THORIUM

By James B. Hedrick

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. 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 Bureau of Mines, U.S. Department of the Interior. 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 ore 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 is consumed; most is discarded as waste.

Limited demand for thorium, relative to the rare earths, continued to create an extensive world oversupply of thorium compounds and residues. Several 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 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 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 factor in switching to alternative non-radioactive materials.

Legislation and Government Programs

The calendar year 1994 included the U.S. Government fiscal years for 1994 and 1995. Public Law 103-160, the National Defense Authorization Act for Fiscal Year 1994, was enacted on November 30, 1993, and covered the year 1994 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 1995, Public Law 103-337, was enacted on October 5, 1994, and covered the last 3 months of 1994. It continued authorization for disposal of 2,947,301 kilograms (6,497,687 pounds) of thorium nitrate classified as excess to goal.

Production

Domestic mine production data for thorium-bearing monazite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations entitled the Rare Earths, Thorium, and Scandium. The one mine to which a survey form was sent responded, representing 100% of domestic production. Mine production data for thorium are withheld to avoid disclosing company proprietary data.

RGC (USA) Minerals Inc., a wholly owned subsidiary of the Australia-based Renison Goldfields Consolidated Ltd., operated a dredging operation at Green Cove Springs, FL. RGC (USA) recovered monazite for its rare-earth content as a byproduct during processing for titanium and zirconium minerals. Byproduct monazite production decreased 27% from the previous years level, amid decreased demand for thorium-bearing rare-earth ores.

None of the domestically produced monazite was processed in the United States for its thorium content. 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 either imports, company stocks, or 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 17.3 metric tons of thorium oxide equivalent in 1994, an increase of 4.5 tons from the 1993 level. Nonenergy uses accounted for essentially all of the total consumption. Increased consumption was primarily the result of increased demand for thorium in carbon arc lighting. 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, 90%; welding electrodes, 8%; ceramics and refractories, 2%; metallurgical applications, <0.5%.

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 which 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 also was 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 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 have been developed with similar properties 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. Only a few foreign-based nuclear reactors continued to operate 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 National Defense Stockpile were 3,219,457 kilograms (7,097,687 pounds) on December 31, 1993. No stocks of thorium nitrate were sold or shipped in 1994. The stockpile's goal at yearend was 272,155 kilograms (600,000 pounds) of thorium nitrate. Stocks classified as excess to goal totaled 2,947,301 kilograms (6,497,687 pounds) and were all authorized for disposal.

The U.S. Department of Energy's inventory at yearend was 1,017,283 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 1994, resulting from a weaker U.S. dollar on world markets, caused the U.S. dollar to be down $0.10 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased significantly to US$233-US$272[3] per ton at yearend 1994, compared with US$204-US$238[4] per ton at yearend 1993. Prices for monazite remained depressed as several major world processors continued to accept only thorium-free rare-earth feed materials.

Thorium prices quoted by Reade Manufacturing Co., a division of Magnesium Elektron Inc., Lakehurst, NJ, at yearend 1994 were $330.76 per kilogram ($150.03 per pound) for thorium hardener (80%Mg-20%Th) in single drum quantities and $63.78 per kilogram ($28.03 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).

World Review

Demand for thorium remained depressed as industrial consumers continued to be concerned with potential liabilities, the cost of compliance with environmental regulations, and decreases in the number of approved waste disposal sites.

Australia.—Tioxide Group Ltd. (TGL), a wholly owned subsidiary of ICI, divested itself of its 44.5% holdings in Westralian Sands Ltd. (WSL), a producer of heavy mineral sands, including monazite. The Japanese company, Ishihara Sangyo Kaisha Ltd. (ISK), also sold its 18.9% interest in WSL. Both TGL and ISK reportedly have long-term contracts with WSL for the purchase of minerals sands, but will concentrate investments in other areas. WSL reopened its Yoganup Extended mine in the first quarter of 1994 as markets for mineral sands improved. A new mineral sands concentrator was commissioned at the reopened mine in March to improve recovery rates.[5]

Minproc Holdings, a 50% owner in the Tiwest mineral sands joint venture at Cooljarloo, Western Australia, changed its name to Ticor Ltd. The joint venture, which includes Kerr-McGee Corp.'s (U.S.) Australian subsidiary, KMCC Western Australia Pty. Ltd., produced heavy mineral sands near Cataby and operated a dry separation plant and synthetic rutile plant at Chandala.[6]

Consolidated Rutile Ltd.'s (CRL), Gordon Mine on North Stradbroke Island suspended operation in March 1994 due to the sinking of its 3,000 metric ton per hour dredge. The dredge was refloated at midyear and resumed operation. CRL's other mineral sands operation, the Bayside Mine in Queensland, continued to operate. CRL noted it had ceased recovery of thorium-bearing monazite due to decreased world demand and problems in storing radioactive materials.[7]

Cable Sands announced the opening of the Jangardup minerals sands operation in Western Australia. The operation, located 60 kilometers south of Nannup in southern Western Australia, has a capacity to produce 230,000 metric tons of heavy mineral sands per year.[8]

