

# Rare-Earth Minerals and Metals

By John G. Parker<sup>1</sup>

The apparent domestic industrial consumption of rare-earth and yttrium compounds and concentrates, expressed as rare-earth oxide (REO), was about 85 percent that of 1966, the highest year on record. A large quantity of REO, in materials excess to those needed for a conventional war emergency, was authorized for disposal from the national stockpile. Requirements for high-purity yttrium and europium oxides in color television tubes decreased substantially.

**Legislation and Government Programs.**—At yearend the General Services Administration (GSA) held a total of 15,788 tons of equivalent rare-earth oxides (REO) in various forms in the strategic and supplemental stockpiles. The strategic stockpile held 9,975 and the

supplemental, 5,813 tons. Of the 12,788 tons excess to that needed for a conventional warfare emergency, 7,640 tons of REO in rare-earth materials was authorized for disposal by H.R. 5787 signed by the President on November 22. The customary 6-month waiting period was waived. On December 21, successful bids by two companies led to sales of 319 short tons equivalent REO, mostly in the form of rare-earth sodium sulfate. Of the additional stockpile materials currently authorized for disposal, rare-earth sodium sulfate constituted almost 62 percent and bastnaesite the remainder.

In 1966, over 84,000 pounds of excess yttrium-bearing material consisting of yttrium metal, alloys, oxide, fluoride, and concentrate was sold to four companies by GSA.

## DOMESTIC PRODUCTION

**Concentrate.**—Output at the mine and mill at Mountain Pass, Calif., owned by Molybdenum Corporation of America, increased slightly during 1967 to 25.5 million pounds REO in bastnaesite concentrates compared with 25.2 million pounds the previous year. A new mill had been completed in May 1966 and its capacity had been expanded to 50 million pounds REO in December of that year.

In Folkston, Charlton County, Ga., Humphreys Mining Co. processed alluvial deposits on E. I. du Pont de Nemours & Co., Inc., property, thereby recovering substantial byproduct monazite with titanium and zirconium mineral concentrate. Also, near Jacksonville, Fla., Carpc Research and Engineering, Inc., under contract with Titanium Alloy Manufacturing Division of National Lead Co., reclaimed monazite and a small quantity of xenotime from former beach sand processing residues. The Climax Molyb-

denum Co. mine at Climax, Colo., recovered monazite-wolframite concentrate from molybdenum mine tailings and sold low-grade monazite concentrate for further upgrading. Metal Traders, Inc., New York City, sold the last of low-grade yttrium oxide concentrate which had been produced from former GSA residues by Colorado School of Mines Research Foundation, Inc., Golden, Colo. Late in 1966, Michigan Chemical Corp., a subsidiary of Chicago and Northwestern Railway Co., with a rare-earth processing plant in St. Louis, Mich., bought the Porter Brothers Corp. mining and concentrating operation in Bear Valley, Idaho, thereby assuring itself of a long term rare-earth and yttrium raw material source.

**Compounds and Metals.**—Production of europium oxide at Mountain Pass dropped

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to 9,000 pounds compared with 11,400 pounds in 1966. The decrease in production and sales was attributed to accumulation of excessive inventories of color television phosphors and to improved efficiency in applying phosphors to picture tubes. Company shipments of rare-earth and yttrium materials for phosphors dropped but those for petroleum cracking catalysts increased from 6.9 percent to 14.5 percent of the total sales of \$10.2 million, 2 percent greater than 1966 sales. Also at Mountain Pass, cerium hydrate, lanthanum hydrate, and lanthanum carbonate production circuits were installed in the chemical plant. In December, after Molybdenum Corp. had acquired full control of Yttrium Corporation of America by buying the minority interest held by The Pyrites Co., Inc., the subsidiary was merged into the parent corporation. The Yttrium Corp. plant at Louviers, Colo., continued using solvent extraction to produce high-purity yttrium oxide, and production began in the fall on rare-earth materials such as high-purity neodymium and praseodymium oxides.<sup>2</sup>

