THORIUM

By James B. Hedrick

Thorium was discovered in 1828 by Swedish chemist and mineralogist Jons Jakob Berzelius. He named it thoria, after Thor, the ancient Norse god of thunder. He isolated the element from a black silicate mineral from the island of Lövö near Brevig, Norway. Subsequently, the black mineral from which thoria was derived was named thorite. Thorium's radioactivity was discovered independently in 1898 by Madame Curie and C. G. Schmidt.

Thorium is the 39th most abundant of the common elements (78) in the Earth's crust at 7.2 parts per million. It is a soft, very ductile, silvery-white metal that emits radioactive alpha particles. Th^{232} has a very long half-life of 1.389×10^{10} years. Daughter products of thorium's disintegration produce alpha, beta, and gamma emissions, however, most have relatively short half-lives. The metal weighs about six times as much as magnesium and has a very high melting point. Thorium oxide, which is also called thoria, has the highest melting point of all the oxides. Its high-temperature properties are used in the manufacture of high-strength, high-temperature alloys and in refractory ceramics.

Domestic consumption of refined thorium products increased, according to the U.S. Geological Survey (USGS). The value of thorium metal and compounds used by the domestic industry correspondingly increased and was estimated to be about $250,000. Thorium production was primarily from the rare-earth-thorium phosphate mineral, monazite, a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Thorium compounds were produced from monazite during processing for the rare earths. Only a small portion of the thorium produced was consumed; most was discarded as waste. The major monazite producing countries were Australia, Brazil, China, India, Malaysia, and Thailand. Essentially all of the thorium compounds, metal, and alloys used by the domestic industry were derived from imports, company stocks, or material sold from U.S. Government stocks.

Limited demand for thorium, relative to the rare earths, continued to create an extensive world oversupply of thorium compounds and residues. Most major rare-earth processors have switched feed materials to thorium-free intermediate compounds. Excess thorium, not designated for commercial use, was either disposed of as a radioactive waste or stored for potential use as a nuclear fuel or other application. Major nonenergy uses have shifted from refractories to carbon arc lighting and welding electrodes.

Problems associated with thorium's natural radioactivity represented a significant cost to those companies involved in its mining, processing, manufacture, and use. Increased costs to comply with environmental regulations, potential legal liabilities, and the costs to purchase storage and waste disposal space were the principal deterrents to its commercial use. According to industry sources, health concerns associated with thorium's natural radioactivity, which is solely alpha emissions, have not been a factor in switching to alternative non-radioactive materials.

Legislation and Government Programs

The calendar year 1995 included the U.S. Government fiscal years for 1995 and 1996. Public Law 103-337, the National Defense Authorization Act for Fiscal Year 1995, was enacted on October 5, 1994 and covered the year 1995 through September 30. It continued the previous authorization for disposal of all stocks of thorium nitrate in excess of the National Defense Stockpile (NDS) goal of 272,155 kilograms (600,000 pounds). The National Defense Authorization Act for Fiscal Year 1996, Public Law 104-106, was not enacted until February 10, 1996, because of significant delays in the Congressional budget process. It did not change previous authorizations for the disposal of 2,946,185 kilograms (6,495,225 pounds) of thorium nitrate classified as excess to goal.

Production

Domestic mine production data for thorium-bearing monazite were developed by the USGS from a voluntary survey of U.S. operations entitled, Thorium. The one mine to which a survey form was sent responded, representing 100% of the mines surveyed. Thorium was not produced in 1995, however, the mine which had previously produced thorium-bearing monazite continued to operate and maintained capacity on standby.

RGC (USA) Minerals Inc., a wholly owned subsidiary of the Australia-based Renison Goldfields Consolidated Ltd., ceased monazite recovery at its dredging operation at Green Cove Springs, FL. RGC (USA) discontinued byproduct recovery of monazite due to decreased demand for thorium-bearing ores. Processing of titanium and zirconium minerals continued at the site.

The largest previous domestic processor of monazite, Grace Davison, (previously Davison Specialty Chemical Co.) in Chattanooga, TN, continued to use thorium-free rare-earth chloride and rare-earth concentrates as feed materials. Essentially all thorium alloys and compounds used by the domestic industry were derived from imports, company stocks, or materials sold from U.S. Government stockpiles. Domestic companies processed or fabricated various forms of thorium for nonenergy uses such as ceramics, incandescent lamp mantles, carbon arc lamps, magnesium-thorium alloys, refractories, and welding electrodes.

