Thorium

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Monazite, the principal source of thorium, continued to be a byproduct of titanium and tin mining and was recovered domestically for its rare-earth content in Florida. Thorium-containing residues remaining after extraction of rare earths from monazite were stored for future use. Practically all thorium compounds used by the domestic industry during 1977 came from existing company stocks or imports.

No major developments occurred in the nonenergy uses of thorium, which include mantles for incandescent lamps, hardeners in magnesium alloys, refractories, and electronic and chemical applications.

The future prospects for thorium's use in nuclear fuels remained uncertain in 1977. The only commercial thorium-fueled, high-temperature, gas-cooled reactor (HTGR), located at Fort St. Vrain, Colo., with a capacity of 330 megawatts, reached almost 70% of power capacity in 1977. The experimental thorium-fueled, light-water breeder reactor (LWBR), at Shippingport, Pa., reached full capacity by yearend.

The U.S. Geological Survey (USGS) began an evaluation of thorium resources recoverable at costs of $30 and $50 per pound.

DOMESTIC PRODUCTION

Exploration.—Five deposits of heavy minerals containing thorium were reported[2] in ancient beach sands in Charleston County, S.C., by the USGS. An aerial geophysical survey and preliminary ground checks indicated that the deposits contain 2 million tons of potentially economic heavy minerals, including monazite. The three largest deposits are 9 miles north of McClellanville, 9 miles southwest of Charleston, and 12 miles southwest of Charleston.

Buttes Gas and Oil Co. continued feasibility and pilot-plant studies of its southwestern Colorado titanium prospect.[3] The ore mineral perovskite reportedly contains significant amounts of thorium that could be recovered.

The USGS began studying thorium resources available at $30 and $50 per pound for the U.S. Department of Energy (DOE).[4] The first phase of the study, to be completed in May 1978, was to assess better known deposits. The U.S. Bureau of Mines provided mining and milling cost analyses for the USGS study. The principal deposits to be studied included the vein deposits of the Wet Mountains, Colo., Lemhi Pass, Idaho, and the Bokan Mountains, Ala.; massive carbonatites of the Powderhorn Pass district, Colo., and Mountain Pass district, Calif.; deposits in fractured and brecciated rocks in Wyoming and Illinois; Piedmont-stream placers of the Carolinas; and current monazite-producing areas in northern Florida. Coproducts were also to be considered.

Mine Production.—Monazite, a thorium-containing, rare-earth, phosphate mineral, was produced as a byproduct of processing beach sands for titanium minerals in 1977. Two mines in Florida, Humphreys Mining Co., near Hilliard, and Titanium Enterprises, near Green Cove Springs, were the only domestic producers of monazite. Humphreys Mining Co. continued to truck wet titanium concentrates from its mine in Florida to the company's dry plant at Folkston, Ga.

Refinery Production.—In 1977, there was only one domestic firm, W. R. Grace & Co., Davison Chemical Div., at Chattanooga, Tenn., with facilities for processing large tonnages of monazite. Although W. R. Grace did not produce any thorium compounds from monazite for sale, thorium was extracted from monazite during the refining of rare-earth elements and stored.

Table 1.—Companies with thorium processing and fabricating capacity

Company	Plant location	Operations and products
Atomergic Chemetals Corp	Plainview, N.Y	Processes oxide, fluoride, and metal.
Babcock & Wilcox Co	Apollo, Pa	Nuclear fuels.
Do	Leechburg, Pa	Do.
Do	Lynchburg, Va	Do.
Bettis Atomic Power Laboratory	West Mifflin, Pa	Nuclear fuels, Government research and development.
Cerac, Inc	Milwaukee, Wis	Processes compounds.
Ceradyne, Inc	Santa Anna, Calif	Processes oxide.
Consolidated Aluminum Corp	Madison, Ill	Magnesium-thorium alloy.
Controlled Castings Corp	Plainview, N.Y	Do.
General Atomic Co	San Diego, Calif	Nuclear fuels.
General Electric Co	San Jose, Calif	Do.
Do	Wilmington, N.C	Do.
W. R. Grace & Co	Chattanooga, Tenn	Processes domestic and imported monazite; stocks thorium-containing residues.
Hitchcock Industries, Inc	South Bloomington,Minn	Magnesium-thorium alloys.
Kerr-McGee Chemical Corp	Cimarron, Okla	Nuclear fuels.
Tennessee Nuclear Specialities, Inc	Jonesboro, Tenn	Do.
Union Carbide Corp., Nuclear Div	Oak Ridge, Tenn	Nuclear fuels, test quantities.
Ventron Corp.,Alfa Div	Danvers, Mass	Metallic thorium.
Westinghouse Electric Corp	Bloomfield, N.J	Processes compounds; produces metallic thorium.
Do	Columbia, S.C	Nuclear fuels.

