Rare-Earth Minerals and Metals

By Christine M. Moore[1]

Domestic production of rare-earth oxide (REO) contained in bastnäsite and monazite increased sharply in 1979, due primarily to the sizeable increase in bastnäsite production. Molycorp, Inc., and W. R. Grace & Co. were the principal processors of rare earths in 1978 and 1979. Petroleum catalysts and metallurgical applications were the major end uses both years.

Legislation and Government Programs.—Shipments of rare earths from the U.S. General Services Administration totaled 2,973 short tons REO in 1978 and 1,226 short tons REO in 1979. Stocks of REO contained in sodium sulfate, an intermediate product in the processing of monazite, totaled 505 tons at yearend 1979. Government stocks of yttrium oxide remained unchanged at 237 pounds.

The Tokyo Round of negotiations was completed in 1979, resulting in new tariff agreements between the developed nations of the world. The agreements, which affected rare-earth tariffs, placed most nations on a most-favored-nation status with generally lower rates to be phased in, or staged, over an 8-year period beginning Jan. 1, 1980. The new rare-earth tariff schedule is shown in table 1.

Table 1.—U.S. import duties

Tariff classification	Article	Most favored nation (MFN)		Non-MFN
		Jan. 1, 1980	Jan. 1, 1987	Jan. 1, 1980
601.12, 601.45	Ore and concentrate	Free	Free	Free.
418.40, 418.42, 418.44	Cerium chloride, oxide, compounds	14% ad valorem	7.2% ad valorem	35% ad valorem.
423.003	Rare-earth oxides except cerium oxide	4.8% ad valorem	3.7% ad valorem	25% ad valorem.
632.38	Rare-earth metals (including scandium and yttrium)	4.8% ad valorem	3.7% ad valorem	25% ad valorem.
632.78	Alloys wholly or almost wholly of rare-earth metals (mischmetal)	47 cents per pound	32 cents per pound	$2 per pound.
632.79	Other alloys wholly or almost wholly of rare-earth metals	46 cents per pound plus 5.6% ad valorem	20 cents per pound plus 2.4% ad valorem	$2 per pound plus 25% ad valorem.
755.35	Ferrocerium and other pyrophoric alloys	46 cents per pound plus 5.6% ad valorem	22 cents per pound plus 2.6% ad valorem	$2 per pound plus 25% ad valorem.

DOMESTIC PRODUCTION

Concentrate.—Domestic production of REO in bastnäsite and monazite in 1979 increased 15% from the 1978 level. Production of REO in bastnäsite and monazite in 1978 was slightly below the 1977 level. Bastnäsite continued to be the major domestic source of rare earths; the remainder, less than 10%, was produced from monazite.

Molycorp, Inc., produced bastnäsite concentrate at its Mountain Pass, Calif., facility. According to the annual report of the Union Oil Co. of California, the parent firm of Molycorp, production of REO contained in bastnäsite concentrate totaled 15,595 short tons REO in 1978 and 18,205 tons REO in 1979.

Titanium Enterprises, jointly owned by American Cyanamid Co. and Union Camp Corp., ceased dredging operations for titanium minerals, including monazite, at its Green Cove Springs, Fla., facility during 1979. The company reprocessed tailings from earlier dredging operations to extract monazite, zircon, and staurolite throughout 1978 and 1979. Output of monazite in 1979 remained at the 1978 level.

Humphreys Mining Co. recovered monazite from heavy-mineral concentrates until the last quarter of 1979 when its orebody near Hilliard, Fla., was depleted.

Compounds and Metals.—Molycorp announced plans to add six solvent-extraction units at its Mountain Pass, Calif., facility. The new units, scheduled to begin production in 1981, would increase the separation capabilities for samarium, cerium, lanthanum, neodymium, and praseodymium. Molycorp also planned modifications at its York, Pa. facility that would increase the company's production capacity for high-purity compounds.

Rhône-Poulenc Inc. of France announced plans to build a rare-earth separation facility in Freeport, Tex. The facility, scheduled for startup in 1981, will process monazite.

