THORIUM

By James B. Hedrick

Domestic survey data and tables were prepared by Jason T. Collins, statistical assistant, and the world production tables were prepared by Ronald L. Hatch, lead international data coordinator.

Thorium is the second member of the actinide series of elements in the periodic table. As a pure metal, it is a soft, very ductile, heavy, silver-gray metallic element. It is represented by the chemical symbol Th and several isotopic symbols, the most common being, thorium-232 (Th^{232}). Thorium metal has a very high melting point at 1,750° C. The oxide, which is also called thoria, has the highest melting point of all the binary oxides at about 3,300° C. Th^{232} is the most abundant of the four naturally occurring isotopes of thorium. Th^{232} emits radioactive alpha particles and has a very long half-life of 1.405×10^{10} years. Daughter products created by the radioactive decay of Th^{232} emit alpha, beta, and gamma emissions. Most products of the disintegration series have short half-lifes, ranging from 5.75 years to 0.145 second. The final decay product of the Th^{232} series is the stable isotope Pb^{208}. Thorium's other naturally occurring isotopes (typically uranium decay products), Th^{228}, Th^{230}, and Th^{234}, have half-lifes of 1.9116 years, 75,380 years, and 24.1 days, respectively.

Thorium was discovered in 1828 by Swedish chemist and mineralogist Jöns Jakob Berzelius (Söderbaum, 1929). 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 (Weeks and Leicester, 1968, p. 532). Subsequently, the black mineral from which thoria was derived was named thorite. In 1898, thorium's radioactivity was discovered independently by Marie S. Curie (Curie, 1928) and Gerhard C. Schmidt (Badash, 1966).

At 7.2 parts per million, thorium is the 39th most abundant of the 78 common elements in the Earth's crust. It is about three times more abundant than uranium and is associated with uranium in igneous rock. Because the primary thorium minerals are more resistant to geochemical and physical weathering, the thorium-to-uranium ratio in sedimentary rock is typically higher than its ratio in igneous source rock. Thorium occurs in several minerals, the most common being the rare earth thorium-phosphate mineral monazite, the thorium silicate minerals thorite (Berzelius, 1829) and huttonite (Pabst, 1951), and the hydrated thorium silicate mineral thorogummite (Hidden and Mackintosh, 1889, p. 480-481).

Domestic consumption of refined thorium products decreased substantially in 2000 (table 1). The value of thorium metal and compounds used by the domestic industry was estimated to be about $285,000. Thorium and its compounds were produced primarily from monazite recovered as a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or for tin minerals. Monazite was recovered primarily for its rare-earth content, and only a small portion of the thorium produced was consumed. The major monazite-producing countries were Brazil, India, Malaysia, and Sri Lanka. All thorium compounds, metal, and alloys used by the domestic industry were derived from imports, company stocks, or material previously sold from U.S. Government stocks.

Limited demand for thorium, relative to the rare earths, 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, nitrates, or hydroxides. 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, chemical catalysts, and lighting.

Problems associated with thorium's natural radioactivity represented a significant cost to companies involved in its

Thorium in the 20th Century

In 1900, thorium brightened the world by providing light in the form of brilliant white incandescent lamp mantles. Thorium was derived entirely from the mineral monazite, which was mined for both the oxides of the rare earths and the thorium it contained. At the turn of the last century, 412 metric tons of monazite valued at $48,805 were produced in North Carolina. Most of the monazite produced domestically was exported to Germany and Austria for the manufacture of lamp mantles. Domestic demand for thorium-bearing monazite increased in 1900 when the competing deposits in Brazil came under the control of a single group, and the price of thorium increased. The use of thorium in lamp mantle manufacture was its only commercial application at the start of the 20th century and accounted for 92% of its nonfuel use in 1950. Large demand for thorium, however, had started dimming by 1912 as the gas mantle was largely replaced in the home by incandescent electric light.