CONSUMPTION AND USES

It was estimated that industrial demand for thorium was about 50 tons, ThO_2 equivalent, and was met by imports and existing company stocks.

Nonenergy uses consumed about 40 tons of ThO_2. The principal application was as a constituent in mantles for Welsbach incandescent lamps (estimated to be around 20 tons). Other nonenergy uses were as follows: As a hardener in magnesium-thorium alloys (5 tons), in refractories (5 tons), in electronic and chemical applications, plus other applications and research (10 tons).

The 330-megawatt HTGR at Fort St. Vrain, Colo., was up to almost 70% of electrical power capacity by yearend 1977. The commercial reactor was the Nation's first to use a prestressed concrete reactor vessel, helium coolant, steam turbine-driven, primary coolant helium circulators, and a fully ceramic core utilizing the uranium-thorium fuel cycle. The core of the reactor contains about 22 tons of thorium. A reload section containing about 3 tons of thorium was scheduled to be added in 1978. The organization of a utility industry group to promote HTGR utilization was planned in 1977, and General Atomic Co. (GA), developer of the HTGR, and Combustion Engineering were reported to be negotiating an arrangement to jointly sell HTGRs. HTGRs reportedly exhibit higher conversion efficiency, superior fuel utilization, and lower fuel costs than light-water reactors (LWR); however, there have been startup problems associated with commercialization of the new technology.

Development of a 50-megawatt LWBR by DOE continued at Shippingport, Pa. Initial loading of about 46 tons of thorium took place in 1977 and full power production was reached on December 2. The LWBR was converted from a 90-megawatt, pressurized-water reactor, using current LWR plant technology. Although some existing reactors could be converted to LWBRs, the economic viability was uncertain.[5]

STOCKS

On December 31, 1977, the stockpile inventory of the General Services Administration (GSA) totaled 7,221,646 pounds of thorium nitrate (1,675 short tons ThO_2 equivalent). The thorium nitrate stockpile goal remained 1.8 million pounds (418 short tons ThO_2 equivalent).

The DOE inventory as of December 31, 1977, was 1,059 short tons of thorium. About 122 tons of this material was being utilized in research and development.

PRICES

Prices for domestic monazite containing approximately 4% ThO_2 rose about 5% in 1977. The average declared value of imported monazite (from Australia and Malaysia) decreased to $164 per short ton from $205 in 1976. The average price per short ton of Australian monazite quoted in Metal Bulletin (London) was $171-$186 (A$154-A$168) until June 1977 when it decreased to $166-$176 (A$150-A$159).

Prices for thorium compounds varied depending upon purity and quantity. Thorium nitrate was quoted at $2.75 per pound; thorium oxide, 99.99% pure, $7.94 per pound; thorium metal in pellets, $15 per pound; and nuclear-grade metal powder, $100 per pound.

FOREIGN TRADE

During 1977, no thorium concentrates or ores were exported. Other thorium export data were combined with those for uranium. Although these two elements were not statistically differentiated, it was believed that the amount of thorium exported was minor.

Monazite containing about 6% thorium was imported from Australia and Malaysia for its rare-earth content. In 1977, imports of gas mantles and thorium compounds decreased. France was the major country of origin of thorium compounds imported into the United States.