W. R. Grace & Co. consolidated its industrial catalyst and rare-earth manufacturing and marketing activities in 1978 under one firm known as Davison Specialty Chemical Co.

During 1978 and 1979, Molycorp and W.R. Grace were the principal producers and processors of rare-earth compounds. Production and shipments of both mixed and purified rare-earth compounds in 1978 increased over the 1977 level, with the largest increase reported for production of purified rare-earth compounds. Production of high-purity rare-earth metals decreased 6% during 1978, and returned to the 1977 level in 1979.

Producers of high-purity oxides and compounds during 1978 and 1979 were Molycorp; W.R. Grace, Chattanooga, Tenn.; Research Chemicals Div. of Nucor Corp., Phoenix, Ariz.; Reactive Metals and Alloys Corp. (REMACOR), West Pittsburg, Pa.; and Transelco Div. of Ferro Corp., Penn Yan, N.Y.

Mischmetal production increased in 1978 and again in 1979. REMACOR and Ronson Metals Corp., Newark, N.J., produced mischmetal both years.

Production of rare-earth silicide by Foote Mineral Co., Exton, Pa.; Molycorp; and REMACOR nearly tripled in 1978, compared with the 1977 level, to meet rising demand in metallurgical applicatons. In addition, American Metallurgical Products Co. announced plans to produce 3 to 5 million pounds per year of rare-earth silicide at a new $1 million plant at Springdale, Pa.

Molycorp and Research Chemicals were the major processors of yttrium oxide. Research Chemicals also produced high-purity rare-earth metals during the year.

CONSUMPTION AND USES

Domestic rare-earth processors consumed an estimated 17,000 tons of REO contained in raw materials in 1978, reflecting an 11% increase from the 15,300 tons consumed in 1977. Bastnäsite consumption increased 7%, and monazite consumption increased 10%. Shipments of rare-earth and yttrium products from primary processing plants to domestic end-use consumers were about 11,000 tons contained REO. Consumption and shipment data for 1979 were not available.

The approximate distribution of rare earths and yttrium by end use in 1978, based on information supplied by primary processors and certain consumers, was as follows; petroleum cracking catalysts, 41%; metallurgical uses (including nodular iron and steel, other alloys, and mischmetal), 35%; ceramics and glass, 19%; and miscellaneous (including electrical, arc carbons, and research), 5%.

Consumption of high-purity rare-earth oxides and chemicals increased during 1979, due to growing use of the rare earths in several recently developed appplications. The use of rare earths as phosphor materials in X-ray equipment and color television tubes as well as lighting equipment continued to grow. Bubble memories, which use small amounts of gadolinium, began to be used on a commercial scale. High-purity lanthanum oxide was used in optical fibers.

Consumption of cerium continued to grow for use in glass and ceramic applications as well as metallurgical applications and, by yearend 1979, the supply of cerium was tight.

Rare earths were used in several forms for metallurgical applications. Consumption of rare earths for this end use has increased dramatically in recent years. Production of mischmetal and rare-earth silicide was increased to meet the demand, and imports of these materials supplemented the domestic supply.

Metallurgical applications of rare earths include additives in iron and steel production, additives for magnesium castings, and alloying agents in high-strength low-alloy steel, and in permanent magnets.

An estimated 165 short tons of samarium oxide were consumed in the production of rare-earth cobalt permanent magnets during 1978.[2] Use of this kind of magnet in earrings and necklace clasps accounted for most of the sharp increase from approximately 55 tons of samarium oxide consumed in 1977. Samarium-cobalt permanent magnets were also used in traveling wave tubes, alternators and generators, line printers, and various missile applications.

STOCKS

Stocks of rare earths in all forms, held by 14 producing, processing, or consuming companies, increased 14% during 1978, and by an additional 25% in 1979.

