2016, United States imports included 16 metric tons (t) of thorium ores and concentrates from Canada, the first imports of this type since 2012. India was the source of 96% of the thorium compound imports to the United States. Imports of thorium compounds increased by 14% compared with those in 2015. The United States was a net exporter of thorium compounds, and the value of thorium compounds exports was $1.79 million. In 2016, the unit value of domestic exports of thorium compounds was $28 per kilogram compared with $91 per kilogram for U.S. imports for consumption according to data collected by the U.S. Census Bureau (tables 1, 2). Global mine production of thorium-bearing monazite concentrate was 9,430 t (table 3).

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 placers 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 for the tin mineral cassiterite. Monazite was recovered primarily for its rare-earth-element content, and only a small fraction of the byproduct thorium produced was consumed. In 2016, monazite-producing countries included Brazil, India, Malaysia, Thailand, and Vietnam. Other countries, such as China, produced monazite and thorium compounds, but data were inadequate to make reliable production estimates (table 3).

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 a low-level radioactive waste or stored. Although research into thorium-fueled nuclear reactors continues, there were no industrial-scale nuclear reactors using thorium in 2016. In the United States, only minor amounts, estimated at about 1 t of thorium oxide ($ThO_2$), are typically used annually. Principal uses include catalysts, ceramics, lighting, and welding electrodes.

## Production

Domestic mine production data for thorium-bearing minerals were developed by the U.S. Geological Survey from a voluntary canvass of U.S. mining operations and information gathered from publicly available reports. Although monazite itself may be recovered as a byproduct of processing heavy-mineral sands, monazite was not produced domestically as a salable product in 2016.

## Consumption

Thorium consumption worldwide is small compared with that of most other mineral commodities. Thorium is used in a variety of catalysts, ceramics, optics, and metal applications. In catalysts, $ThO_2$ 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's use in nuclear fuels continues, in part owing to its high abundance relative to uranium.

Statistics on domestic thorium consumption were developed by evaluating import and export data and canvassing processors. Insufficient data were collected from thorium processors to determine consumption of $ThO_2$ equivalent in 2016. Thorium alloys and compounds used by the domestic industry were derived from imports or stockpiled inventory.

Corporations, research institutions, and government agencies were active in the pursuit of commercializing thorium as a nuclear fuel material. Thorium-based nuclear research and development programs have been underway in Belgium, Brazil, Canada, China, Czechia, France, Germany, India, Indonesia, Israel, Japan, the Netherlands, Norway, Russia, the United Kingdom, and the United States. In the United States, companies known to be involved in these efforts included 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 nitrate were not available. According to export statistics from India's Ministry of

Commerce, the unit value of thorium nitrate exports was $54 per kilogram, a slight increase compared with the unit value in 2015 (IHS Markit Inc., 2018). In the United States, the average unit value of imported thorium compounds was $91 per kilogram, a 15% increase compared with $79 per kilogram in 2015. The average unit value of exported thorium compounds decreased to $28 per kilogram from $359 per kilogram in 2015 (table 2). For imports and exports, the data are often skewed by a mix of high-volume, low-unit-value shipments and low-volume, high-unit-value shipments. For example, unit values for exports in 2016 ranged from about $2 per kilogram to $3,000 per kilogram.

**Foreign Trade**

Owing to limited demand, thorium ores and concentrates and thorium compounds are imported and exported sporadically. There were no reported exports of thorium ores and concentrates in 2016; exports were last reported in 2010. Imports of thorium ores and concentrates were 16 t in 2016, the first imports of this type since 2012. Exports of thorium compounds from the United States were 63.9 t valued at $1.79 million, a significant increase from 2.16 t valued at $779,000 in 2015 (table 2). The principal destinations were Vietnam (31%), Brazil (23%), and China (22%). Imports of thorium compounds in 2016 totaled 3.12 t valued at $284,000, an increase from 2.74 t valued at $216,000 in 2015. India continued to be the leading supplier of thorium compound imports in 2016. According to statistics from India's Ministry of Commerce, United States imports of thorium compounds were primarily in the form of thorium nitrate (IHS Markit Inc., 2018).

**World Review**

Thorium demand worldwide was limited by concerns about its naturally occurring radioactivity. In 2016, exploration and development of several rare-earth projects associated with thorium were underway, but progress on most projects slowed because of an oversupply of rare-earth materials and declining prices.

***Brazil.***—In 2016, Brazil's exports of monazite concentrate to China were 3,730 t, a 129% increase compared with those in 2015 (IHS Markit Inc., 2018). Although no data were available for 2016, according to the Departamento Nacional de Produção Mineral, Brazil's prior shipments were derived from Indústrias Nucleares do Brasil S.A. (INB) inventories in Sao Francisco do Itabapoana (Andrade, 2016, p. 108, 109). INB reported that it produced monazite concentrate from previously mined ore and heavy-mineral concentrates at its Buena operations in Sao Francisco de Itabapoana, Rio de Janeiro State (Indústrias Nucleares do Brasil S.A., undated).

