



2014 Minerals Yearbook

THORIUM [ADVANCE RELEASE]

THORIUM

By Joseph Gambogi

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

There was no reported domestic production, imports, or exports of thorium ores and concentrates in 2014. Thorium alloys, compounds, and metal used by the domestic industry were derived from imports or stocks. In 2014, India was the source of 99.9% of thorium compound imports to the United States. The United Kingdom (0.1%) was the source of high unit value (\$3,800 per kilogram) thorium compound imports to the United States that were likely used for research purposes. Global mine production was 2,700 metric tons (t) (table 3).

Domestic producers of thorium compounds processed imports into higher unit value exports. Owing to increased global demand for value added products, domestic imports for consumption and exports of thorium compounds increased significantly in 2014, according to data collected by the U.S. Census Bureau (tables 1, 2).

The United States was a net exporter of thorium compounds and the value of thorium compounds imported by the domestic industry in 2014 was \$761,000. In 2014, the average duty-paid unit import value of thorium compounds was \$72 per kilogram compared with the average free alongside ship export value of \$128 per kilogram. Exports to Colombia may have been misclassified judging by the free alongside ship export value of \$2.5 per kilogram, significantly less than the total average.

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 and 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 heavy-mineral sands for zircon and the titanium minerals, ilmenite and rutile, or 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. In 2014, monazite-producing countries included Malaysia, Thailand, and Vietnam. China, India, and other countries produced monazite and thorium compounds, but data were inadequate for the formulation of 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 2014.

In the United States, only minor amounts, about 1 t of thorium oxide (ThO₂), are typically used annually. Principal uses include ceramics, catalysts, lighting, and welding electrodes. Large fluctuations in apparent consumption are caused by intermittent use, especially for applications that do not require annual replenishment of thorium supply.

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 publically 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 2014.

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, ThO₂ is used in petroleum cracking 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 ThO₂ provide an intense white light but were not produced domestically in 2014 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 high abundance relative to uranium.

Statistics on domestic thorium consumption were developed by evaluating import and export data and surveying processors. Insufficient data were collected from thorium processors to determine consumption of ThO₂ equivalent in 2014. Thorium alloys and compounds used by the domestic industry were derived from imports or stockpiled inventory.

Several companies and countries were active in the pursuit of commercializing thorium as a nuclear fuel material. Thorium-based nuclear research and development programs have been or are underway in Belgium, Brazil, Canada, China, the Czech Republic, France, Germany, India, 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 Babcock & Wilcox Nuclear Energy, Inc. (Charlotte, NC), Flibe Energy Inc. (Huntsville, AL), General Atomics (San Diego, CA), Lightbridge Corp. (McLean, VA),

Martingale Inc. (Tavernier, FL), Transatomic Power Corp. (Cambridge, MA), and X-energy, LLC (Greenbelt, MD).

Prices

Published prices for ThO₂ and nitrate were not available. The average unit value of imported thorium compounds was \$69.10 per kilogram, a 6% increase compared with \$65.00 per kilogram in 2013. The average unit value of exported thorium compounds decreased to \$129 per kilogram from \$518 per kilogram in 2013. The significant change may be attributed in part to a change in the quantity of low-unit-value exports to Colombia. Exports to Colombia were 5.49 t (\$2.54 per kilogram) and may have been misclassified based on their unit value.

Foreign Trade

Owing to limited demand, thorium ores and concentrates and thorium compounds are imported and exported sporadically. There were no reported imports or exports of thorium ores and concentrates in 2014. Exports of thorium compounds from the United States were 14.8 t valued at \$1,900,000, an increase from 1.01 t valued at \$523,000 in 2013 (table 2). Principal destinations were, in descending order, the Republic of Korea, Colombia, and the United Kingdom. Imports of thorium compounds in 2014 totaled 11.0 t valued at \$761,000, an increase from 2.83 t valued at \$184,000 in 2013. India continued to be the leading supplier of thorium compound imports in 2014.

World Review

Thorium demand worldwide remained depressed because of concerns about its naturally occurring radioactivity. In 2014, exploration and development of rare-earth projects associated with thorium were underway around the globe, but progress on most projects slowed because of an oversupply of rare-earth materials and declining prices.

Canada.—Medallion Resources Ltd. continued to pursue the development of 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 2014, the company was conducting lab-scale metallurgical testing and held a non-binding agreement with Takamol Investment Co. to investigate rare-earth production and processing opportunities within the Arab League (Medallion Resources Ltd., 2015).

