science for a changing world

2019 Minerals Yearbook

THORIUM [ADVANCE RELEASE]

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THORIUM

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An estimated 1,700 metric tons (t) of thorium ores and concentrates, including monazite, was produced in 2019 as a byproduct of heavy-mineral concentrates produced in the United States (table 1). Monazite is a source of rare earths and thorium (a naturally occurring radioactive element). Thorium alloys, compounds, and metal used by 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 the thorium supply.

In 2019, the United States imported no thorium ores and concentrates and exported 1,680 t (table 1), all of which went to China. Imports of thorium compounds equaled 3.97 t, a decrease from 9.0 t in 2018. India provided 50% of the total imports of thorium compounds and France provided 48%. The United States exported 154 t of thorium compounds, mostly (90%) to China. In 2019, the total value of imports of thorium compounds was $213,000 and the total value of exports was $9,380,000 (table 2). In 2016–19, exports of thorium compounds were unusually high relative to historical exports and may have included misclassified materials (table 1).

Global mine production of thorium-bearing monazite concentrate was 34,400 t (table 3). In 2019, monazite-producing countries included Brazil, India, Madagascar, Nigeria, Thailand, the United States, and Vietnam. Other countries, such as China, Indonesia, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States, produced monazite and thorium compounds, but data were inadequate to make reliable production estimates.

Thorium occurs widely throughout the world 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 in vein deposits, thorite ores in vein deposits, and thorium recovered as a byproduct of uranium mining. The United States produced monazite concentrates, which were exported. Elsewhere, monazite was recovered primarily for its rare-earth-element (REE) content and only a small fraction of the byproduct thorium produced was consumed. Excess thorium that was not designated for commercial use was either disposed of as low-level radioactive waste or stored.

Issues associated with thorium's natural radioactivity were and continue to be a significant deterrent to its commercial use. In the United States, only minor amounts of thorium are used annually. In 2019, research into thorium-fueled nuclear reactors continued but no industrial-scale nuclear reactors used thorium. The principal uses of thorium included catalysts, ceramics, 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 2019, an estimated 1,700 t of thorium ores and concentrates were recovered as a byproduct of processing heavy-mineral sands and exported as a salable product.

Beach sands in Brazil, India, Indonesia, the Republic of Korea, Madagascar, Thailand, the United States, and Vietnam were processed to produce monazite concentrates, which may contain 3 to 14 weight percent (wt. %) thorium dioxide (ThO_2) and 41 to 65 wt. % rare-earth oxide (REO). However, monazite from some granitic rocks can contain up to 27 wt. % ThO_2 (René, 2017, p. 204).

Consumption

Insufficient data were collected from thorium processors to determine the consumption of thorium during 2019. Thorium alloys and compounds used by domestic industry were derived from imports or stockpiled inventory.

Thorium consumption was small compared with most other mineral commodities in the world, mainly owing to its radioactive nature. Thorium was used in a variety of catalysts, ceramics, metal applications, nuclear medicine, and optics.

One of the major uses of thorium was 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 were used in cathode heaters, high-intensity discharge lamps, and vacuum tubes for radio transmitters and audio amplifiers.

Thorium dioxide was used in the catalytic cracking of petroleum (converting crude oil into lighter fractions) and as a catalyst in the production of nitric and sulfuric acids. As a fluoride, thorium was used in antireflection materials in optical coatings. In the past, thorium was used as an alloying agent in magnesium and nickel alloys for heat-resistant applications.

One of the oldest uses of thorium was 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.

Thorium was used in nuclear medicine and in radiation therapy. In colloidal form, ^{233}Th was used in electron microscopy as a stain for acid mucopolysaccharides (Lünsdorf and others, 2006).

Interest in thorium as a nuclear fuel continued owing to its being more abundant than uranium and its waste products not as readily exploitable for weapons. Research on thorium fuel cycles was taking place in Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Italy, Japan, the Republic of Korea, the Netherlands, Norway, Russia, the United Kingdom, the United States, and 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 the fuel. The protactinium formed in the thorium fuel cycle also introduces complications which need a solution. As of yearend 2019, experimental nuclear reactors based on a thorium fuel cycle were operated only in India (René, 2017, p. 210). China has developed demonstration prototypes of the Thorium Molten Salt Reactor (TMSR).

Thorium-based nuclear research and development programs have been underway in the United States. The U.S. Department of Energy supported the development of innovative nuclear energy technologies, including the use of thorium fuels, through its Office of Advanced Reactor Technologies (OART) (U.S. Department of Energy, undated). U.S. 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). Moltex Energy, a United Kingdom- and Canada-based company also has been funded by OART.