Other chemical firms processing large quantities of rare-earth and yttrium concentrates to compounds included American Potash & Chemical Corp., Rare Earth Division, West Chicago, Ill.; and W. R. Grace & Co., Davison Chemical Division, Chattanooga, Tenn., and Pompton Plains, N. J. The Pompton Plains plant made principally rare-earth polishing powders. Besides Yttrium Corp., yttrium oxide producers included American Potash, W. R. Grace, Michigan Chemical Corp., and

Research Chemicals, Division of Nuclear Corporation of America, Phoenix, Ariz. Small producers of rare-earth compounds were Atomergic Chemetals Co., Division of Gallard-Schlesinger Chemical Manufacturing Corp., Carle Place, N. Y., which made some yttrium oxide, and Transelco, Inc., Penn Yan, N. Y., which specialized in making low-cost cerium oxide for polishing compounds. Rare-earth bearing silicon compounds, for use as metal additives, were produced by Molybdenum Corporation of America, Washington, Pa., and by Union Carbide Corp., Alloy, W. Va. Production at Alloy was about 26 percent that of the previous year.

The two companies which produced misch metal were Ronson Metals Corp., Newark, N. J., and American Metallurgical Products Co., Inc., New Castle, Pa. Misch metal sales were about 5 percent greater than those of 1966 and 20 percent greater than those of 1965. Producers of higher purity rare-earth metals included American Potash, Gallard-Schlesinger, Michigan Chemical, Ronson, and Lunex Co., Pleasant Valley, Iowa. Lunex produced about 119 pounds of high-purity metals on contract, of which about 31 percent was yttrium, 20 percent was lanthanum, 18 percent was gadolinium, and 10 percent was erbium. These metals were said to be destined for research and development.

Stockholders near yearend 1967 voted a merger between American Potash & Chemical Corp. and Kerr-McGee Corp., with American Potash to become a subsidiary of Kerr-McGee.

## CONSUMPTION AND USES

The apparent domestic industrial consumption of rare-earth and yttrium compounds and concentrates, based largely on shipments from chemical processors, dropped 15 percent to about 4,850 tons of rare-earth oxide equivalent valued at about \$15 million. This was compared with a weight of 5,740 tons and value of nearly \$21 million in 1966. In addition to domestic sales, a considerable quantity of concentrate was shipped abroad. Comparative percentage figures for domestic shipments of europium and yttrium oxides, by weight and value, were as follows: 1967, 1 percent and 50 percent, and 1966, about 2 percent and almost 70 percent. Based on value, 1967 industrial consump-

tion of other rare-earth compounds consisted of about 17 percent in glass, usually as polishing powders, and some in ceramics and glazes; 10 percent in petroleum catalysts; 5 percent in steel and alloy production and in the making of misch metal and lighter flints; 5 percent in carbon arc production; 5 percent in electronics; and 8 percent in other applications.

In terms of oxide equivalent, use of oxides constituted 35 percent of the total; chlorides, 29 percent; hydrates, 11 percent; fluorides, 6 percent, and bastnaesite and lanthanum concentrates, and rare-

<sup>2</sup> Molybdenum Corporation of America. 1967 Annual Report. Mar. 15, 1968, 8 pp.

earth oxalate, chlorate, nitrate, carbonate, and silicite the remainder.

Nearly 10,000 pounds of high-purity metal valued at about \$235,000 reportedly was sold but about nine-tenths of this was too low in value to be of the highest purity. The low unit value of an additional 30,000 pounds of metal indicated that it was probably an alloy such as misch metal.

The use of yttrium and europium oxides in color television phosphors is well established. Combinations of these in several compounds provide a superior red color. For instance, at least one company was said to use an yttrium oxysulfide, and it is known that others use an yttrium orthovanadate, both compounds being doped with europium. Terbium is being tried in a green phosphor but the merits have not been fully established. Some firms said that blue and green phosphors employing rare-earth materials do not have energy efficiencies equal to those of conventional phosphors. A glass filter plate, containing neodymium oxide, laminated onto the viewing surface of color television tubes, was said to improve the brightness and contrast and to produce more saturated red, green, and blue colors. Recently developed fluorescent lamps coated with phosphors containing europium and yttrium oxides were stated to have higher light output and better color balance. Also, industrial mercury vapor lamps are improved by the combination of dysprosium with mercury and argon gas in the inner arc tube.

