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2007 Minerals Yearbook

THORIUM [ADVANCE RELEASE]

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THORIUM

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Thorium consumption worldwide is relatively small compared with that of most other mineral commodities. There was no domestic production of thorium in 2007. All thorium alloys, metal, and compounds used by the domestic industry were derived from company stocks, imports, or material previously acquired from the U.S. Government stockpile. Domestic imports for consumption of refined thorium products decreased by 87% in 2007, according to data collected by the U.S. International Trade Commission (table 1). The value of thorium compounds used by the domestic industry in 2007 was estimated to be about $318,000, a decrease from $1.56 million in 2006. Only minor amounts, less than 10 metric tons (t), of thorium are typically used annually. However, large fluctuations in consumption are caused by intermittent use, especially for catalytic applications that do not require annual replenishment. In 2007, thorium compounds were imported from France (84%) and Canada (16%).

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 content, and only a small fraction of the byproduct thorium produced was consumed. Monazite-producing countries were Brazil, India, and Malaysia.

Problems associated with thorium's natural radioactivity represented a significant cost to those companies involved in its mining, processing, manufacture, transport, and use. The costs to comply with environmental regulations and potential legal liabilities and the high costs to purchase storage and waste disposal space were the principal deterrents to its commercial use. Health concerns associated with thorium's natural radioactivity have not been a significant factor in switching to alternative nonradioactive materials (Ed Loughlin, Grace-Davison division of W.R. Grace & Co., oral commun., 1997; Don Whitesell, The Coleman Company, Inc., oral commun., 2002).

Limited demand for thorium, compared with demand for rare earths produced from thorium-containing minerals, continued to create a worldwide oversupply of thorium compounds and residues. Most major rare-earth processors have switched feed materials to thorium-free intermediate compounds, such as rare-earth chlorides, hydroxides, or nitrates. Excess thorium not designated for commercial use was either disposed of as a low-level radioactive waste or stored for potential use as a nuclear fuel or in other applications. Principal nonenergy uses have shifted from refractory applications to chemical catalysts, lighting, and welding electrodes.

Legislation and Government Programs

No stocks of thorium nitrate remain in the National Defense Stockpile (NDS). Thorium nitrate previously stored at the Defense National Stockpile Center depots at Curtis Bay, MD, and Hammond, IN, were shipped to the low-level radioactive waste disposal area of the Nevada Test Site, NV. Shipments to Nevada from both depots were completed by the end of fiscal year 2005.

Production

Domestic mine production data for thorium-bearing minerals were developed by the U.S. Geological Survey from a voluntary canvass of U.S. thorium operations. The one mine to which a canvass form was sent responded. Although thorium was not produced in the United States in 2007, the mine that had previously produced thorium-bearing monazite continued to produce titanium minerals and zircon and maintained its monazite capacity on standby. Production of monazite in Florida was expected to resume in 2007; Iluka Resources Limited planned to reprocess tailings mainly for the zircon content. Monazite was last produced in the United States in 1994.

Consumption

Statistics on domestic thorium consumption were developed by analyzing Government stockpile shipments, evaluating import and export data, and surveying various processors and manufacturers.

Domestic thorium producers and processors that were surveyed reported no consumption of thorium oxide equivalent in 2007. Additional information on domestic consumption was not available. Essentially all thorium alloys and compounds used by the domestic industry were derived from imports, company stocks, or materials previously sold from the National Defense Stockpile. Domestic companies processed or fabricated various forms of thorium for nonenergy uses, such as ceramics, chemical catalysts, lighting, and welding electrodes.

Thorium Power Ltd., a leading innovator of thorium-based nuclear fuel designs in the United States, announced that it had signed an agreement with Red Star (GP Krasnaya Zvezda), a Russian Government-owned nuclear reactor design company. Thorium Power's seed and blanket design will undergo testing with the goal of scaling-up for use in a full-sized commercial reactor, such as the Russian VVER-1000 reactor. The agreement will require ratification by the Russian Federal Agency for Atomic Energy (RosAtom). The last milestone will be demonstration testing of the fuel lead-test assemblies for use in a full-size commercial reactor, the last stage before installation in multiple powerplants (Thorium Power Ltd., 2007a). In March, the company announced the successful completion of thermal-hydraulic testing of the scaled-up nuclear fuel at OKB Mechanical Engineering (OKBM) facilities (Thorium Power Ltd., 2007b). Two of the recently completed tests simulated emergency pressure and temperature conditions that would be experienced inside a commercial reactor core. The first test was conducted for thorium fuel design assembly conditions of a Russian VVER-1000 reactor, while the second test simulated a Western-design pressurized water reactor (PWR).