***Canada.***—Medallion Resources Ltd. continued to pursue plans to develop a processing facility for the production of mixed rare-earth compounds from monazite. Medallion's proposed facility would purchase monazite byproduct from heavy-mineral-sands operations and produce rare-earth compounds. In 2016, the company was working to raise capital to proceed with pilot-plant studies and was testing samples from heavy-mineral-sands producers to locate suitable monazite feed (Medallion Resources Ltd., 2017, p. 1, 11, 12).

Commerce Resources Corp. continued to advance its Ashram Project in northern Quebec. The proposed project was based on the production of 16,900 metric tons per year (t/yr) of rare-earth-oxide (REO) equivalent derived from monazite and to a lesser degree bastnäsite and xenotime. Thorium was to be selectively removed and was expected to be contained in the mill tailings. In 2016, the company initiated studies that included defining resources, testing hydrogeology, and gathering environmental baseline data. In June, Commerce Resources announced that it had been awarded 300,000 Canadian dollars in a grant from the Quebec government to support optimizing tailings management for the project (Commerce Resources Corp., 2015, p. 13; 2017, p. 3, 4).

***China.***—China produced substantial but unknown quantities of thorium byproducts during the processing of domestic and imported mineral concentrates for the production of rare-earth compounds. In 2016, China's imports of thorium ores and concentrates were 7,120 t (gross weight), a 35% increase compared with those in 2015. The import sources, in descending order, were Brazil (3,730 t), Thailand (2,670 t), Vietnam (402 t), and Malaysia (321 t). Thorium may also be present in imports of mixed heavy-mineral concentrates not specifically classified as thorium bearing (IHS Markit Inc., 2018).

***Greenland.***—Greenland Minerals and Energy Ltd. (GMEL) continued to advance its Kvanefjeld Project for production of fluorspar, rare-earth, uranium, and 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, the Government of Greenland was reviewing the project's environmental and social impact assessments. In the fourth quarter, Shenghe Resources Holding Ltd., a China-based company engaged in the mining and processing of rare earths, acquired a 12.5% interest in GMEL. GMEL and Shenghe were expected to conduct joint technical work in 2017 to improve the cost structure of the Kvanefjeld Project (Greenland Minerals and Energy Ltd., 2017, p. 2–6).

***India.***—India's Atomic Minerals Directorate for Exploration and Research estimate of monazite resources for 128 deposits totaled 11.9 million metric tons (Mt) containing about 1.07 Mt of $ThO_2$. The leading States for these resources were Andhra Pradesh (3.72 Mt), Tamil Nadu (2.46 Mt), Odisha (2.41 Mt), Kerala (1.90 Mt), and West Bengal (1.22 Mt) (Indian Department of Atomic Energy, 2016).

India's producers of monazite concentrate included Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. Because of regulations governing the mining, processing, and storage of radioactive minerals, India had a stockpile of monazite-rich tailings from heavy-mineral operations. According to India's Atomic Energy Regulatory Board, there were two types of tailings: (1) large quantities containing less than 5% monazite, mixed with silica sand and (2) small quantities containing greater than 5% monazite, stored in trenches and topped with silica sand. The stockpiled tailings were not quantified (Bhattacharya, 2015, p. 41).

In 2016, IREL's Aluva Rare Earth Division in the Ernakulam district, Kerala State, was capable of processing monazite into rare-earth compounds and thorium hydroxide. In Odisha State, IREL's production capacity included 2,000 t/yr of thorium oxalate and 150 t/yr of thorium nitrate (Singh, 2016, p. 13). According to the Indian Bureau of Mines, IREL held a large stockpile of impure thorium hydroxide associated with rare earths and unreacted materials (Indian Bureau of Mines, 2018). India's exports in 2016 included $ThO_2$ (21 kilograms), thorium nitrate (3 t), and other thorium compounds (5.4 t) (IHS Markit Inc., 2018).

***Kazakhstan.***—Summit Atom Rare Earth Co. (SARECO), a joint venture between Kazakhstan's Kazatomprom National Atomic Co. (51%) and Japan's Sumitomo Corp. (49%), continued efforts to commercialize a plant in Stepnogorsk designed to recover rare earths from a residue from processing uranium ore. Unspecified quantities of thorium byproduct contained in the concentrates were expected to be removed during the processing of the residue. During 2016, the company signed an agreement with Irtysh Rare Earth Co. Ltd., a producer of rare-earth compounds, to supply intermediate rare-earth compounds. SARECO was also exploring the use of separation technology from REEtec AS of Norway (Kazatomprom National Atomic Co., 2017, p. 76). In December, Kazatomprom National Atomic Co. was reported to be selling partial interest in the joint venture (Metal-Pages, 2016).