Yttrium iron garnet was said to have become the most widely used ferrite material in microwave applications. It is available in polycrystalline and, more recently, in single crystal forms weighing as much as one-half pound. Polycrystalline garnets can be operated in low magnetic fields in the lower microwave frequencies and have a low susceptibility to temperature changes, particularly when the yttrium is partly replaced with gadolinium. Single crystals have been used as insulating magnetic material in lasers, light modulators, and ultrasonic devices. Yttrium aluminum garnets (YAGS) doped with neodymium oxide were used in a sun-pumped laser capable of carrying television modulation. Hydrogen-free solvents, containing rare-earth oxides such as neodymia in solution, were believed to

be at least as efficient as some of the crystalline lasers and have the advantage that the liquid can be cooled by circulation. Neodymium glass lasers showed promise in microwelding applications.

Most of the misch metal produced was used in producing ferrocerium lighter flints, alloyed with iron to impart strength, hardness, and brittleness. In other instances, misch metal was used to desulfurize, refine grain size, and increase the impact strength and ductility of certain steel alloys, and promote resistance to creep and improve fatigue properties in magnesium and aluminum alloys at intermediate temperatures. Misch metal and magnesium iron silicides containing rare-earth metals received increased attention as nodulizing alloys that promote ductility in cast iron by producing graphite spheroids in the matrix. Adding rare-earth elements and subsequently treating with hydrogen to eliminate brittleness overcame hot shortness due to deleterious impurities in magnesium-zinc alloys, thereby providing good castability and ductility.

Yttrium in chromium alloys promoted workability and acted as a grain refiner. In iron-chromium alloys, 1 percent yttrium was equal to 5 percent aluminum in improving resistance to oxidation at elevated temperatures.

Yttrium, and rare-earth metals such as cerium, praseodymium, and samarium, showed promise in new permanent-magnet materials because they were easily fabricated by powder metallurgy methods and could be densely packed, giving a remanent flux density close to the saturation of massive material. Economically, magnets using the pure rare-earth materials probably can compete only with certain expensive grades of Alnico magnets or with platinum cobalt magnets, but cerium-rich misch metal added to cobalt in these intermetallic compounds was believed to be competitive with medium-grade Alnicos, ESD magnets, and anisotropic ferrites.

Much of the output of lower purity, commercial-grade rare-earth compounds went to the glass and ceramic industries. Cerium and mixed rare-earth oxides powders were used extensively in polishing eyeglasses, camera and instrument lenses, mirrors, television tubes, and plate glass, although the latter use has been reduced by the introduction into this

country of the Pilkington float-glass process.

Less important in the glass industry was the use of certain rare-earth oxides as ingredients in the glass. For example, cerium oxide is used as a glass decolorizer; also, in larger quantities in the glass, cerium oxide and neodymium oxide absorb ultraviolet light in welders goggles and in special sunglasses and optical filters. Due to its ultraviolet absorptive properties, cerium oxide in glass prevents spoilage of food in transparent containers. Glass is colored lavender by neodymium oxide, greenish yellow by praseodymium oxide, and yellow or brown by cerium oxide forming cerates with titanium or lead. Cerium oxide also prevents discoloration due to radiation in television tube glasses and can be used as a white opacifier in glass and enamel. In optical uses, especially in certain borosilicate or borate camera lenses, lanthanum oxide increases the refractive indices and decreases dispersion. Praseodymium oxide mixed with zirconium oxide is used in a bright yellow ceramic tile stain.

A new single-phase, polycrystalline ceramic material, a solid solution of 90 percent yttrium oxide and 10 percent thorium oxide, has the advantages of being transparent and melting at a temperature in excess of 2,200° C, almost twice that of the softening of glass. It has received consideration for use in high-intensity incandescent and discharge lamps, in windows in high-temperature furnaces, and in microscope lenses used to study molten samples. Yttrium oxide is well known as a stabilizer of zirconium dioxide.

Rare-earth elements are used in petroleum cracking and in dehydrogenating reforming catalysts. Rare-earth chloride is an important component of a petroleum cracking catalyst and is used in a copper

catalyst employed to recover chlorine from byproduct hydrochloric acid.

Rare-earth oxides and fluorides are used in core materials for carbon-arc electrodes emitting intense white light, useful in military searchlights and in color motion picture photography and projection.