Prices

Published prices for ThO_2 and thorium nitrate were not available. In 2019, the unit value of thorium nitrate exports from India was $72 per kilogram, unchanged compared with the unit value in 2018 (Zen Innovations AG, 2019). In the United States, the average unit value of imported thorium compounds was $54 per kilogram, a 15% decrease compared with $63 per kilogram in 2018. The average unit value of exported thorium compounds increased to $61 per kilogram in 2019 from $55 per kilogram in 2018 (table 2). For imports and exports, the data often are 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 thorium compound imports by country in 2019 ranged from about $29 per kilogram (shipped from France to New York, NY, in October) to $3,550 per kilogram (shipped from Germany to Savannah, GA, in August) according to the U.S. Census Bureau.

Foreign Trade

Owing to limited consumption, thorium mineral ores and concentrates and compounds were imported and exported sporadically. The United States did not report exports of thorium ores and concentrates from 2015 through 2017 (table 2). In 2018, exports of thorium ores and concentrates totaled 521 t, and in 2019 these exports were nearly 1,680 t. Exports of thorium compounds in 2019 totaled 154 t valued at $9.38 million, an increase from 20.8 t valued at $1.15 million in 2018. The principal destinations of United States exports were China (90%) and Brazil (2%); smaller amounts were shipped to other countries. Most imports of thorium compounds were from India (50%) and France (48%).

World Review

Thorium consumption worldwide was limited by concerns about its naturally occurring radioactivity. In 2019, exploration and development of several rare-earth projects associated with thorium were underway, but most projects emphasized the rare-earth components rather than the thorium because demand and prices for thorium were low.

Brazil.—In 2019, an estimated 1,200 t of monazite was mined the Guaju Mine in Paraiba State, the only active operation in the country. Heavy-mineral sands were mined for REEs, titanium, and zirconium. These sands are close to the surface and readily mined, but there were no reliable estimates of their extent (Gonçalves and Braga, 2019, p. 2–4). The production of heavy-mineral sands in Brazil fluctuated markedly over the prior decade according to the Departamento Nacional de Produção Mineral (now called Agência Nacional de Mineração) (Agência Nacional de Mineração, 2020). There was no production of thorium compounds, and there were no current plans to do so (Gomiero, 2012).

Canada.—In collaboration with DBI Operating Co. (United States), Thorium Power Canada Inc. designed a breeder reactor capable of being built in 2 years (compared with 5 to 7 years for conventional reactors). It was modular and scalable, and like other thorium-based reactors, did not produce waste usable in nuclear weapons. According to the company, no waste would be produced until decommissioning in 30 to 60 years when it would be encapsulated in glass within the reactor (not requiring an external depository, such as Yucca Mountain). Any "unspent" fuel could be transferred to a second-generation reactor. Thorium Power Canada applied to build a 10-megawatt (MW) reactor in Chile to supply power to a 20-million-liter desalination plant, and the company planned to build a 25-MW reactor in Indonesia (Thorium Power Canada Inc., undated).

Commerce Resources Corp. (CRC), an exploration and development company concentrating on the Ashram REE deposit in northern Quebec, was working in association with Université Laval to develop hydrometallurgical processes to separate REEs from gangue into light-REE, SEG (samarium, europium, and gadolinium), and heavy-REE fractions. A flowsheet was established for commercial-scale development of the project (Commerce Resources Corp., 2018). In May 2019, CRC announced that Nayumivik Landholding Corp. of Kuujjuaq and the Makivik Corp. had signed a letter of intent with CRC for the ongoing development of the Ashram deposit (Commerce Resources Corp., 2019). Analysis of drill-hole data in November 2019 reinforced earlier data on REO grades. The prospect of producing salable fluorspar was established (Commerce Resources Corp., 2020). Thorium could be removed during REE extraction, but CRC did not plan on recovering thorium as of yearend 2019.

Medallion Resources Ltd. (MRL) was focused on extracting REEs for magnets for commercial and military use. MRL's approach was to obtain monazite from external sources and use proprietary hydrometallurgical processes to extract the REEs for magnets (Medallion Resources Ltd., 2019). The plant output would be rich in neodymium (Nd) and praseodymium (Pr) for the NdPr products critical to make lightweight magnets for defense purposes, electric vehicles, and other advanced equipment. In accordance with its strategy, MRL initiated a site selection process in the United States for its plant and was exploring funding options. Although thorium could be a byproduct of the REE extraction from monazite, MRL had no plans to recover thorium as of yearend 2019 (Medallion Resources Ltd., 2020).