Table 2.—U.S. foreign trade in thorium and thorium-bearing materials

(Quantity in pounds unless otherwise specified)

	1975		1976		1977		Principal sources and destinations, 1977
	Quantity	Value	Quantity	Value	Quantity	Value	
EXPORTS[1]							
Metals and alloys[2]	14,840	$203,415	7,018	$145,758	2,840	$137,199	Canada 1,514; United Kingdom 573; Japan 345; Belgium-Luxembourg 175; Others 233.
Compounds[2]	3,837,266	52,039,852	369,036	7,232,389	245,570	2,847,944	United Kingdom 240,584; Canada 2.204; France 1,289; Brazil 500; Others 993.
IMPORTS							
Ore and concentrate:							
Monazite (short tons)	2,565	531,958	2,103	430,551	5,480	900,191	Australia 3,149; Malaysia 2,331.
ThO_2 content	307,800	XX	252,360	XX	657,600	XX	
Waste and scrap	115	2,165	--	--	--	--	
Compounds:							
Nitrate	66,102	118,343	69,900	152,860	46,440	118,555	France 23,680; Canada 22,760.
Oxide	9,500	55,382	5,007	16,517	10,911	46,147	France 8,707; Netherlands 2,204.
Oxide equivalent, in gas mantles[e 3]	2,374	361,268	1,889	355,885	1,288	191,165	Malta 655; United Kingdom 316; Brazil 182; Others 135.
Other	76	18,438	71	19,085	473	52,947	Switzerland 462; Federal Republic of Germany 11.

[e]Estimate. XX Not applicable.
[1]No thorium ore and concentrates have been exported for the years 1975 through 1977.
[2]Includes uranium; thorium and uranium are undifferentiated in official statistics.
[3]Based on the manufacture of 1,000 gas mantles per pound ThO_2.

WORLD REVIEW

The predominate source of the world's thorium is monazite, a byproduct of titanium and tin mining. Australia, India, Malaysia, Brazil, and the United States continued to be the leading monazite producers among market economy countries. The small world demand for thorium, however, is not reflected by the quantity of this production, since monazite is processed mainly for its rare-earth element content.

Table 3.—Monazite concentrates: World production, by country

(Short tons)

Country[1]	1975	1976	1977[p]
Australia	4,968	5,016	9,646
Brazil	[e]1,600	1,775	[e]2,000
India[e]	3,300	3,300	3,300
Korea, Republic of[e]	10	10	10
Malaysia[2]	3,621	2,071	[e]2,200
Nigeria[e]	20	20	20
Sri Lanka	[e]5	1	[e]5
Thailand	405	--	--
United States	W	W	W
Zaire	328	265	106
Total	14,257	12,458	17,287

[e]Estimate. [p]Preliminary. W Withheld to avoid disclosing individual company confidential data.
[1]In addition to the countries listed, Indonesia and North Korea may produce monazite, but information is inadequate to make reliable estimates of output levels.
[2]Exports.

Australia.—According to the Mineral Sands Producers Association, Ltd., 1977 monazite production by member companies, by State, was as follows: New South Wales, 327 short tons; Queensland, 683 short tons; and Western Australia, 8,635 short tons.

A 2-year modernization program was being carried out by Cable Sands Pty., Ltd., of Western Australia. The Wickham separation plant in New South Wales of Rutile and Zircon Mines (New Castle) Ltd., was reportedly inactive.[6]

DuPont increased its ownership in Allied Eneabba Pty., Ltd., of Western Australia, from 25% to 40%. Westralian Sands Ltd., was merged with Western Mineral Sands and Ilmenite Pty.[7] Jennings Mining Ltd. reduced production by 75% at Eneabba and Geraldton. Western Mining Corporation's mine and treatment plant at Jurian Bay was on standby status.

Cameroon.—Resources of thorium were reported in a mineral research survey funded by the Canadian Government.[8]

Canada.—Research continued on a thorium fuel cycle for the Canadian-deuterium-uranium (CANDU) reactor. It was estimated[9] that development of the cycle would take 20 to 25 years and cost about $2 billion. The thorium fuel cycle could halve Canadian uranium requirements by early in the next century.

A selected bibliography on the geology of Canadian deposits and occurrences of uranium and thorium was published.[10]

Germany, Federal Republic of.—Construction of the 300-megawatt, pebble-bed, thorium high-temperature reactor (THTR) continued at the Hamm-Uentrop station of Vereinigte Elektrizitaetswerke Westfalen AG. The prestressed concrete reactor vessel was completed.

Operation of the THTR developed by Hochtemperatur-Reaktorbau GmbH was rescheduled for 1979.

Another THTR was studied[11] by the electrical authorities of Cologne and Dusseldorf. They are considering a 600-megawatt reactor at a cost of $420-$630 million, which would be scheduled for operation for 1985.