In 1978 and 1979, bastnäsite concentrate stocks held by the principal producer and four other processors, decreased. Yearend inventories of monazite increased markedly during both years. Stocks of mixed rare-earth compounds nearly doubled over the 2-year period, and stocks of purified rare-earth compounds more than doubled in the same period. Stocks of mischmetal and other alloys decreased more than 10% in 1979 after a sharp increase in 1978. Rare-earth silicide inventories to yearend 1978 decreased 22% from the yearend 1977 level and then more than doubled during 1979.

PRICES

The average declared value of imported monazite increased during 1978 to $209 per short ton and again in 1979 to $242 per short ton. The price per short ton of Australian monazite (minimum 60% REO including ThO_2), as quoted in Metal Bulletin (London), increased from A$223 to A$268 ($206 to $248) per ton at yearend 1978 to A$313 to A$357 ($282 to $322) per ton by yearend 1979. Quoted prices for Malaysian xenotime, an yttrium-rich rare-earth mineral, remained at $2 to $3 per pound, c.i.f.

Prices of unleached, leached, and calcined bastnäsite containing 60%, 70%, and 85% REO increased from $.71, $.76, and $.86 per pound of contained REO, respectively, at yearend 1978 to $.85, $.90, and $1.05 per pound of contained REO at yearend 1979. The price of cerium concentrate quoted by American Metal Market remained at the yearend 1978 level of $1.15 per pound during 1979. The price of lanthanum concentrate increased from 85 cents per pound at yearend 1978 to 90 cents per pound at yearend 1979. Mischmetal prices, as quoted by American Metal Market, increased from $3.95 per pound at yearend 1977 to $4.20 per pound during 1978, where the price level remained during 1979.

Chemical Div. of Rhône-Poulenc Inc., Monmouth Junction, N.J., quoted REO prices per kilogram (2.2046 pounds) f.o.b., New Brunswick, N.J., as follows at yearend 1979:

Product (oxide)	Percent purity	Quantity (kilograms)	Price
Europium	99.99	25	$1,500.00
Gadolinium	99.99	50	102.50
Lanthanum	99.9	1,000	9.90
Neodymium	95	500	5.95
Praseodymium	96	500	32.25
Samarium	96	500	38.75
Terbium	99.9	50	985.00
Yttrium	99.99	50	75.00

Nominal prices for various rare-earth materials were also quoted by Research Chemicals in dollars per kilogram at year-end 1979 as follows:

Element	Oxide[1]	Metal[2]
Cerium	$18	$108
Dysprosium	100	270
Erbium	120	450
Europium	1,650	6,500
Gadolinium	120	430
Holmium	375	1,100
Lanthanum	17	108
Lutetium	4,200	[3]6,600
Neodymium	65	250
Praseodymium	110	290
Samarium	110	280
Terbium	825	2,000
Thulium	2,650	[3]3,500
Ytterbium	180	720
Yttrium	74	320

[1]Minimum 99.9% purity, 1 to 20 kilograms.
[2]Ingot form, 1 to 5 kilograms.
[3]Per 500 grams.

FOREIGN TRADE

Exports of ferrocerium and other pyrophoric alloys containing rare earths totaled 38,056 pounds in 1978. Major destinations were Canada (30%), Mexico (22%), and Venezuela (12%). In 1979, exports more than doubled, totaling 84,100 pounds. The Republic of Korea received 63% of the shipments. In 1978, 545 tons of monazite valued at $87,500 were exported to France. No exports of monazite were reported in 1979.

Imports for consumption of rare earths, shown in Table 3, continued to increase, with a marked increase in the quantity received from France in 1978 and 1979. Monazite imports during 1979 included 3 tons from the Republic of South Africa, the first reported receipt from that country since 1966.

Table 2.—U.S. imports for consumption of monazite

Country	1975		1976		1977		1978		1979	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Australia	--	--	--	--	3,149	$491	5,532	$1,154	6,268	$1,501
Malaysia	2,462	$508	2,103	$431	2,331	409	1,276	255	618	161
South Africa, Republic of	--	--	--	--	--	--	--	--	3	2
Thailand	103	24	--	--	--	--	846	193	42	13
Total	2,565	532	2,103	431	5,480	900	7,654	1,602	6,931	1,677
REO content[e]	1,411	XX	1,157	XX	3,014	XX	4,209	XX	3,812	XX

[e]Estimate. XX Not applicable.