The high thermal-neutron cross section of certain rare-earth elements has proved of value in some nuclear applications. Oxides of europium, gadolinium, dysprosium, and samarium have been dispersed in control rods in a few commercial nuclear power reactors. In a new development, rare-earth oxides such as dysprosium and erbium, were combined with hafnium oxide, another material with high neutron cross section, into rare-earth pyrohafnates. This was said to provide an inexpensive means of incorporating hafnium into control rods. New ceramic pellets made of aluminum and samarium oxides or aluminum and gadolinium oxides were developed as atomic fire extinguishers. These can be inserted rapidly into a reactor to absorb excess neutrons whenever the reactor approaches a dangerous operating level. Lastly, highly efficient radiation shields were developed which contain layers of carbon and lead, dysprosium and lead, gadolinium alone and mixed with lead and tungsten, and a final layer of lead or tungsten with depleted uranium.

Crucibles composed of yttrium oxide were used in reducing uranium oxide to the metal. Other high-temperature metal casting crucibles were made from mixed cerium-thorium sulfides. Gadolinium selenide has been offered commercially in thermoelectric generating equipment. Other rare-earth sesquisulfides, such as those of samarium and cerium, withstand high operating temperatures in these generators.

## STOCKS

At yearend, bastnaesite concentrate held by the principal domestic mining company and chemical processors was almost three times larger than at the close of 1966. The yearend supply of monazite concentrate, held almost entirely by two chemical processing firms, was slightly less than that at the end of the previous year, but stocks of rare-earth sodium sulfate, held by one proc-

essor, were about 33 percent greater than that at yearend 1966. Stocks of refined yttrium oxide were eight times those of 1966 and those of europium oxide showed an even larger comparative increase. Misch metal stocks held by the two main producers and some of the principal users decreased 22 percent, but those of pure metals more than doubled.

## PRICES

According to Metals Week nominal prices per pound of imported monazite, c.i.f. U.S. ports, remained as follows for over half the year: Massive, 55 percent rare-earth oxides, 14 cents; sand, 55 percent, 8 cents; sand, 60 percent, 10 cents; and sand, 66 percent, 12 cents. In August price quotations for the massive variety were discontinued and the nominal price for a long ton of monazite sand was quoted at \$180 to \$200. On the London market, average c.i.f. prices per long ton of Australian monazite containing a minimum of 60 percent rare-earth oxides plus thorium varied from an early year quote of £70 to £85 (\$196 to \$238) to £80 to £90 (\$192 to \$216) near yearend. A general increase in freight rates and higher packaging costs part way through 1966 had been responsible for the higher prices in 1967 compared with those of early 1966. Domestic bastnaesite concentrates, which had been quoted for the first time in January 1966, remained at, per pound f.o.b. Nipton, Calif.: 55 to 60 percent rare-earth oxides, 30 cents, and 68 to 72 percent rare-earth oxides, 35 cents. Rare-earth oxide from the same source was quoted at 45 cents per pound for 88 to 92 percent pure material.

Prices for mixed or lower grade rare-earth compounds, called production chemicals by American Potash & Chemical Corp., were the same as those of 1966. In lots of 50 to 99 pounds, ceric hydrate sold for \$1.75 to \$2.00 per pound and ceric oxide sold for \$1.90 per pound. Similar-sized lots of didymium and rare-earth chlorides were \$0.55 per pound and didymium carbonate was \$1.30 per pound. Other quoted prices were \$1.40 to \$1.74 per pound for cerium hydrate in lots of 100 pounds or more, depending upon purity, and \$1.85 to \$1.90 per pound for optical grade ceric oxide in lot sizes of 50 pounds or more, delivered in bags.<sup>3</sup>

Price lists were available from chemical processors such as Research Chemicals, American Potash & Chemical, and Michigan Chemical, and some products were quoted in trade journals.<sup>4</sup>

According to these sources, the price per pound of various oxides, in the common lot size of 2 to 99 pounds was cerium oxide 99.9 percent pure \$7.50 to

\$9.50; neodymium oxide \$30.00 to \$37.50; europium oxide \$850 to \$950; gadolinium oxide \$85 to \$95; yttrium oxide \$44 to \$55; and lutetium oxide \$3,000 to \$3,500. The price of europium oxide from American Potash dropped to \$850 per pound from \$1,350 in 1966, but because prices on large quantities are lower and are subject to negotiation, this oxide may sell at \$550 to \$800 per pound, depending upon purity. Fluorides from one company were priced the same as the oxides, and other salts, including chlorides, nitrates, oxalates, and sulfates in quantities and purities such as the previously mentioned oxides, were generally priced at 60 percent of the prices of the oxides.

