THORIUM

By James B. Hedrick

Thorium is a soft, very ductile, silver-gray, heavy, metallic element of the actinide series of elements. It is represented by the chemical symbol Th or the isotopic symbol Th^{232}. Thorium metal has a very high melting point, while the oxide, which is also called thoria, has the highest melting point of all the oxides. Twelve isotopes of thorium are known with atomic masses from 223 to 234. Th^{232} emits radioactive alpha particles and has a very long half-life of 1.41×10^{10} years. Daughter products of thorium's disintegration produce alpha, beta, and gamma emissions; however, most have relatively short half-lives.

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. Berzelius 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 78 common elements in the Earth's crust, at 7.2 parts per million. It is about three times more abundant than uranium and is associated with uranium in igneous rocks. In sedimentary rock, thorium and uranium contents are more distinct, as the primary thorium minerals are typically more resistant to geochemical and physical weathering. Thorium occurs in several minerals, the most common being monazite and thorite.

Domestic consumption of refined thorium products decreased in 1996, according to the U.S. Geological Survey (USGS). The value of thorium metal and compounds used by the domestic industry was estimated to be about $300,000. 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 Brazil, China, India, Malaysia, and Sri Lanka. 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. Principal nonenergy uses have shifted from refractory applications to welding electrodes and lighting.

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 have not been a significant factor in switching to alternative nonradioactive materials.

Legislation and Government Programs

The calendar year 1996 included parts of the U.S. Government fiscal years 1996 and 1997. Public Law 104-106, the National Defense Authorization Act for fiscal year 1996, was not enacted until February 10, 1996, because of significant delays in the Congressional budget process and a Presidential veto. It did not change 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 1997, Public Law 104-201, was enacted on September 23, 1996. 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. Thorium was not produced in 1996; however, the mine that 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, in 1994. RGC (USA) discontinued byproduct recovery of monazite due to decreased demand for thorium-bearing rare-earth ores. Processing of titanium and zirconium minerals continued at the site.

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 4.9 metric tons of thorium oxide equivalent in 1996, a decrease of 10% from the revised 1995 level of 5.4 tons. Nonenergy uses accounted for essentially all of the total consumption. 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: welding electrodes, 65%; lighting, 20%; ceramics and refractories, 14%; nuclear applications, 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 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 also was 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. Thorium metal has a high meeting temperature of 1,750 °C and a boiling point of about 4,790 °C. Magnesium-thorium alloys used by the aerospace industry are lightweight and 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 3,218,551 kilograms (7,095,691 pounds) on December 31, 1996. The NDS shipped 815 kilograms (1,796 pounds) for waste disposal research in 1996. No stocks of thorium nitrate were sold during the year.

The U.S. Department of Energy's (DOE) inventory at yearend was 672,000 kilograms of thorium oxide equivalent contained in ore, metal, and various compounds. The DOE contractor shipped an estimated 129,000 kilograms to waste disposal in 1996.

Prices

The price range of Australian monazite [minimum 55% rare-earth oxide including thoria, free-on-board (f.o.b.)/free into container depot (f.i.d.)], as quoted in Australian dollars (A$), remained unchanged at the previous years range of A$300-A$350 per ton. Changes in the United States-Australia foreign exchange rate in 1996, resulting from a weaker U.S. dollar on world markets, caused the U.S. dollar exchange rate to be down $0.07 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased slightly to US$244-US$285[1] per ton at yearend 1996, compared with US$222-US$259[2] per ton at yearend 1995 (Metal Bulletin, 1995; 1996). 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. were unchanged from yearend 1995, 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 1996 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 available

[1]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of U.S. $1.00=A$1.2290 based on yearend foreign exchange rates (U.S. Department of the Treasury, Financial Management Service, Treasury Reporting Rates of Exchange as of December 31, 1996, [1997], p. 1.)

[2]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 foreign exchange rates (U.S. Department of the Treasury, Financial Management Service, Treasury Reporting Rates of Exchange as of December 31, 1995, [1996], p. 1.)

only from Magnesium Elektron 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.

Outlook

Nonenergy uses for thorium in the United States have decreased substantially over the past seven 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, paint and coating evaporation materials, magnesium alloys, ceramics, and investment molds. The traditionally small markets for thorium compounds, welding electrodes, and lighting, are expected to remain the leading consumers of thorium compounds through the end of the millennium. 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 are expected to continue to depress its future use.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

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

(Kilograms of thorium dioxide, unless otherwise specified)

	1992	1993	1994	1995	1996
Exports: Compounds	93	189	7	75	58
Imports:					
Thorium ore metal, excluding monazite	187,000	--	--	--	--
Compounds	13,500	18,300	3,150	20,500	26,400
Shipments from Government stockpile excesses	--	--	--	--	--
Consumption, reported nonenergy applications 2/	35,400 r/	8,260 r/	3,590 r/	5,390 r/	4,920
Prices, yearend, dollars per kilogram:					
Nitrate	$21.36 3/	$22.25 3/	$23.30 3/	$23.30 3/	$14.32 4/
Oxide	$63.80 3/	$65.00 3/	$63.80 3/	NA	$64.45 4/

r/ Revised. NA Not available.
1/ Data are rounded to three significant digits.
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.
4/ Source: Bureau of the Census, average import price.

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

(Kilograms, unless otherwise specified)

	1995		1996		Principal destinations,
	Quantity	Value	Quantity	Value	sources, and quantities, 1996
Exports:					
Thorium ore, monazite concentrate	--	--	2,000	$3,360	United Kingdom 2,000.
Compounds	75	$25,300	58	14,400	Germany 50; Canada 8.
Imports:					
Thorium ore, monazite concentrate	40	10,500	101	41,000	Australia 81; France 20.
Compounds	20,500	942,000	26,400	1,440,000	France 26,300; Switzerland 16.

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/	1992	1993	1994	1995	1996 e/
Australia e/	6,000	3,000	--	--	--
Brazil e/	1,400 4/	1,400	1,400	1,400	1,400
China e/	1,800	1,800	1,800	1,800	1,800
India e/	4,000	4,600	4,600	5,000	5,000
Malaysia	777	407	425	814	450
South Africa e/ 5/	430	430	131	--	--
Sri Lanka e/	200	200	200	200	200
Thailand	89	220	57	60	--
United States	W	W	W	--	--
Zaire e/	50	20	20	20 r/	10
Total	14,700	12,100	8,630	9,230 r/	8,860

e/ Estimated. r/ Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."
1/ Table includes data available through May 28, 1997.
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.
5/ Monazite occurs in association with titanium sands mining but is not necessarily recovered.