Table 3.—U.S. imports for consumption of rare-earths, by country

	1977		1978		1979	
	Quantity (pounds)	Value (dollars)	Quantity (pounds)	Value (dollars)	Quantity (pounds)	Value (dollars)
Cerium oxide:						
Austria	--	--	--	--	220	$1,002
Belgium	--	--	--	--	2,205	14,150
France	2,425	$9,486	6,920	$40,068	5,840	40,519
Germany, Federal Republic of	--	--	--	--	10	1,624
Japan	--	--	150	309	--	--
Switzerland	14	659	--	--	98	4,769
United Kingdom	2	300	--	--	5,295	53,788
Total	2,441	10,445	7,070	40,377	13,668	115,852
Rare-earth oxide, excluding cerium oxide:						
Belgium	NA	NA	--	--	2,205	49,492
Brazil	NA	NA	--	--	110	880
Canada	NA	NA	37,991	287	--	--
France	NA	NA	193,996	2,095,182	535,230	7,660,675
Germany, Federal Republic of	NA	NA	64,310	887,775	136,729	3,276,152
Japan	NA	NA	--	--	44,028	1,298,004
Malaysia	NA	NA	--	--	35,274	152,232
Norway	NA	NA	2,428	75,909	8,479	282,976
Switzerland	NA	NA	663	102,000	--	--
U.S.S.R	NA	NA	73,672	3,329,576	85,696	2,417,062
United Kingdom	NA	NA	365	15,235	330	15,996
Total	NA	NA	373,425	6,505,964	848,081	15,153,469
Rare-earth metals (alloys):						
Austria	220,488	639,470	66,339	213,287	--	--
Brazil	149,389	358,846	312,646	805,030	44,092	159,070
France	--	--	110	346	1,212	14,331
Germany, Federal Republic of	55,228	230,726	102,694	392,091	352	2,728
Italy	--	--	200,868	620,160	--	--
Japan	70,245	189,118	92,593	242,746	22,046	63,626
U.S.S.R	3,303	27,013	--	--	--	--
United Kingdom	--	--	45,294	116,005	77,162	337,407
Total	498,653	1,445,173	820,544	2,389,665	144,864	577,162
Rare-earth metals, including scandium and yttrium:						
France	--	--	3,045	41,061	4,079	52,129
U.S.S.R	55	1,875	9,470	192,413	4,412	104,592
United Kingdom	36	9,933	114	26,958	483	29,277
Total	91	11,808	12,629	260,432	8,974	185,998
Other rare-earth metals:						
Germany, Federal Republic of	1,147	23,508	70	4,137	1	261
Ferrocerium and other pyrophoric alloys:						
Austria	--	--	613	4,868	414	3,821
Belgium	--	--	220	2,500	--	--
Brazil	1,842	5,574	5,040	16,934	417	750
France	40,304	233,806	73,060	380,803	92,123	518,935
Germany, Federal Republic of	659	2,592	--	--	74	1,663
Hong Kong	179	332	1,681	1,653	--	--
Italy	--	--	7,518	39,954	--	--
Japan	750	3,605	41,047	186,769	29,000	143,810
Switzerland	750	8,382	8	648	4	352
United Kingdom	1,392	8,146	895	7,255	1,186	10,281
Total	45,876	262,437	130,082	641,384	123,218	679,612

NA Not available.

WORLD REVIEW

World production of monazite increased for the fourth consecutive year, due to rapid expansion of Australian production. Bastnäsite production also increased in 1979. Those countries with processing capability for various rare-earth products included Austria, France, the Federal Republic of Germany, Japan, the U.S.S.R., and the United Kingdom.