In 50- to 100-pound lots, prices for 99.8 percent misch metal from Ronson Metals Corp. increased to \$3.00 per pound in April 1967 from \$2.90 in 1966. Cerium-free misch metal remained at \$5.00 per pound, didymium metal of 97 percent purity stayed at \$15 per pound, cerium metal of 99.9 percent purity stayed at \$20, and lanthanum metal of 99.9 percent purity stayed at \$27.50.

In general, prices of high-purity metals decreased. The price list of Research Chemicals, Division of Nuclear Corp. of America, quoted some rare-earth metal prices as follows:

<i>Metal ingots, 99.9 percent pure, small lots</i>	<i>Dollars per pound</i>	
	1966	1967
Cerium .....	75	70
Europium .....	5,000	3,600
Lanthanum .....	75	70
Neodymium .....	150	115
Samarium .....	220	160
Yttrium .....	180	160

Prices for distilled metals were about 50 percent greater than the ingots. Metal powders in 1-pound lots generally were \$40 to \$50 per pound greater than the ingot prices for lower priced metals and up to \$200 to \$300 per pound greater than the ingot prices in the rare and higher priced metals such as lutetium and thulium.

<sup>3</sup> Oil, Paint and Drug Reporter. Current Prices of Chemicals and Related Materials. V. 191, Nos. 1-26, Jan. 2-June 26, 1967; V. 192, Nos. 1-26, July 3-Dec. 25, 1967.

<sup>4</sup> American Metal Market. V. 74, Nos. 1-250, Jan. 3-Dec. 29, 1967.

## FOREIGN TRADE

Pyrophoric alloys, including ferrocerium, were shipped to Canada, United Kingdom, West Germany, and 20 other countries and totaled 141,338 pounds valued at \$303,499. The average unit value of these exports was \$1.25 per pound less than that in 1966.

Monazite sand concentrate totaling 2,091 short tons valued at \$270,063 was received from Australia (74 percent of weight), Malaysia (13 percent), Nigeria (6 percent), Indonesia (3 percent), and South Korea and West Germany (4 percent). The average unit value of these imports was \$15.60 per short ton more than that in 1966. One company reported that it imported a small quantity of xenotime from Japan.

Cerium chloride imports, mostly from Canada, totaled 33,486 pounds and was valued at \$3,135. The unit value of the Canadian material was much lower than chloride prices quoted by U.S. processors. Cerium oxide from United Kingdom, Finland, France, Austria, and Switzerland totaled 18,249 pounds valued at \$22,274. Cerium salts and other cerium compounds, from France, United

Kingdom, West Germany, Austria, and Switzerland in decreasing quantity, totaled 12,890 pounds worth \$13,727. The Swiss materials were of high unit value indicating that they were of a special high purity. Rare-earth metals, having a reported value of \$30,152, were received from three countries, United Kingdom, U.S.S.R., and West Germany. The unit values of the material from United Kingdom and U.S.S.R. were high, indicating high-purity metals, but over 99 percent of the material, from West Germany, had a very low unit value, to be expected of low-value alloys. Imports of low-value alloys, including misch metal, were reported as totaling 10,484 pounds worth \$13,339, mostly from West Germany and some from the United Kingdom. Other alloys of rare-earth metals, totaling 2 pounds worth \$328, were imported from West Germany. Ferrocerium and other pyrophoric alloys, from Japan, West Germany, Austria, and France totaled 7,241 pounds valued at \$35,062 compared with 13,903 pounds valued at \$65,407 in 1966.