BHP continued to assess development of the Beenup mineral sands deposit. Located in the Scott River area of Western Australia, the Beenup deposit would likely be mined by BHP's subsidiary Mineral Deposits Ltd. (MDL). MDL presently operates three mines in New South Wales.[9]

Renison Consolidated Goldfields Limited (RGC) operated four mineral sands mines in 1994. Three mines were operated in Western Australia, the Eneabba West, Eneabba North, and Capel. RGC's fourth mine produced mineral sands at Green Cove Springs, FL, in the United States. Except for the Eneabba North Mine operating at 75% of capacity, all other RGC mines reportedly operated at full capacity. RGC was a major world producer of monazite.[10]

France.—Rhône-Poulenc S.A. (RP) announced it had switched feed materials for its La Rochelle separation plant from monazite to a thorium-free intermediate compound, rare-earth chloride. Thorium waste generated during processing for the rare earths was previously sent for disposal to a French Government approved site in northern France until 1991. A 3 year extension of disposal privileges was allowed at a temporary storage facility through 1994.[11]

Malaysia.—Malaysian Rare Earth Corporation Sdn. Bhd.'s rare-earth plant at Ipoh, Perak State, announced it would close because of strong world competition, mainly from China. The plant had been closed because of public concerns over disposal of thorium waste generated during processing of the rare earths. The joint-venture operation was 35% owned by Mitsubishi Chemical Industries Ltd. of Japan.[12] *(See tables 2 and 3.)*

Outlook

Nonenergy uses for thorium in the United States have decreased substantially over the past 5 years. Domestic demand is forecast to remain at depressed levels unless low-cost technology is developed to dispose of residues. Industry manufacturers have been successful in developing 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. 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. High disposal costs, increasing regulations, and public concerns related to thorium's natural radioactivity are 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. 7942, Fri, Dec. 30, 1994, p.25.

[3] Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.2878=US$1.00 based on yearend 1994 foreign exchange rates reported in the Wall Street Journal.

[4] Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.4725=US$1.00 based on yearend 1993 foreign exchange rates reported in the Wall Street Journal.

[5] Westralian Sands Limited. 1994 Annual Report.

[6] Personal communication with A. Barry Brandt, vice president of investor relations and communications, Kerr-McGee Corp.

[7] Personal communication with Consolidated Rutile Ltd. company representative.

[8] Mining Journal (London). Jangardup Opened. V. 323, No. 8285, July 22, 1994, p. 59.

[9] Industrial Minerals (London). Scott River Mineral Sands Interests. No. 265, Oct. 1994, p. 12.

[10] Renison Goldfields Consolidated Limited. 1994 Annual Report. 47 pp.

[11] Industrial Minerals (London). RP Switches Rare Earth Ore. No. 319, Apr. 1994, pp. 15-16.

[12] Mining Journal (London). Malaysian Rare Earth Plant to Close. V. 322, No. 8262, Feb. 11, 1994, p. 106.

OTHER SOURCES OF INFORMATION

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)

	1990	1991	1992	1993	1994
Exports:					
Compounds	220	2,650	93	189	7
Imports:					
Thorium ore metal, excluding monazite	189,000	205,000	187,000	--	--
Compounds	18,600	42,600	13,500	18,300	3,150
Shipments from Government stockpile excesses	2,170	--	--	--	--
Consumption, reported nonenergy applications 2/	65,500	54,300	40,400	12,800	17,300
Prices, yearend, dollars per kilogram, thorium dioxide equivalent: 3/					
Nitrate, mantle-grade	$16.55	$19.94	$21.36	$22.25	$23.30
Oxide, 99%-grade	$55.00	$63.80	$63.80	$65.00	$63.80

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines 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.

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

(Kilograms, unless otherwise specified)

	1993		1994		Principal destinations, sources, and quantities, 1994
	Quantity	Value	Quantity	Value	
EXPORTS					
Thorium ore, monazite concentrate	W	W	33,000	$21,100	Mexico 33,000.
Compounds	189	$68,100	7	12,600	Algeria 3; United Kingdom 2; Spain 1.
IMPORTS					
Compounds	18,300	479,000	3,150	140,000	France 3,120.

W Withheld to avoid disclosing company proprietary data.

1/ Previously published and 1994 data are rounded by the U. S. Bureau of Mines 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/	1990	1991	1992	1993	1994 e/
Australia e/	11,000	7,000	6,000 r/	16,000 r/	6,000
Brazil	1,660	1,310	1,400	1,400 e/	1,400
China	2,380	1,190	1,800 e/	1,800 e/	1,800
India e/	4,500	4,000	4,000	4,600	4,600
Malaysia	3,320	1,980	777	407 r/	425 4/
South Africa, Republic of e/	1,320 4/	1,300	1,300	1,300	1,300
Sri Lanka e/	200	200	200	200	200
Thailand	377	400 e/	89	220 r/	200
United States	W	W	W	W	W
Zaire e/	124 4/	120	50	50	60
Total	24,900	17,500	15,600 r/	26,000 r/	16,000

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

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.

2/ Table includes data available through June 23, 1995.

3/ In addition to the countries listed, Indonesia, North Korea, 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.