In 2000, thorium was no longer produced in the United States and most other parts of the world because of concerns about its naturally occurring radioactivity. The real and potential costs related to compliance with State and Federal regulations, proper disposal, legal liability, and monitoring of its radioactivity have severely limited thorium's commercial value. Most major domestic thorium consumers switched to nonradioactive substitutes in the 1990s. Monazite production in the United States ceased at the end of 1994 owing to decreased demand for thorium-containing ores. Principal uses for thorium in 2000 were in welding electrodes, chemical catalysts, high-temperature refractory applications, incandescent lamp mantles, traveling wave tubes, and microwave-emitting magnetron tubes for radar and microwave ovens.

mining, processing, manufacture, and use. Increased costs to comply with environmental regulations, to deter potential legal liabilities, and to purchase storage and waste disposal space were the principal deterrents to its commercial use. Concern of the effect of thorium's natural radioactivity on health has not been a significant factor in switching to alternative nonradioactive materials.

Legislation and Government Programs

The National Defense Authorization Act for Fiscal Year 2000 (Public Law 106-65), which was enacted on October 5, 1999, did not change the previous authorization for the disposal of all stocks of thorium nitrate in excess of the National Defense Stockpile (NDS) goal of 272,155 kilograms (kg) (600,000 pounds). The law authorized the transfer of no more than $150 million from the NDS transaction fund to the operation and maintenance accounts (no more than $50 million each) of the Army, Navy, and Air Force (section 304). The law also obligated no more than $78.7 million of the NDS transaction fund for the operation of the NDS program, including disposal of hazardous materials that are environmentally sensitive, which would include thorium.

The Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (Public Law 106-398), which was enacted on October 30, 2000, continued the funding of $150 million ($50 million each) of the operation and maintenance accounts of the Army, Navy, and Air Force by the NDS transaction fund. The law obligated no more than $71 million of the NDS transaction fund for the operation of the NDS program, including disposal of hazardous materials that are environmentally sensitive, a decrease of $7.7 million from the previous fiscal year. The revised annual material plan for fiscal year 2000 authorized the disposal of 2,946,033 kg (6,494,891 pounds) of thorium nitrate from the NDS classified as excess to goal.

Production

Domestic mine production data for thorium-bearing minerals were developed by the U.S. Geological Survey from a voluntary survey of U.S. thorium operations. The survey form was sent to one mine, the only previously producing thorium-bearing monazite mine still in operation and it responded. Although thorium was not produced in the United States in 2000, the mine that had previously produced thorium-bearing monazite continued to operate and maintained capacity on standby. Monazite was last produced in the United States in 1994.

Essentially all thorium alloys and compounds used by the domestic industry were derived from imports, company stocks, or materials sold from the NDS. Domestic companies processed or fabricated various forms of thorium for nonenergy uses, such as lighting, chemical catalysts, and welding electrodes.

Consumption

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

Domestic thorium producers reported consumption of 6 metric tons (t) of thorium oxide equivalent in 2000, a decrease from the 7 t consumed in 1999 (table 1). Nonenergy uses accounted for almost all domestic consumption.

Because of the high melting point of thorium oxide it was used in several refractory applications. High-temperature uses were in ceramic parts, investment molds, and crucibles.

Thorium nitrate was used overseas in the manufacture of lamp mantles for use in incandescent camping lanterns, and natural gas and oil lamps. Thorium mantles provide an intense white light that can be adjusted towards the yellow region by the addition of a small amount of cerium. Thoriated mantles have not been produced domestically since the development of a suitable thorium-free substitute, a proprietary yttrium-based mixture.

Thorium nitrate was also used to produce thoriated tungsten welding electrodes. These 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 (cathodes) of magnetron tubes and traveling wave tubes, also known as TWTs. Thorium was used because of its ability to emit free electrons at ambient temperatures when heated in a vacuum. With an improved work function and lower operating temperature, thoriated cathodes lasted longer than nonthoriated filaments. Magnetron tubes were used microwave ovens and to emit electrons at microwave frequencies in radar systems for air traffic control, surveillance, weather monitoring, and weapon systems.