India.—The Bhabha Atomic Research Center (BARC) was designing an experimental reactor to be fueled by less than one-half a kilogram of U_{233}.[12] Thorium had been irradiated in nuclear reactor cores to produce the U_{233}. A 14-megawatt fast-breeder test reactor, in which large quantities of U_{233} could be bred from thorium, was being built at Kalpakkam with French assistance.

India's nuclear development was oriented toward the thorium fuel cycle because the country has large reserves of thorium and relatively small reserves of uranium.

Pakistan.—Thorium associated with uranium was indicated[13] in the Baghalchur area, west of Dera Ghazi Khan. Followup drilling was planned.

TECHNOLOGY

A book describing the mechanisms of migration of thorium and uranium within the earth and their significance to exploration programs was published.[14]

A method of determining thorium and uranium concentrations of up to 100 parts per million (ppm) in geologic samples by X-ray spectrometry was discussed.[15] Studies indicated that only one calibration curve for each element was necessary, because scattered tube radiation was used as an internal standard. The estimated error was 1.2 ppm thorium for a single analysis. This method may be useful in large-scale exploration programs.

The International Atomic Energy Agency published a report on the status of thorium technology.[16]

A new magnesium casting alloy, which contains from 0.6% to 1.6% thorium, was described.[17] The alloy, which possesses elevated temperature properties superior to other magnesium-sand casting alloys, could compete with high-strength aluminum alloys for aerospace applications.

A 2-year occupational health study for DOE and the Nuclear Regulatory Commission to determine possible effects of thorium on the human body continued at the Argonne National Laboratory. The study involves over 100 former employees of the now-closed Lindsay Light and Chemical Co., a former thorium processor. A preliminary summary of results was scheduled to be published in the summer of 1978.

In April, President Carter proposed to indefinitely postpone development of the Clinch River Breeder Reactor (CRBR) due to concern about the proliferation of nuclear weapons, and to redirect some research efforts toward alternate sources of energy, including the thorium fuel cycle of nuclear power generation.[18] Although the fate of the CRBR was uncertain at yearend, interest in the use of the thorium fuel cycle increased. A nuclear reactor fuel unsuitable for use in nuclear weapons could reportedly be made by diluting U_{233} bred from thorium with a small amount of naturally occurring U_{238}.[19] The current costly, time-consuming, advanced technology of isotope separation would be necessary to obtain a weapons-grade material from such a fuel. There are currently no similar means of diluting plutonium. Current research using lasers may, however, lead to a comparatively cheap and simple method of isotope separation.

Research continued on the thorium fuel cycle, with some emphasis on nonproliferation aspects, in several different reactors, including the HTGR, LWBR, CANDU, LWR, liquid-metal fast-breeder reactor, and gas-cooled fast-breeder reactor (GCFR). Large-scale development of any of these reactors could substantially increase the consumption of thorium.

Ramco, Inc., studied HTGR technology commercialization for DOE[20] and concluded that no major engineering problems associated with the technology exist and that there will be a market for the steam cycle HTGR. Ramco also concluded that commercialization would be beneficial as a means of uranium conservation and would enhance the control of nuclear proliferation. It was suggested that utilities, reactor vendors, and government form a new relationship which recognizes their interdependence and shares the risks involved in development of new reactor types.

Research on the use of a thorium-breeder blanket in a GCFR was conducted by GA. The GCFR utilizes the coolant and nonnuclear component technology of the conventional HTGR.

A GCFR commercialization study, which included consideration of a thorium-breeder blanket, was conducted by Helium Breeder Associates, a utility industry group.

A governmental information exchange agreement concerning high-temperature reactor development was reached by the United States, the Federal Republic of Germany, France, and Switzerland. Although no implementation agreements were signed, informal research and development cooperation between countries took place.[21]

A comprehensive study of the thorium fuel cycle in power reactors was published in January 1977 by Oak Ridge National

Laboratories.[22] The report concluded that the use of the thorium fuel cycle in thermal reactors would result in better uranium utilization and, in some cases, better economic performance, as well as add flexibility to the nuclear industry in case of delays in development of fast-breeder reactors. The HTGR was the only reactor type studied that was more economic with the thorium cycle than with the uranium cycle at current nuclear fuel costs.

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