Australia.—According to the Mineral Sands Producers' Association Ltd., monazite production in short tons was as follows:

State	1977	1978	1979
New South Wales	327	372	1,861
Queensland	683	--	--
Western Australia	8,636	16,147	16,162
Total	9,646	16,519	18,023

Associated Minerals Consolidated Ltd. and Consolidated Rutile Ltd., agreed to jointly mine and process zircon, rutile, monazite, and other heavy minerals located along a common lease boundry on North Stradbroke Island, Queensland. Jennings Industries announced plans to sell its leases on monazite-bearing lands near Eneabba to Consolidated Goldfields of Australia. The company's processing facilities and equipment at Eneabba and Geraldton were to be sold to Associated Minerals Consolidated, a subsidiary of Consolidated Goldfields of Australia.

Western Titanium Ltd., a subsidiary of Associated Minerals Consolidated, announced plans to increase rutile production at its Eneabba heavy minerals separation facility. The company produced monazite concentrates at the plant.

E.I. du Pont de Nemours & Co., Inc., became the major shareholder in Allied Eneabba Pty. Ltd., a major monazite producer, by increasing its equity to 58.5%. The remaining 41.5% equity was held by public shareholders.

Brazil.—A group of 10 banks headed by Chemical Bank of New York loaned Government-owned Mineração Vale do Paranaiba $30 million to investigate a carbonatite complex at Tapira, Minas Gerais. The company's initial plans were to develop processing facilities for phosphate. Associated minerals that may be processed include anatase, columbium, and rare-earth ores.

Canada.—Denison Mines Ltd. ceased production of yttrium concentrates from uranium tailings at its Elliot Lake, Ontario, facilities due to high production costs. The facilities were scheduled to remain on a care-and-maintenance basis.

A summary of rare-earth occurrences in Canada was issued.[3]

China, Mainland.—Inoue Japax Research Inc. concluded an agreement with the Government of China to undertake joint research and development of rare-earth technology, including ore analysis, ore dressing, and product applicaton.

Two rare-earth treatment facilities were reportedly under consideration by the Government of China—one at Baotou to produce 5,500 tons per year of concentrate and a second, at an unannounced location, to produce 1,100 tons per year.

Mitsui Metal Mining Co. and Mitsui & Co. sent teams to China to investigate a possible joint project involving development of rare-earth processing based on the Poyun iron ore deposit.

India.—The Orissa Sand Complex Project, a venture of Indian Rare Earths Ltd., was established to begin work on mineral sands separation facilities near Chatrapur, Orissa. The complex would produce monazite, synthetic rutile, zircon, and sillimanite.

Japan.—Sumitimo Metal Mining began production of samarium-cobalt magnet alloys at Kunitimo, Hokkaido. The company plans to double the capacity of the 44-short-ton-per-year plant by 1980. Production of samarium-cobalt magnets in Japan was 20 short tons in 1976, 45 tons in 1977, and was estimated at 66 tons in 1978.

Kenya.—The Government of Kenya approved the assignment of the right to develop a rare-earth deposit at Mrima Hill to Rhône-Poulenc Inc.

Malaysia.—A Japanese group reportedly began studies of rare-earth resources in Malaysia.

Norway.—Mitsubishi Chemical Industries Ltd. and Megon A/S formed MCI-Megon to process Malaysian xenotime concentrate to high-purity yttrium oxide at a facility in Kjeller, Norway.

Sri Lanka.—In 1978, Ceylon Mineral Sands Corporation reportedly began stockpiling approximately 300 long tons per year of crude monazite that resulted from processing heavy mineral sands for ilmenite, rutile, and zircon.

United Kingdom.—Steetly Chemicals Ltd. began production of various rare-earth oxides, chlorides, and hydrates from imported monazite at Widnes. The facility reportedly has a rated capacity of 1,650 tons per year REO.