Pele Mountain Resources Inc. announced it had revised plans for the development of a thorium-bearing Eco Ridge deposit at Elliot Lake, Ontario. The revised business model focused on the development of processing operations for monazite concentrates at Elliot Lake that would be sourced from mineral sands mine tailings in other countries. At yearend, no details were available in regard to the scale of this operation (Pele Mountain Resources Inc., 2014).

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 2014, sources of China's imports of thorium ores

and concentrates were led by Thailand (3,570 t) and Malaysia (313 t). Thorium may also be present in mixed heavy-mineral concentrates not specifically classified as thorium bearing.

The Chinese Academy of Sciences continued a research initiative to develop thorium molten-salt reactor (TMSR) technologies. In 2014, the effort employed more than 400 scientists and engineers and was led by the TMSR Center at the Shanghai Institute of Applied Physics. The TMSR Center planned for the construction of two 2-megawatt (MW) research reactors by 2017. Construction of a 1,000-MW reactor in the 2030s was expected to help demonstrate the commercial feasibility of the technology (Economist, The, 2014; Endicott, 2013, p. 14; Xu and others, 2013, p. 24).

Greenland.—Greenland Minerals and Energy Ltd. (GMEL) continued to pursue the development of its thorium-bearing Kvanefjeld mining project for the production of rare-earth and uranium concentrates. In 2014, GMEL signed an agreement with China Non-Ferrous Metal Industry's Foreign Engineering and Construction Co. Ltd. (NFC) to pursue a rare-earth partnership. After the agreement, process designs for the proposed operation were sent to NFC for technical review. In 2015, GMEL planned to complete environmental and social impact studies and begin the mine permitting process. In 2014, GMEL provided 30 t of ore for a demonstration study sponsored by the European Union's (EU's) EURARE program that was scheduled to be completed in 2015. EURARE was formed to encourage the sustainable supply of EU rare-earth raw materials (Greenland Minerals and Energy Ltd., 2015, p. 3, 11).

India.—India's producers of monazite concentrate include Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. (KMML). IREL's Manavalakurichi (MK) division near Kanyakumari, Tamil Nadu, is a heavy-mineral-sands operation with a capacity to produce as much as 6,000 tons per year (t/yr) of monazite concentrate. KMML's production capacity at its Chavara, Kerala, heavy-mineral-sands operation is estimated to be 240 t/yr of monazite concentrate. IREL's Aluva Rare Earth Division (RED) in the Ernakulam district, Kerala, is capable of processing monazite into rare-earth compounds and thorium hydroxide. Although India reported no production of rare-earth compounds, a small amount of thorium hydroxide was converted to nuclear-grade ThO₂ for the Bhabha Atomic Research Center and Nuclear Fuel Complex. IREL's Orissa Sands Complex (OSCOM) near Chatrapur, Odisha, is also reported to produce as much as 240 t/yr of mantle-grade thorium nitrate (Indian Bureau of Mines, 2015). In Odisha, IREL completed construction and began commissioning a rare-earth processing plant that could consume monazite and produce 10,400 t/yr of rare-earth chloride, 800 t/yr of rare-earth fluoride, and an unspecified amount of byproduct thorium compounds (Metal-Pages, 2014).

India continued its plan for a three-phase development of its nuclear power program. The first phase of the program was based on natural uranium-fueled, heavy water-moderated pressure tube-type reactors commonly known as Pressurized Heavy Water Reactors. In the second phase of the program, still under development, Fast Breeder Reactors would generate fissile plutonium (or uranium-233 for thorium reactors). The third phase of India's nuclear power program was planned to

take advantage of the country's substantial thorium resources; however, the large-scale use of thorium-based fuel for nuclear energy was not expected for several decades. India's Department of Atomic Energy continued the design and development of an advanced heavy water reactor (AHWR) fueled by a thorium-mixed-oxide fuel (thorium-MOX) and its Molten Salt Reactor (MSR) technology. A 300-MW AHWR demonstration reactor was expected to be operational by 2022 (Vijayan and others, 2013).

Kazakhstan.—Summit Atom Rare Earth Co. (SARECO), a joint venture between Japan's Sumitomo Corp. and Kazakhstan's NAC Kazatomprom, commissioned a plant in Stepnogorsk to recover rare earths from uranium-ore residue. The SARECO plant's design capacity was 1,500 t/yr of rare-earth oxide (REO) with a goal to increase capacity to 5,000 to 6,000 t/yr of REO by 2017 (Industrial Minerals, 2014). In 2014, SARECO produced 240 t of rare-earth concentrates; however, the volume and radiological activity of thorium associated with the uranium residues were unknown (Nuclear Society of Kazakhstan, 2015).