Early oceanographers noted that deep-sea organisms are nourished by a "rain" of organic detritus from the overlying surface (Agassiz, 1888, p. 313). Researchers at the Woods Hole Oceanographic Institution and other research facilities assessed the use of sediment traps deployed in the upper ocean, including the typically measured isotope thorium-234. The loss of thorium-234, a natural oceanic decay product, from surface waters is a direct indication of the removal rate of material on sinking particles from the upper ocean because its highly reactive chemistry causes it to stick to particle surfaces. The measurement and calculation of the movement or flux of these particulates in the oceanic water column has been accomplished by deploying neutrally buoyant carbon flux traps to collect particulates and measure the thorium-234 activity. In an analysis of four annual time-series thorium-234 trap comparison studies in the upper ocean, under collection of thorium-234 carrying particles was found to be low by a factor of two. The factors for the under collection are unclear but may be issues with the comparison between radionuclide models and trap flux, a missed episodic flux event, trap shape, and ocean system variables, or various other ocean column dynamics (Buesseler and others, 2007).

Prices

Thorium oxide prices in 2007, as quoted by Rhodia Electronics and Catalysis, Inc.'s U.S. subsidiary Rhodia, Inc., increased from those of the previous year (table 1). At yearend, the price for thorium oxide delivered, duty paid, was $200.00 per kilogram for 99.9% purity, an increase from the revised $175.00 per kilogram at yearend of 2006. In 2007, the 99.99% purity thorium oxide product was discontinued. Thorium nitrate prices from Rhodia were unchanged at $27.00 per kilogram for mantle-grade material. Thorium nitrate was used in the manufacture of mantles for incandescent "camping" lanterns, including natural gas lamps and oil lamps. Thorium mantles provide an intense white light that is adjusted towards the yellow region by a small addition of cerium. Thoriated mantles were not produced domestically owing to the development of a suitable thorium-free substitute.

Foreign Trade

Exports of thorium compounds from the United States were 1,630 kilograms (kg) valued at $500,000, an increase from 1,086 kg in 2006 (table 2). Principal destinations were, in order of quantity, Argentina, Singapore, Austria, and Senegal. Domestic exports of thorium ore (monazite concentrates) were 1 t valued at $34,918.

Imports of thorium compounds in 2007 were from Canada and France and were 6,370 kg valued at $318,000, a decrease from the 48,600 kg valued at $1.56 million in 2006 (table 2). Rhodia Electronics & Catalysis' rare-earth separation plant in La Rochelle, France, remained the principal source of thorium compounds imported into the United States and was also the actual source for some of the thorium imported through Canada. Most of the thorium was supplied from older stocks that were produced when the plant was processing monazite. The La Rochelle plant processes intermediate rare-earth concentrates that have had the thorium removed.

In 2007, no thorium ores and concentrates were imported, a decrease from the 10 t imported from Canada in 2006 valued at $4,800.

World Review

Thorium demand worldwide remained depressed because of concerns over its naturally occurring radioactivity. Industrial consumers expressed concerns about the potential liabilities, the cost of environmental monitoring to comply with regulations, and the cost of disposal at approved waste burial sites. Interest in thorium increased worldwide as various countries have exhibited an interest in thorium-fueled nuclear power as an alternative to uranium. In 2007, geologic exploration for thorium resources continued in Canada, India, and the United States.

India.—The Indian Government continued to advance its three-stage plan to use its modest uranium and vast thorium resources. Its vast thorium resources are contained in numerous heavy-mineral sands deposits in the States of Andhra Pradesh, Kerala, Orissa, and Tamil Nadu. Stage three of the plan was to use thorium to meet the energy needs of India. Several steps towards this third stage have been completed including setting up the Kamini research reactor at Kalpakkam using uranium-233 as a fuel created from irradiated thorium; irradiating thorium fuel bundles in the Indian research reactor at Trombay and in pressurized heavy-water reactors; designing an advanced heavy-water reactor using thorium fuel; and developing technologies to reprocess irradiated thorium-232 fuel and fabricate uranium-233 fuel. India's Department of Science and Technology reported that India has a stockpile of 30,000 t of thorium concentrate in silos for future energy generation (India Department of Science and Technology, 2007).