Table 4.—Monazite concentrates: World production, by country

(Short tons)

Country[1]	1976	1977	1978[p]	1979[e]
Australia	[r]5,853	9,377	14,864	17,000
Brazil	1,775	2,691	[e]2,700	2,700
India[e]	3,300	3,014	3,607	3,100
Korea, Republic of[e]	10	10	10	10
Malaysia[2]	2,071	2,179	1,392	2,200
Nigeria[e]	20	20	20	--
Sri Lanka	1	[e]5	220	220
Thailand	--	--	845	800
United States	W	W	W	W
Zaire	265	106	85	85
Total	[r]13,295	17,402	23,743	26,115

[e]Estimate. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]In addition to the countries listed, Indonesia and North Korea 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.

[2]Exports.

TECHNOLOGY

General Motors investigated a new method of fabricating thin curved rare-earth cobalt magnets.[4] The process involves two steps to compact rare-earth cobalt powder to precise final shape, including a means of gently restraining the pressed part to allow it to shrink during sintering to its final density of 96% of its theoretical density. The process would reportedly lower manufacturing costs by eliminating the need for diamond grinding, and reducing material waste and the potential for magnetic breakage. The magnet used in the investigation was made of 75% samarium and 25% mischmetal in a 1:5 rare-earth to cobalt ratio.

A chemical engine using a lanthanum-nickel alloy powder was investigated to recycle heat from low-temperature industrial process fluids and gases.[5] When the powder is heated, the lanthanum-nickel emits hydrogen at sufficient pressure to operate a piston in a cylinder. The new development enables the use of heat of less than 100°C.

The U.S. National Aeronautics and Space Administration elected to study processing of neodymium^{+3}-doped laser glass as one of the 14 programs in its materials-processing programs aboard the space shuttle transport.[6] The anticipated suppression of crystallization by containerless processing could be used to extend the glass-forming region, which presumably would result in the ability to produce a laser glass with an enhanced lasing-line cross section.

An alternative to purification of gadolinium metal by distillation was investigated.[7] The study involved the evaluation of LiF-GdF_3 and LiF-BaF_2-GdF_3 as electrolytes for electrorefining gadolinium. The effects of electrolyte composition and purity, temperature, and current density on the purity of the final product were studied.

A review of fused-salt electrowinning of individual rare-earth metals-yttrium metal, and mischmetal-from their respective chlorides and oxides was published. The article included a review of preparation of alloys of yttrium and rare-earth metals by fused-salt electrolysis and electrorefining of yttrium metal.[8]

The effects of rare earths on the structure and properties of cast irons were reviewed.[9]

Silicon nitride for high-temperature engineering applications was studied by several groups. Two studies reported using yttria as an additive to improve high-temperature properties of silicon nitride.[10] The effects of impurties (Al, Fe, and Ca) in hot-pressing of yttria-doped silicon nitride were discussed.[11] The densification and phase transformation behavior of yttria-doped silicon nitride were studied by comparing its behavior with that of magnesium oxide (MgO)-doped and lithia-doped silicon nitride.[12]

A report on current research concerning rare earths in the U.S.S.R. was published.[13] Included in the report were industrial and military uses of rare earths as well as descriptions of ongoing research for the use of rare earths in laser systems, electronic applications, magnetohydrodynamic power generation, refractory applications, and catalysts.

Researchers at Oak Ridge National Laboratory developed a cyclic process using ceric oxide to generate hydrogen from water or carbon monoxide from carbon dioxide at temperatures within the range of present solar-thermal technology.[14]

The Bureau of Mines began studies to increase rare-earth recovery from bastnäsite as well as to cut energy consumption in the flotation process. A patent application was filed for a rare-earth-metal cobalt magnet containing copper and magnesium developed by the Bureau. The magnet does not contain samarium as an essential component.[15]

Results of research involving the production, characteristics, and use of rare-earth cobalt intermetallic compounds and permanent magnets were summarized at the Third and Fourth International Workshops on Rare-Earth-Cobalt Permanent Magnets.[16]

The 14th Rare Earth Research Conference was held at Fargo, N. Dak., in June 1979. The program reviewed all phases of rare-earth research and development and included sessions on spectrosopy; metallurgy and materials preparation; magnetism; solution, solvation, and analytical chemistry; X-ray and neutron diffraction; and rare-earth technology. Publication of the proceedings was planned.

