THORIUM

By James B. Hedrick

Domestic survey data and tables were prepared by Heather A. Geissler, statistical assistant, and the world production table was prepared by Glenn J. Wallace, 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 or several isotopic symbols, the most common being Th^{232}. Thorium metal has a very high melting point, 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 of the Th^{232} disintegration series produce 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 Th^{228}, Th^{230}, and Th^{234} have half-lifes of 1.9116 years, 75,380 years, and 24.1 days, respectively.

Domestic consumption of refined thorium products decreased substantially in 2001, according to the survey conducted by the U.S. Geological Survey (USGS). The value of thorium metal and compounds used by the domestic industry was estimated to be about $70,000. Thorium and its compounds were produced primarily from monazite, recovered as a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Monazite was recovered primarily for its rare-earth content and only a small portion of the thorium produced was consumed. The monazite-producing countries were Brazil, China, 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 chemical catalysts, 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 and potential legal liabilities and 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 (Don Whitesell, The Coleman Co., Inc., oral commun.; Ed Loughlin, Grace-Davison division of W.R. Grace & Co., oral commun.).

Legislation and Government Programs

Public Law 106-398, the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001, was enacted on October 30, 2000. The National Defense Stockpile (NDS) Transaction Fund continued to fund $150 million to the operation and maintenance accounts of the Army, Navy, and Air Force, providing up to $50 million for each. The law obligated up to $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 Materials Plan for fiscal year 2000 authorized the disposal of 2,946,033 kilograms (kg) (6,494,891 pounds) of thorium nitrate from the NDS classified as excess to goal.

Public Law 107-107, the National Defense Authorization Act for Fiscal Year 2002, was enacted on December 28, 2002. The law authorized the disposal of 272,155 kg (600,000 pounds) of thorium nitrate in the NDS considered obsolete and excess. The NDS manager was authorized to obligate up to $65.2 million for the uses under section 9(b)(2) of the Strategic and Critical Materials Stock Piling Act, including the disposal of hazardous materials that are environmentally sensitive, which would include thorium nitrate.

Production

Domestic mine production data for thorium-bearing minerals were developed by the USGS from a voluntary survey of U.S. thorium operations. The one mine to which a survey form was sent responded. Although thorium was not produced in the United States in 2001, 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 are developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing Government stockpile shipments.

Domestic thorium producers reported no consumption of thorium oxide equivalent in 2001, a decrease from the 6 metric tons (t) consumed in 2000 (table 1).

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

Thorium nitrate was used in the foreign manufacture of lamp mantles for use in incandescent camping lanterns, natural gas lamps, and oil lamps. Thorium mantles provide an intense white light that is 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.

Thorium nitrate also was 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 also was 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 last longer than nonthoriated filaments. Magnetron tubes were used to emit electrons at microwave frequencies in radar systems for air traffic control, surveillance, weather monitoring, and weapon systems and to heat food in microwave ovens.

Thorium was used in other applications as chemical catalysts, in electron-emitting tubes, elements in special-use light bulbs, fuel cell elements, high-refractivity glass, photoconductive films, radiation detectors, and target materials for x-ray tubes.

In metallurgical applications, thorium has previously been alloyed with other metals, primarily magnesium. Thorium metal has a high melting temperature of 1,750° C and a boiling point of about 4,790° C. 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.

Thorium was used as a nuclear fuel in the Th^{232}/U^{233} fuel cycle. No foreign or domestic commercial reactors are operating with this fuel cycle (U.S. Department of Energy, oral communication, 2002). 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, 2001. 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; however, the NDS received additional stocks of 1,349 kg (2,974 pounds) of thorium nitrate.

The U.S. Department of Energy's (DOE) inventory at yearend was 96,000 kg of thorium oxide equivalent contained in metal and various compounds. During the year, The DOE contractor Fernald Environmental Restoration Management Co. (a division of Fluor Corp.'s subsidiary Fluor Daniel Inc.) shipped 86 t of thorium oxide equivalent to Nevada for disposal during the year.

Prices

Thorium oxide prices in 2001, quoted by Rhodia, Inc., were unchanged from the previous year's level. At yearend, thorium oxide prices f.o.b. Shelton, CT, were $82.50 per kilogram 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 because industrial consumers expressed concerns with the potential liabilities, the cost of complying with environmental monitoring and regulations, and the disposal costs at approved waste burial sites.

Outlook

Thorium's use in the United States has decreased substantially during the past decade. Domestic demand is forecast to remain at recent 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 catalysis. Manufacturers have successfully developed acceptable substitutes for thorium-containing ceramics, incandescent lamp mantles, investment molds, magnesium alloys, and paint and coating evaporation materials. The traditionally small markets for domestic thorium compounds as chemical catalysts, in lighting, and in welding electrodes are expected to remain the leading consumers of thorium compounds throughout the next decade. Thorium's potential for growth in nonenergy applications is limited by its natural radioactivity. Its greatest potential exists in energy applications as a source of nuclear energy as an atomic fuel, using atomic fission in the Th^{232}/U^{233} cycle; or as a subatomic fuel, using a particle accelerator to produce protons (subatomic particles) that interact with Th^{232} and U^{233} to produce fast neutrons (subatomic particle) in a process called spallation. This results in a nuclear cascading effect rather than the self-sustaining chain reaction of a conventional reactor. In both processes, the use of thorium as a nuclear fuel may resume in the next decade because it generates fewer radionuclide byproducts than uranium-fueled reactors. 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 future use in nonenergy applications, especially in the United States.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

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

Other

Uranium Industry Annual 2001, U.S. Department of Energy.
Thorium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.

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

(Kilograms of thorium dioxide, unless otherwise specified)

	1997	1998	1999	2000	2001
Exports, compounds	241	1,130	2,520	4,640	7,300
Imports:					
Thorium ore, including monazite	1,400	--	--	--	--
Compounds	13,500	7,450	5,290	11,100	1,850
Consumption, reported nonenergy applications 2/	13,000	7,000	7,000	6,000	NA
Prices, yearend:					
Nitrate 3/	$27.00	$27.00	$27.00	$27.00	$27.00
Oxide 4/	$82.50	$82.50	$82.50	$82.50	$82.50

NA Not available. -- 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 OF THORIUM COMPOUNDS 1/

(Kilograms, unless otherwise specified)

	2000		2001		
	Quantity	Value	Quantity	Value	Principal destinations, sources, and quantities, 2001
Exports	4,640	$478,000	7,300	$291,000	Canada 5,380; Japan 1,800; Singapore 110; United Kingdom 9; Belgium 3
Imports	11,100	528,000	1,850	68,400	France 1,850; United Kingdom 1.

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/	1997	1998	1999	2000 e/	2001 e/
Brazil e/	200 r/ 4/	200 r/	200 r/	200 r/	200
India e/	5,000	5,000	5,000	5,000	5,000
Madagascar	100 e/ 5/	-- 5/	-- 5/	--	--
Malaysia	767	517	1,147	818 r/ 4/	510
Sri Lanka e/	200	200	200	-- r/	--
Thailand	12	--	--	--	--
Total	6,280 r/	5,920 r/	6,550 r/	6,020 r/	5,710

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, 2002.
3/ In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and successor countries of the former Soviet Union may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.
4/ Reported figure.
5/ Source: World Mineral Statistics, British Geological Survey, 1995-99.