Other applications of thorium included chemical catalysts, electron-emitting tubes, special-use light bulbs, fuel cells, high-refractivity glass, photoconductive films, radiation detectors, and target materials for x-ray tubes.

In metallurgical applications, thorium had been used as an alloy with other metals, primarily magnesium. Magnesium-thorium alloys were used by the aerospace industry for their lightweight, high strength, and excellent creep resistance at elevated temperatures. Thorium-free magnesium alloys with similar properties have been developed and have replaced most of the thorium-magnesium alloys. Small quantities of thorium were used in dispersion-hardened alloys for high-strength, high-temperature applications, because thorium metal has a high melting temperature of 1,750° C and a boiling point of about 4,790° C.

Thorium was used as a nuclear fuel in the Th^{232}/U^{233} fuel cycle. No foreign or domestic commercial reactors were operating with this fuel cycle; however, thorium was being tested as a fuel component in Russia.

Stocks

Government stocks of thorium nitrate in the NDS were 3,218,177 kg (7,094,865 pounds) on December 31, 2000. The NDS inventory included 273,181 kg (602,262 pounds) of containerized thorium nitrate allocated to meet the NDS goal requirements and 2,944,995 kg (6,492,603 pounds) classified as excess to the goal. No stocks of thorium nitrate were sold or shipped during the year, the NDS, however, received additional stocks of 1,349 kg (2,974 pounds) of thorium nitrate.

The U.S. Department of Energy (DOE) inventory at yearend

2000 was 182,000 kg of thorium oxide equivalent contained in metal and various compounds. The DOE contractor, Fernald Environmental Restoration Management Co., which is a division of the Fluor Corp. subsidiary Fluor Daniel Inc., shipped 353 t of thorium oxide to Nevada for disposal during the year.

Prices

The price of monazite concentrate (typically sold with a minimum 55% rare-earth oxide content, including thorium oxide), free-on-board (f.o.b.) as quoted in U.S. dollars and based on 1997 U.S. import data, remained unchanged at $400.00 per metric ton. In 2000, no monazite was imported into the United States.

Thorium oxide prices in 2000, quoted by Rhodia, Inc., were unchanged from the previous year's level. At yearend, thorium oxide prices per kilogram f.o.b. Shelton, CT, were $82.50 for 99.9% purity and $107.25 per kilogram for 99.99% purity. Thorium nitrate prices from Rhodia were $27.00 per kilogram for mantle-grade material.

World Review

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

Current Research and Technology

Radkowsky Thorium Power Corp. (RTPC) received its fourth and final U.S. patent for its nonproliferative seed-and-blanket fuel assembly. The patent was issued to inventor Alvin Radkowsky and the assignee, RTPC. The invention details an improved seed-blanket reactor, which can provide optimum operation from an economic and a nonproliferative perspective. An additional objective is to provide a reactor design that uses large quantities of plutonium and thorium without generating proliferative waste byproducts (U.S. patent No. 6,026,136, issued February 15, 2000).

In July, the Kurchatov Institute obtained a license from the Russian Nuclear Regulatory Committee to begin testing the Radkowsky-designed thorium fuel. An additional 35 scientists at the Kurchatov Institute in Russia were assigned to work with the Radkowsky thorium fuel team. Fuel irradiation experiments began by testing the thorium fuel ampoules in an IR-8 reactor (Thorium Power, July 2000, Thorium power—2000, accessed January 5, 2001, at URL http://www.thoriumpower.com/whats_new/2000.html).

Outlook

Thorium's use in the United States has decreased substantially during the past decade. Domestic demand is forecast to remain at 2000 depressed levels unless low-cost technology is developed to dispose of residues or its use as a nonproliferative nuclear fuel gains widespread commercialization. Its future use in nonenergy applications is expected to continue as a chemical catalyst. 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 domestic thorium compounds, chemical catalysts, welding electrodes, and lighting are expected to remain the leading consumers of thorium compounds through the next decade and longer.