China.—In January 2011, the Chinese Academy of Sciences initiated China's TMSR program. This was conceived as a 3-stage program. The first stage was to study the technology involved and develop the equipment required. The second stage was to build a 100-MW solid-fueled demonstration TMSR (TMSR-SF2) and 10-MW liquid-fueled molten salt experimental reactor (TMSR-LF2). The third stage would entail gradual commercialization. The TMSR-SF2 would be operated with a once-through fuel cycle, and the TMSR-LF2 would use a thorium-modified open or fully closed fuel cycle (Liu and others, 2015).

The design of the first commercial reactor was approved in June 2018, and the materials and equipment were selected. Construction design was completed in February 2019. The designated modular reactor site was in Wuwei, Gansu Province, and construction began in 2019 (Zou, 2020).

In 2019, China imported 22,700 t of thorium ores and concentrates, primarily from Madagascar (70%), Thailand (14%), Vietnam (10%), and Brazil (5%) (Zen Innovations AG, 2019). The United States exported monazite to China.

Greenland.—Greenland Minerals and Energy Ltd. completed a feasibility study in May 2015 of the Kvanefjeld Project, a multielement deposit containing REEs, uranium, and zinc, with a potential projected mine life of 37 years at a mining rate of 3 million metric tons per year. Unspecified quantities of thorium contained in the concentrates were expected to be removed during the processing of the mineral concentrates. Shenge Resources Holding Ltd. (China) was the largest shareholder of Greenland Minerals and Energy and contributed REE-processing and marketing expertise to the project (Webb, 2016). In June 2018, the company changed its name to Greenland Minerals Ltd. As of yearend 2019, Kvanefjeld's mineral resource and feasibility documentation had been approved by the Greenland Ministry of Mineral Resources and Labour. Environmental permitting in Greenland required three impact assessments: an Environmental Impact Assessment (EIA), a Maritime Safety Study (MSS), and a Social Impact Assessment (SIA). The SIA and MSS were accepted for public comments. The EIA was still in review related to the tailings dam closure design. In addition, the seismic analysis and modelling were accepted (Greenland Minerals Ltd., 2020).

India.—India's estimated monazite resources were about 13 million metric tons (Mt). 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, 2020).

Thorium does not split to release energy. When exposed to neutrons, thorium undergoes a series of nuclear reactions until it emerges as ^{233}U. This isotope of uranium splits on absorbing a neutron and releases energy. Some reactors in India were constructed on this principle, including the KAMINI research reactor located at Kalpakkam, Tamil Nadu, which attained criticality in October 1996, and the Bhavini Prototype Fast Breeder Reactor, also at Kalpakkam, which was expected to attain criticality in December 2021 (Usha and others, 2006; World Nuclear News, 2019).

The Government of India regulated all mining, processing, and storage of monazite-containing sands and concentrates. The Atomic Mineral Concession Rules (2016) stipulated that all beach sands containing more than 0.75% monazite were reserved for Government-owned corporations. The only producers of concentrates were Indian Rare Earths Ltd. (IREL) and Kerala Metals and Minerals Ltd. (KMML), both Government entities. The monazite concentrates were stockpiled contingent on the percentage of monazite contained. IREL had a plant at Udyogamandal in Ernakulam district, Kerala, which processed monazite to produce rare-earth chlorides and thorium hydroxide. IREL also had a monazite-processing plant in Odisha capable of producing 11,000 metric tons per year of rare-earth chlorides and associated products. India had an agreement with Japan to produce rare earths (Indian Bureau of Mines, 2020).

According to trade data from India, the country exported 2,300 kilograms (kg) of thorium nitrate in 2019, of which 2,000 kg was exported to the United States and 300 kg was sent to Germany (Zen Innovations AG, 2019).

Malaysia.—As the use of thorium as a fuel for nuclear power develops, Malaysia planned to use this resource for energy production. Historically, most of the monazite in the country was used to recover REEs, which were crucial for use in several advanced technology products. The waste stream from these processes (which includes thorium) is radioactive, which has caused environmental and safety concerns among the public. This issue was first raised in the 1990s but became more acute since the licensing of the Lynas Advanced Materials Plant (LAMP) in Gebeng, Pahang. Lynas Corp. Ltd. (Australia) mined monazite at its Mt. Weld deposit in Australia, and the concentrate was shipped to Malaysia for further refinement at LAMP. A concept to remove the thorium from the leach was proposed that could reduce the radioactivity by 80% depending on the process used (AL-Areqi and others, 2015). This had the advantage that thorium would be isolated and later used for power generation. On August 13, 2019, Malaysia's Atomic Energy Licensing Board extended Lynas' operating license for 6 months (Annuar, 2020).