A U.S. company, Dauvergne Brothers Inc. (DBI), has offered to build a thorium-fueled reactor in India. The breeder reactor operates on the thorium-232/uranium-233 cycle. The reactor would initially use fissile uranium-233 to initiate fission, since thorium is not fissile by itself. Incrementally, the fuel will generate or breed its own uranium-233 from the thorium-232 and eventually operate by adding only thorium fuel to maintain the reaction. The design does not require fuel reprocessing as do conventional breeder reactors—instead a portion of the thorium activated fuel would be transferred to a second reactor at a higher output rate than the original rate. Fresh thorium bundles would be added to the reactor to perpetuate the fuel cycle (Hindustan Times, 2007). The company claims the DBI reactor will operate for 10 years on a 25% uranium oxide and 75% thorium oxide core before it requires refueling. This would be a similar refueling schedule to that of conventional thorium breeder reactors that operated at Fort St. Vrain, CO, and Shippingsport, PA.

Russia.—Thorium Power Ltd. announced that it had signed an agreement with the Russian nuclear company, Kurchatov Institute, related to irradiation testing of Thorium Power's thorium fuel designs. Since 2002, testing has been ongoing at Kurchatov Institute's nuclear energy research facilities in Moscow. The agreement assigns worldwide rights to Thorium Power Inc. (a subsidiary of Thorium Power Ltd.) for title and interest in the technical data created from the testing of the thorium ampoule for use in seed and blanket fuel assemblies. The ampoule irradiation testing provides the long-term testing necessary for nuclear regulatory licensing of Thorium Power's fuel designs (Thorium Power Ltd., 2007c). The planned thorium reactor design was expected to only require refueling every 9 years compared with every 3 to 4 years for a conventional uranium-fueled reactor.

United States.—Idaho Engineering and Geology, Inc. studied the thorium and rare-earth reserves of the Lemhi Pass area of Idaho and Montana for Thorium Energy, Inc. and Williams Investment Company. The thorium and rare-earth deposits in the region were initially studied by the U.S. Geological Survey (Sharp and Cavender, 1962; Staatz, 1972, 1979) and others, including the Idaho Bureau of Mines and Geology, Idaho Energy Reserves Company (IERCO), a subsidiary of Idaho Power Company, the Idaho Geological Survey (Gillerman and others, 2003), Tenneco Oil Company, the U.S. Atomic Energy Commission, and the U.S. Bureau of Mines. The Last Chance claims in Lemhi Pass, ID, are held by Thorium Energy and have an average concentration of 0.39% thorium oxide and 0.33% rare-earth oxide and a measured reserve of 16,425 t of ore containing 194 t of thorium oxide and 153 t of rare-earth oxide. Measured and indicated reserves are 582,000 t of ore and an additional inferred reserve of 330,000 t or ore. Total reserves of the Last Chance vein deposit are 915,000 t of ore containing 3,579 t of thorium oxide and 2,977 t of rare-earth oxide (Reed, 2007).

Outlook

Thorium has been found to some extent in virtually every continent of the world, but is found in concentration in relatively few geologic deposit types. Basically, there are three principal sources of thorium that 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 use in the United States has decreased substantially during the past decade. Domestic consumption is expected to remain at recent depressed levels unless thorium's use as a nonproliferative nuclear fuel gains widespread commercialization or a low-cost technology is developed to dispose of thorium residues created as a byproduct during mineral processing, specifically for monazite. In the long term, high-disposal costs, increasingly stringent regulations, and public concerns related to thorium's natural radioactivity are expected to continue to depress its use in nonenergy applications in the United States as well as worldwide.

References Cited

Agassiz, Alexander, 1888, Three cruises of the United States Coast and Geodetic Survey steamer *Blake* in the Gulf of Mexico, in the Caribbean Sea, and along the Atlantic coast of the United States from 1877 to 1880: Bulletin Museum Comparative Zoology, Harvard University, v. 14, no. 15, 314 p.

Buesseler, K.O., and others, 2007, An assessment of the use of sediment traps for estimating upper ocean particle fluxes: Journal of Marine Research, v. 65, p. 345-416.