Norway.—Thor Energy AS led the Thorium Irradiation Consortium (TIC), a partnership with an international consortium of utilities, industry, and research organizations whose other members included Atomic Energy Research Institute (Republic of Korea), Fortum Oyj (Finland), Institute for Energy Technology (Norway), Institute for Transuranium Elements (Germany), National Nuclear Laboratory (United Kingdom), and Westinghouse Electric Co. (United States). TIC was in the midst of a multiyear test of thorium-MOX. The objective of the test was to gather data and demonstrate that thorium-MOX fuel could operate safely in a commercial reactor. The thorium-MOX fuel is a dense ThO₂ ceramic matrix containing about 10% finely blended plutonium oxide as a fissile driver. The testing was being performed by the Institute for Energy Technology at a fuel-testing reactor in Halden (Thor Energy AS, 2016; World Nuclear News, 2013).

South Africa.—Great Western Minerals Group Ltd. (GWMG), through its subsidiary Rare Earth Extraction Co. Ltd., was proceeding with plans to refurbish the Steenkampskraal monazite mine for the production of rare-earth minerals. In 2014, a feasibility study was completed, mine-site preparations were underway, and the company was continuing the mine-permitting process. GWMG planned to secure financing to advance the project in 2015 (Great Western Minerals Group Ltd., 2014).

Outlook

During the next decade, concerns related to thorium's natural radioactivity are expected to continue to limit its use in nonenergy applications. The potential supply from rare-earth production is expected to increase over time. In the long term, thorium's consumption will increase substantially if its use as a nuclear fuel becomes commercialized. In 2014, the U.S. Nuclear Regulatory Commission (NRC) published a report on safety and regulatory issues of the thorium fuel cycle. In this report, the NRC put forth possible scenarios for using thorium in the nuclear fuel cycle, including use in different nuclear reactor types, and predicted that the most likely near-term nuclear

application of thorium in the United States was in existing operating light water reactors (LWRs). Thorium use in LWRs would mix thorium with uranium, add thorium fuel to LWR fuel assemblies, or use mixed plutonium and thorium fuel assemblies (U.S. Nuclear Regulatory Commission, 2014, p. iii).

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TABLE 1
SALIENT U.S. THORIUM STATISTICS

		2010	2011	2012	2013	2014
Exports, gross weight:						
Thorium ores and concentrates, including monazite	metric tons	1	--	--	--	--
Compounds	do.	1.50	4.28	3.16	1.01	14.80
Imports for consumption, gross weight:						
Thorium ores and concentrates, including monazite	do.	--	30	43	--	--
Compounds	do.	3.03	5.71	4.40	2.83	11.01
Prices, yearend, thorium compounds, gross weight:¹						
France	dollars per kilogram	131	158	153	NA	NA
India	do.	58	58	60	65	65

do. Ditto. NA Not available. -- Zero.

¹Source: U.S. Census Bureau.

TABLE 2
U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS¹

	2013		2014	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Exports:				
Thorium ores and concentrates, including monazite	--	--	--	--
Compounds:				
Colombia	0.01	\$10,500	5.49	\$13,900
Korea, Republic of	--	--	6.46	900,000
United Kingdom	0.45	91,600	2.10	430,000
Other	0.56 ^r	421,000 ^r	0.71	559,000
Total	1.01	523,000	14.80	1,900,000
Imports for consumption:				
Thorium ores and concentrates, including monazite	--	--	--	--
Compounds:				
India	2.83	184,000	11.00	715,000
Other	--	--	0.01	45,900
Total	2.83	184,000	11.01	761,000

^rRevised. -- Zero.

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

Source: U.S. Census Bureau.

TABLE 3
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons, gross weight)

Country ³	2010	2011	2012	2013	2014 ^e
Brazil ⁴	249	290	206	600	--
India ^e	5,200	5,200	5,400	NA ^r	NA
Malaysia	622	571	600	500	500
Thailand	9,405	4,500 ^r	3,500 ^r	1,400 ^r	2,000
Vietnam ⁵	309	361	369	178 ^{r,6}	200
Total	15,800	10,900 ^r	10,100 ^r	2,680 ^r	2,700

^eEstimated. ^rRevised. NA Not available. -- 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 December 23, 2015.

³In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may produce monazite, but available information is inadequate for formulation of reliable estimates of output levels.

⁴Reported production was derived from stockpiled mineral concentrates.

⁵Chinese imports from Vietnam.

⁶Estimated figure based on Vietnam's inferred exports of titanium ores to China, Japan, and the Republic of Korea.