Norway.—Thor Energy AS formed a consortium, including companies from Finland, the Republic of Korea, Norway, the United Kingdom, and the United States (Westinghouse Electric Corp.), to develop a thorium-based oxide fuel and was testing fuels at its Halden facility. Phase 3 of the tests started on February 6, 2018, and used thorium-mixed oxide pellets developed by Thor Energy. Once these thorium fuels were approved, they could be used in new and existing light-water reactors (Thor Energy AS, 2016, 2018).

South Africa.—The Steenkampskraal Mine (SKK) was an idle monazite mine about 330 kilometers north of Cape Town in the Western Cape Province. It was owned by Steenkampskraal Holdings Ltd. (SHL). The mining rights were owned by Steenkampskraal Monazite Mine (Pty) Ltd. (SMM), a subsidiary of SHL. SMM was awarded the mining rights on June 2, 2010, for a 20-year period, which was renewable. A National Instrument 43–101-compliant mineral resource estimate indicated that ore grades were 14.4% REE and 2.1% thorium. The minable reserves were estimated to be 86,900 t of REO and yttrium oxide (Steenkampskraal Holdings Ltd., 2018a).

SHL won an outstanding legal case in Pretoria's High Court on December 6, 2018 (Steenkampskraal Holdings Ltd., 2018b), and obtained its last permit, a water license from the Department of Water and Sanitation, on November 20, 2019 (Steenkampskraal Holdings Ltd., 2019). In a press release on December 20, 2019, SHL announced that the mine was ready for construction and production activities. The company planned to use the existing mine infrastructure (Mining.com, 2019).

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 three to four times more abundant than uranium). The reactor was a high-temperature, helium-cooled, pebble-bed module capable of accommodating various types of nuclear fuels. The use of thorium as a fertile material was a requirement in STL Nuclear's design and minimized plutonium production [Steenkampskraal Thorium (Pty) Ltd., undated].

Outlook

Currently, the demand for thorium is low because of its radioactivity. Usually, substitutes are preferred when they can be used, except for research or medical purposes.

The use of thorium as a nuclear fuel has been investigated for more than five decades, and some of the approaches have been discussed above. These efforts are expected to be successful within the next decade. When that happens, the demand for thorium is expected to increase markedly.

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

		2015	2016	2017	2018	2019
Production, gross weight, thorium ores and concentrates, including monazite	metric tons	--	--	--	500 e	1,700 e
Exports, gross weight:						
Thorium ores and concentrates, including monazite	do.	--	--	--	521	1,680
Thorium compounds	do.	2.16	63.9	88.6	20.8	154
Imports for consumption, gross weight:						
Thorium ores and concentrates, including monazite	do.	--	16	--	1	--
Thorium compounds	do.	2.74	3.12	8.51	9.00	3.97
Prices, annual average, thorium compounds, gross weight,[2] India	dollars per kilogram	63	65	73	72	72

eEstimated. do. Ditto. -- Zero.
1Table includes data available through August 4, 2020. Data are rounded to no more than three significant digits.
2Source: U.S. Census Bureau.

TABLE 2

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

	2018		2019	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Exports:				
Thorium ores, monazite concentrates (Schedule B number 2612.20.0000):				
China	520	$206,000	1,680	$694,000
United Kingdom	1	7,580	--	--
Total	521	214,000	1,680	694,000
Thorium compounds (Schedule B number 2844.30.1000):				
Brazil	9.83	142,000	23.10	162,000
China	--	--	120.00	8,480,000
Uruguay	7.04	102,000	--	--
Other	3.93 r	906,000 r	11.00	746,000
Total	20.80	1,150,000	154.00	9,380,000
Imports for consumption:				
Thorium ores, monazite concentrates [Harmonized Tariff Schedule of the United States (HTS) code 2612.20.0000], Canada	1	4,260	--	--
Thorium compounds (HTS code 2844.30.1000):				
France	2.07	59,700	1.92	55,400
India	6.90	497,000	2.00	144,000
Other	(2)	10,500	(2)	13,300
Total	9.00	567,000	3.97	213,000

[r]Revised. -- Zero.

[1]Table includes data available through April 16, 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]	2015	2016	2017	2018	2019[e]
Brazil	1,625	4,525	2,900	2,000 e	1,200
India[e]	3,000	2,500	3,000	5,000	5,000
Madagascar	--	--	--	16,000	21,000
Malaysia	499	230 e	130 e	91 e	--
Nigeria	80	--	55	50 e	54
Thailand[e, 3]	1,300	2,600	2,200	1,700	3,200
United States	--	--	--	500 e	1,700
Vietnam[e, 4]	460	400	360	1,500	2,200
Total	6,960 e	10,300 e	8,650 e	26,800	34,400

[e]Estimated. -- Zero.

[1]Table includes data available through May 27, 2020. 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, 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.