The potential for growth in the applications of thorium in nonenergy applications is limited by its natural radioactivity. Its greatest potential exists in energy applications as a nuclear or a subatomic fuel in industries that accept radioactivity. In the long term, however, high disposal costs, increasingly stringent regulations, and public concerns related to thorium's natural radioactivity are expected to continue to depress its future use in nonenergy applications, especially in the United States.

References Cited

Badash, Lawrence, 1966, The discovery of thorium's radioactivity: Journal of Chemical Education, v. 43, p. 219-220.
Berzelius, J.J., 1829, Undersökning af ett nytt mineral (Thorit), som innehåller en förut obekant jord [Investigation of a new mineral (thorite), as contained in a previously unknown earth (oxide)]: Kungl. Svenska Vetenskapsakademien Handlingar, p. 1-30.
Curie, M.S., 1928, Classic of science—Radioactive substances by Madame Curie: Science News Letter, v. 14, p. 137-138.
Hidden, W.E., and Mackintosh, J.B., 1889, A description of several yttria and thoria minerals from Llano County, Texas: American Journal of Science, 3d series, v. 38, no. 228, December, p. 474-486.
Pabst, Adolf, 1951, Huttonite—A new monoclinic thorium silicate: American Mineralogist, v. 36, p. 60-69.
Söderbaum, H.G., 1929, Jac. Berzelius levnadsteckning [Jacob Berzelius—A portrait of his life]: Uppsala, Sweden, Almquist & Wiksells Boktryckeri A-B, v. 2, p. 66-68.
Weeks, M.E., and Leicester, H.M., 1968, Discovery of the elements (7th ed.): Easton, PA, Journal of Chemical Education, 896 p.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Nuclear Fuels. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
Thorium. Mineral Industry Surveys, annual.
Thorium. Ch. in Mineral Commodity Summaries, annual.
Thorium. Ch. in Minerals Yearbook, 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, 1997.

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

(Kilograms of thorium dioxide, unless otherwise specified)

		1996	1997	1998	1999	2000
Exports, compounds		58	241	1,130	2,520	4,640
Imports:						
Thorium ore, including monazite		7,070	1,400	--	--	--
Compounds		26,400	13,500	7,450	5,290	11,100
Shipments from Government stockpile excesses		--	--	--	--	--
Consumption, reported nonenergy applications 2/		4,920	13,000	7,000	7,000	6,000
Prices, yearend						
Nitrate 3/	dollars per killogram	$14.32	$27.00	$27.00	$27.00	$27.00
Oxide 4/	do.	$64.45	$82.50	$82.50	$82.50	$82.50

-- Zero.
1/ Data are rounded to no more than three significant digits, except prices.
2/ All domestically consumed thorium was derived from imported metals, alloys, and compounds.
3/ Source: Rhodia Canada, Inc., f.o.b. port of entry, duty paid, ThO_2 basis
4/ Source: Rhodia Electronics and Catalysis, Inc., 99.9% purity.

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

(Kilograms and dollars)

	1999		2000		
	Quantity	Value	Quantity	Value	Principal destinations/sources and quantities, 2000
Exports, compounds	2,520	318,000	4,640	478,000	Panama 2,000; Canada 1,600; Japan 494.
Imports, compounds	5,290	280,000	11,100	528,000	France 11,100; Switzerland 26.

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

Source: U.S. Census Bureau.

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

(Metric tons, gross weight)

Country 3/	1996	1997	1998	1999	2000 e/
Brazil e/	-- r/	460 r/	-- r/	-- r/	--
India e/	5,000	5,000	5,000	5,000	5,000
Malaysia	618	767	517 r/	1,147 r/	1,000
Sri Lanka e/	200	200	200	200	200
Thailand	--	12	--	--	--
Total	5,820	6,440	5,720	6,350	6,200

e/ Estimated. r/ Revised. -- Zero.
1/ World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
2/ Table includes data available through April 18, 2001.
3/ In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and countries of the former U.S.S.R. may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.