Consumption

Statistics on domestic thorium consumption are developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing Government stockpile shipments. *(See table 1.)*

Domestic thorium producers reported consumption of 18.1 metric tons of thorium oxide equivalent in 1995, an increase of 3.4% from the 1994 level. Nonenergy uses accounted for essentially all of the total consumption. Increased consumption was primarily the result of increased demand for thorium in welding electrodes. The approximate distribution of thorium by end use, on an equivalent oxide basis, based on data supplied by processors and several consumers, was as follows: lighting, 79%; welding electrodes, 18%; ceramics and refractories, 3%; metallurgical applications, <0.1%.

Thorium oxide (thoria) has the highest melting point of all the metal oxides, 3,300 °C. This property contributed to its use in several refractory applications. High-temperature uses were in ceramic parts, investment molds, and crucibles.

Thorium fluoride was used in the manufacture of carbon arc lamps. Carbon arc lamps were used in searchlights, movie projectors, and cinematography lighting to provide a high-intensity white light.

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 due to the development of a suitable thorium-free substitute.

Thorium nitrate was also used to produce thoriated tungsten welding electrodes. Thoriated tungsten welding electrodes were used to join stainless steels, nickel alloys, and other alloys requiring a continuous and stable arc to achieve precision welds.

The nitrate form was also used to produce thoriated tungsten elements used in the negative poles of magnetron tubes. Thorium was used because of its ability to emit electrons at relatively low temperatures when heated in a vacuum. Magnetron tubes were used to emit electrons at microwave frequencies to heat food in microwave ovens and in radar systems used to track aircraft and weather conditions.

Thorium was used in other types of electron emitting-tubes, elements in special use light bulbs, high-refractivity glass, radiation detectors, computer memory components, catalysts, photo conductive films, target materials for x-ray tubes, and fuel cell elements.

In metallurgical applications, thorium was alloyed primarily with magnesium. Magnesium-thorium alloys used by the aerospace industry are lightweight, have high-strength, and excellent creep resistance at elevated temperatures.

Thorium-free magnesium alloys with similar properties have been developed and are expected to replace most of the thorium-magnesium alloys presently used. Small quantities of thorium were used in dispersion hardened alloys for high-strength, high-temperature applications.

Thorium was used as a nuclear fuel in the thorium-232/uranium-233 fuel cycle. No domestic commercial reactors are operating with this fuel cycle. The use of thorium as a nuclear fuel is not expected to grow due to the current availability of low cost uranium.

Stocks

Government stocks of thorium nitrate in the NDS were 3,219,633 kilograms (7,097,487 pounds) on December 31, 1995. No stocks of thorium nitrate were sold in 1995, however, 1,117 kilograms (2,462 pounds) were shipped to Oak Ridge National Laboratory for vitrification research.

The U.S. Department of Energy's inventory at yearend was 983,146 kilograms of thorium oxide equivalent contained in ore, metal, and various compounds.

Prices

The price range of Australian monazite (minimum 55% rare-earth oxide including thoria, f.o.b.)[1], as quoted in Australian dollars (A$)[2], remained unchanged at the previous years range of A$300-A$350 per ton. Changes in the United States-Australia foreign exchange rate in 1995, resulting from a weaker U.S. dollar on world markets, caused the U.S. dollar exchange rate to be up $0.02 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, decreased slightly to US$222-US$259[3] per ton at yearend 1995, compared with US$227-US$265[4] per ton at yearend 1994. Prices for monazite remained depressed as several principal world rare-earth processors continued to process only thorium-free feed materials.

Thorium oxide prices quoted by Rhône-Poulenc Basic Chemicals Co., f.o.b., Shelton, CT, were 99.9% purity, $88.50 per kilogram; and 99.99% purity, $107.25 per kilogram.

Thorium prices quoted by Reade Manufacturing Co., a division of Magnesium Elektron, Lakehurst, NJ, at yearend 1995 were $330.69 per kilogram ($150.00 per pound) for thorium hardener (80%Mg-20%Th) in single drum quantities and $61.73 per kilogram ($28.00 per pound) for thorium-containing HZ-32 magnesium alloy ingot. The commercial magnesium-zinc-thorium alloy, ZH-62, was $47.91 per kilogram ($21.73 per pound). Thorium alloys were only available from Magnesium Elecktron stocks in Manchester, England.

World Review

Thorium demand remained depressed as industrial consumers expressed concerns with the potential liabilities, the costs of complying with environmental monitoring and regulations, and cost increases at approved waste disposal sites.

Malaysia.—Monazite production increased substantially in 1995. Produced during processing for tin minerals, the monazite-bearing mixed heavy mineral concentrate, *amang*, was recovered primarily for its titanium minerals content. Increased demand and processiing of *amang* for its titanium minerals resulted in a corresponding increase in monazite production.