Gillerman, Virginia, Lund, Karen, and Evans, Karl, 2003, Stratigraphy, structure, and mineral deposits of the Lemhi Pass area, central Beaverhead Mountains, Eastern Idaho: Belt Symposium IV—Northwest Geology, v. 32, p. 134-146.

Hindustan Times, 2007, U.S. firm offers India thorium reactors: New Delhi, India, Hindustan Times, September 17, 1 p. (Accessed November 17, 2007, at URL http://www.hindustantimes.com/StoryPage/StoryPage.aspx?id=56bfab2e-8d67-4ac7-9af2-d19d28100ee8.)

India Department of Science and Technology, 2007, Stocks of thorium: New Delhi, India, India Department of Science and Technology media release, November 22, 1 p.

Reed, Rich, 2007, Thorium & rare earth reserves of Thorium Energy, Inc., Lemhi Pass Idaho and Montana: Boise, Idaho, Idaho Engineering & Geology, Inc., 12 p.

Sharp, William, and Cavender, Wayne, 1962, Geology and thorium-bearing deposits of the Lemhi Pass area, Lemhi County, Idaho, and Beaverhead County, Montana: U.S. Geological Survey Bulletin 1126, 76 p.

Staatz, Mortimer, 1972, Geology and descriptions of the thorium-bearing veins, Lemhi Pass quadrangle, Idaho and Montana: U.S. Geological Survey Bulletin 1351, 94 p.

Staatz, Mortimer, 1979, Geology and mineral reserves of the Lemhi Pass thorium district, Idaho and Montana: U.S. Geological Survey Professional Paper 1049–A, 90 p.

Thorium Power Ltd., 2007a, Thorium Power forms strategic alliance with Red Star, leading Russian nuclear design bureau; advances program for lead test assemblies in a full size commercial reactor: McLean, VA, Thorium Power Ltd. media release, April 19, 3 p.

Thorium Power Ltd., 2007b, Thorium Power reaches major milestone in testing of its proprietary nuclear fuel: McLean, VA, Thorium Power Ltd. media release, March 6, 2 p.

Thorium Power Ltd., 2007c, Thorium Power signs new agreement with Russia's Kurchatov Institute: McLean, VA, Thorium Power Ltd. media release, December 31, 1 p.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Nuclear Fuels. Ch. in United States Mineral Resources, Professional Paper 820, 1973.

Thorium. Ch. in Mineral Commodity Summaries, annual.

Other

Thorium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.

Uranium Industry Annual. U.S. Department of Energy, 2002.

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

(Kilograms and dollars per kilogram)

	2003	2004	2005	2006	2007
Exports, gross weight:					
Thorium ore, including monazite	23,000	18,000	--	--	1,000
Compounds	590	731	737	1,090	1,630
Imports, gross weight:					
Thorium ore, including monazite	--	--	--	10,000	--
Compounds	4,140	5,320	4,930	48,600	6,370
Prices, yearend:					
Nitrate, gross weight[2, 3]	27.00	27.00	27.00	27.00	27.00
Oxide, 99.9% purity[3]	82.50	82.50	82.50	175.00 r	200.00

rRevised. -- Zero.
1Data are rounded to no more than three significant digits, except prices.
2Source: Rhodia Canada, Inc., free on board port of entry, duty paid, thorium oxide basis.
3Source: Catalysis, Inc. and Rhodia Electronics.

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

	2006		2007		
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Principal destinations/sources and quantities, 2007
Exports:					
Thorium ore, monazite concentrate	--	--	1,000	$34,900	United Kingdom, 1,000.
Compounds	1,090	424,000	1,630	500,000	Australia, 732; Singapore, 719; Austria, 53; Senegal, 41.
Imports:					
Thorium ore, monazite concentrate	10,000	4,800	--	--	
Compounds	48,630	1,560,000	6,370	318,000	France, 5,370; Canada, 998.

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

Source: U.S. Census Bureau.

TABLE 3
MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons, gross weight)

Country[3]	2003	2004	2005	2006	2007
Brazil	--	731 4	958 r, 4	960 r	960
India	5,000	5,000	5,000	5,000	5,000
Malaysia	795 4	1,683 4	320 4	894 r, 4	800
Total	5,800	7,410	6,280 r	6,850 r	6,760

rRevised. -- Zero.
1World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
2Table includes data available through April 18, 2008.
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; available general information is inadequate for formulation of reliable estimates of output levels.
4Reported figure.