---

[1]Mineral specialist. Section of Nonferrous Metals.

[2]Fort, J. P. Availability of Rare Earths for the Rare Earth-Cobalt Permanent Magnets Market. Pres. at Internat. Workshop on Rare Earth-Cobalt Permanent Magnets and Their Applications, La Jolla, Calif., June 27-30, 1978.

[3]Rose, E. E. Rare-Earth Prospects in Canada. CIM Bulletin, v. 72, No. 805, May 1979, pp. 110-116.

[4]Jandeska, W. F. Fabricating Rare Earth-Cobalt Magnets in Thin, Arc Segments for Lightweight DC Motors. Proc. Internat. Workshop on Rare Earth-Cobalt Magnets and Their Applications. La Jolla, Calif., June 27-30, 1978, pp. 450-464.

[5]Furukawa, T. Japan Testing Heat-Recycling Chemical Engine. Am. Metal Market, v. 86, No. 30, Feb. 13, 1978, p. 15.

[6]Weinberg, M. Glass Processing in Space. The Glass Industry, v. 59, No. 3, March 1978, pp. 22-28.

[7]Willing, G., and K. A. Gschneidner, Jr. Fused Salt Electrorefining of Gadolinium: An Evaluaton of Three Electrolytes. J. Less-Common Metals, v. 60, 1978, pp. 221-230.

[8]Morrice, E., and M. M. Wong. Fused-Salt Electrowinning and Electrorefining of Rare-Earth and Yttrium Metals. Minerals Sci. Eng., v. 11, No. 3, July 1979, pp. 125-136.

[9]Lalich, M. J. Effects of Rare Earths on Structure and Properties of Cast Iron. Foundry Management & Technol., v. 106, No. 3, March 1978, pp. 118-129.

[10]Clarke, D. R., and G. Thomas. Microstructure of Y_2O_3 Fluxed Hot-Pressed Silicon Nitride. J. Am. Ceram. Soc., v. 61, No. 3-4, March-April 1978, pp. 114-118.

———Tsuge, A., and K. Nashida. High Strength Hot-Pressed Si_3N_4 With Concurrent Y_2O_3 and $Al\text{-}O_3$ Additions. Ceram. Bull., v. 57, No. 4, April 1978, pp. 424-426.

[11]Greskovich, C., and C. O'Clair. Effect of Impurities on Sintering Si_3N_4 Containing MgO or Y_2O_3 Additives. Ceram. Bull., v. 57, No. 11, November 1978, pp. 1055-1156.

[12]Bowen, L. J., I. G. Carruthers, and R. J. Brook. Hot-Pressing of Si_3N_4 With Y_2N_3 and Li_2O as Additives. J. Am. Ceram. Soc., v. 61, No. 7-8, July-August 1978, pp. 335-339.

[13]Kliman, M. I. Rare Earth Ceramic Technology (U.S.S.R.). Army Materials and Mechanics Research Center. January 1978, pp. 79; available from National Technical Information Service, Springfield, Va.

[14]Chemical Engineering. Chementator. V. 86, No. 17, Aug. 13, 1979, p. 84.

[15]Metal-Cobalt Magnets Containing Copper and Magnesium. Dec. 15, 1978, 14 pp.; available from National Technical Information Service, Springfield, Va., PB 292 212.

[16]Strnat, K. J. Proc. Internat. Workshop on Rare-Earth-Cobalt Permanent Magnets and Their Applications, June 27-30, 1978, San Diego, Calif., 529 pp.; available from University of Dayton, Magnetics Laboratory, Dayton, Ohio.

———.Proc. 4th Internat. Workshop on Rare-Earth-Cobalt Permanent Magnets and Their Applications, May 22-24, 1979, Hakone National Park, Japan, 450 pp.; available from University of Dayton, Magnetics Laboratory, Dayton, Ohio.