Outlook

Nonenergy uses for thorium in the United States have decreased substantially over the past 6 years. Domestic demand is forecast to remain at current depressed levels unless low-cost technology is developed to dispose of residues. Manufacturers have successfully developed acceptable substitutes for thorium-containing incandescent lamp mantles, carbon arc lights, paint and coating evaporation materials, magnesium alloys, ceramics, and investment molds. The traditionally small markets for thorium compounds, carbon arc lighting and welding electrodes, are expected to remain the leading consumers of thorium compounds through the end of the millenia.

Thorium's potential for growth in nonenergy applications is limited by its natural radioactivity. Its greatest potential exists in energy applications, as a nuclear fuel or subatomic fuel, in an industry that accepts radioactivity. In the long term, high disposal costs, increasing regulations, and public concerns related to thorium’s natural radioactivity is expected to continue to negatively impact its future use.

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[1]Free-on-board.

[2]Metal Bulletin (London). Non-Ferrous Ores. No. 8041, Dec. 29, 1995, p. 21.

[3]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of U.S.$1.00=A$1.3510 based on yearend 1995 foreign exchange rates reported by the U.S. Department of the Treasury, Financial Management Service.

[4]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of U.S.$1.00=A$1.3200 based on yearend 1994 foreign exchange rates reported by the U.S. Department of the Treasury, Financial Management Service.

OTHER SOURCES OF INFORMATION

U.S. Geological Survey Publication

Mineral Commodity Summaries 1996

U.S. Bureau of Mines Publications

Bureau of Mines Annual Mineral Industry Surveys
Bureau of Mines Annual Reports
Bureau of Mines Information Circulars
Bureau of Mines Minerals Yearbook
Bureau of Mines Mineral Facts and Problems

TABLE 1
SALIENT U.S. REFINED THORIUM STATISTICS 1/

(Kilograms of thorium dioxide, unless otherwise specified)

	1991	1992	1993	1994	1995
Exports:					
Compounds	2,650	93	189	7	75
Imports:					
Thorium ore metal, excluding monazite	205,000	187,000	--	--	--
Compounds	42,600	13,500	18,300	3,150	20,500
Shipments from Government stockpile excesses	--	--	--	--	--
Consumption, reported nonenergy applications 2/	54,300	40,400	12,800	17,500 r/	18,100
Prices, yearend, dollars per kilogram, thorium dioxide equivalent: 3/					
Nitrate, mantle-grade	$19.94	$21.36	$22.25	$23.30	$23.30
Oxide, 99%-grade	$63.80	$63.80	$65.00	$63.80	NA

r/ Revised. NA Not available.

1/ Data are rounded to three significant digits, except prices.

2/ All domestically consumed thorium was derived from imported metals, alloys, and compounds; monazite containing thorium has been imported but has not recently been used to produce thorium products.

3/ Source: Rhône-Poulenc Basic Chemicals Co.

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

(Kilograms, unless otherwise specified)

	1994		1995		Principal destinations, sources, and quantities, 1995
	Quantity	Value	Quantity	Value	
Exports:					
Thorium ore, monazite concentrate	33,000	$21,100	--	--	
Compounds	7	12,600	75	$25,300	Germany 64; Japan 8; Hungary 3.
Imports:					
Thorium ore, monazite concentrate	--	--	40	10,500	Australia 40.
Compounds	3,150	140,000	20,500	942,000	France 20,500; Canada 8; Switzerland 2.

1/ Data are rounded to three significant digits.

Source: Bureau of the Census.

TABLE 3
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, gross weight)

Country 3/	1991	1992	1993	1994	1995 e/
Australia e/	7,000	6,000	3,000 r/	-- r/	-- 4/
Brazil	1,308	1,400	1,400 e/	1,400 e/	1,400
China e/	1,185 4/	1,800	1,800	1,800	1,800
India e/	4,000	4,000	4,600	4,600	5,000
Malaysia	1,981	777	407	425	814 4/
South Africa e/	430 r/	430 r/	430 r/	131 r/	--
Sri Lanka e/	200	200	200	200	200
Thailand	400 e/	89	220	57 r/	60
United States	W	W	W	W	--
Zaire e/	120	50	20 r/	20 r/	30
Total	16,600 r/	14,700 r/	12,100 r/	8,630 r/	9,300

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

1/ Table includes data available through June 27, 1996.

2/ World totals and estimated data are rounded to three significant digits; may not add to totals shown.

3/ In addition to the countries listed, Indonesia, North Korea, the Republic of Korea, Nigeria, and the former U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

4/ Reported figure.