***South Africa.***—Steenkampskraal Thorium Ltd. continued plans to develop a processing chain from mine to nuclear fuels. In 2016, the company reported it had made significant efforts to restart the Steenkampskraal monazite mine and planned to produce thorium compounds and mixed rare-earth nitrates through hydrometallurgical treatment of monazite concentrates (Blench and Slabber, 2016, p. 9–11). According to a National Instrument 43–101-compliant study completed in 2013, using a 1% REO cutoff grade, the project's in situ measured resources were 85,000 t and contained about 2.82% $ThO_2$. Using the same cutoff basis, indicated resources were estimated at 154,000 t and contained about 2.09% $ThO_2$ (Venmyn Deloitte (Proprietary) Ltd., 2014, p. 150).

## 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 from rare-earth production is expected to increase over time. In the long term, consumption of thorium will increase substantially if its use as a nuclear fuel becomes commercialized. Many countries are developing thorium-based nuclear technology. In India, a reactor fueled by a thorium-mixed-oxide fuel and its molten-salt reactor technology was expected to be operational by 2022 (World Nuclear Association, 2016). The Chinese Academy of Sciences continued an initiative employing hundreds of scientists and engineers to develop thorium molten-salt reactor technologies. China planned to construct a 2-megawatt (MW) research reactor by 2020 and a 1,000-MW reactor in the 2030s (Martin, 2015).

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

| | | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|
| Exports, thorium compounds, gross weight | kilograms | 3,160 | 1,010 | 14,800 r | 2,160 | 63,900 [2] |
| Imports for consumption, gross weight: | | | | | | |
| Thorium ores and concentrates, including monazite | do. | 43,000 | -- | -- | -- | 16,000 [2] |
| Thorium compounds | do. | 4,400 | 2,830 | 11,000 | 2,740 | 3,120 |
| Price, yearend, thorium compounds, gross weight:[3] | | | | | | |
| France | dollars per kilogram | 153 | NA | NA | NA | NA |
| India | do. | 60 | 65 | 65 | 63 | 65 |

rRevised. do. Ditto. NA Not available. -- Zero.
[1]Table includes data available through May 10, 2018. Data are rounded to no more than three significant digits.
[2]All or part of these data have been referred to the U.S. Census Bureau for verification.
[3]Source: U.S. Census Bureau.

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

| | 2015 | | 2016 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value | Quantity (kilograms) | Value |
| Exports, thorium compounds (HTS[2] code 2844.30.1000): | | | | |
| Brazil | -- | -- | 15,000 [3] | $37,000 [3] |
| Chile | -- | -- | 3,100 [3] | 59,700 [3] |
| China | -- | -- | 14,200 [3] | 438,000 [3] |
| Dominican Republic | -- | -- | 3,180 [3] | 39,000 [3] |
| Germany | 133 | $44,400 | 2,640 [3] | 439,000 [3] |
| Vietnam | -- | -- | 20,100 [3] | 67,000 [3] |
| Other | 2,030 r | 734,000 r | 5,680 [3] | 714,000 [3] |
| Total | 2,160 | 779,000 r | 63,900 [3] | 1,790,000 [3] |
| Imports for consumption: | | | | |
| Thorium ore, monazite concentrate (HTS[2] code 2612.20.0000), Canada | -- | -- | 16,000 [3] | 3,080 [3] |
| Thorium compounds code (HTS[2] code 2844.30.1000): | | | | |
| India | 2,590 | 163,000 | 3,000 | 195,000 |
| Other | 143 | 53,900 r | 115 | 88,800 |
| Total | 2,740 | 216,000 r | 3,130 | 284,000 |

rRevised. -- Zero.
[1]Table includes data available through May 10, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States.
[3]All or part of these data have been referred to the U.S. Census Bureau for verification.

Source: U.S. Census Bureau.

TABLE 3

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

(Metric tons, gross weight)

| Country or locality[2] | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Brazil | 2,700 [3] | 600 [3] | -- | 1,600 [e] | 3,700 [e] |
| India[e] | 3,000 | 3,000 | 3,000 | 3,000 | 2,500 |
| Malaysia | 113 | 261 | 372 | 499 | 230 [e] |
| Thailand[e] | 200 | 210 | 3,200 | 1,300 | 2,600 |
| Vietnam[4] | 370 [e] | 180 [e] | -- | 460 [e] | 400 |
| Total | 6,380 | 4,250 | 6,570 | 6,860 | 9,430 |

[e]Estimated. -- Zero.

[1]Table includes data available through May 12, 2017. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

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

[3]Reported production was derived from stockpiled mineral concentrates.

[4]China's imports from Vietnam.