## WORLD REVIEW

**Australia.**—Proved reserves of 100,000 long tons of monazite were said to be associated with ilmenite deposits of the Geographie Bay area, Western Australia. Monazite production in this state reportedly was running at a rate of about 1,500 long tons per year.<sup>5</sup> Byproduct monazite production by a large Western Australia beach sand processor was 25 percent greater than that of 1966 and 77 percent greater than that of 1965. Based on first quarter production of monazite concentrate, it appeared that annual production would be about 2,250 long tons of concentrate containing about 2,050 long tons monazite.<sup>6</sup> For the years 1965 through 1967, the average grade of the monazite concentrates produced in Australia has been 94, 92.5 and 91 percent respectively. Reportedly, Associated Minerals Consolidated, Ltd. produced rare-earth polishing powders at Southport, Queensland.

**Canada.**—Preliminary Dominion Bureau of Statistics data indicated that 160,078

pounds of yttrium oxide in concentrate, valued at \$1.69 million, was recovered from uranium mill effluent in 1967. A new yttrium processing facility was opened at Denison Mines Ltd. uranium concentrating plant near Elliot Lake, Ontario. The proposed output of this facility was estimated as up to 300,000 pounds annually. The Nordic plant of Rio Algom Mines Ltd., with a rated capacity of 100,000 pounds per year, has been producing yttrium oxide since 1965. Additional equipment for extracting yttrium values was said to have been installed at the thorium recovery facilities of Rio Tinto Nuclear Products, a wholly owned subsidiary of Rio Algom Mines.

Interest was shown in the possible economic extraction of rare-earth elements from phosphate rock deposits at

<sup>5</sup> The Australian Mineral Industry. Quarterly Review. V. 19, pt. 1, No. 4, June 1967, p. 84.

<sup>6</sup> The Australian Mineral Industry. Quarterly Statistics. V. 20, pt. 2, No. 1, September 1967, p. 7.

Table 1.—World production of monazite concentrates, by countries <sup>1 2</sup>

(Short tons)

Country	1963	1964	1965	1966	1967
Australia.....	<sup>r</sup> 2,310	2,219	<sup>r</sup> 2,582	<sup>r</sup> 2,212	2,908
Brazil.....	2,448	733	658	822	NA
Ceylon.....		25	40	40	22
Congo (Kinshasa).....			22	NA	NA
India <sup>3</sup> .....	2,678	<sup>r</sup> 2,307	<sup>e</sup> 2,800	NA	NA
Indonesia.....	169	154	28	NA	5
Korea, South <sup>4</sup> .....				13	14
Malagasy Republic.....	678	1,063	1,196	937	27
Malaysia (exports).....	991	340	777	970	<sup>e</sup> 1,061
Nigeria <sup>3</sup> .....	13	11	9	8	125
South Africa, Republic of.....	2,300				
Total <sup>5</sup> .....	11,587	6,852	8,112	5,002	4,162

<sup>e</sup> Estimate. <sup>r</sup> Revised. NA Not available.<sup>1</sup> United States production data withheld to avoid disclosing individual company confidential data.<sup>2</sup> Compiled mostly from data available March 1968.<sup>3</sup> Year ended March 31 of year following that stated.<sup>4</sup> Reported as concentrates containing 45 to 55 percent REO; also reported as 30 percent cerium, which may be high.<sup>5</sup> Totals are of listed figures only; no undisclosed data included.

Nemegos, Ontario. The deposits, totaling 40 to 80 million tons of apatite, were said to contain about 55 pounds of rare-earth oxides per ton of apatite concentrate.

**Finland.**—In 1967 it was announced that the Korsnäs lead mine of Outokumpu Oy had produced 2,876 short tons of rare-earth concentrate containing 2.63 percent rare-earth oxides, worth \$122,935 (Fmk 394,500). Typpi Oy, Oulu, planned to quadruple its output of rare-earth oxides, using Kola apatite as a raw material.

Two Finnish scientists, Prof. Olavi Erämetsä and Allan Johansson, conducted research on a fuel cell using a praseodymium compound as a solid electrolyte.

**India.**—In Madras State, the Manavalakurichi plant of Indian Rare Earths Ltd., with an annual capacity of 3,000 metric tons of monazite concentrate, was expected to come on stream in 1967. The company made such items as rare-earth chloride and fluoride in its monazite chemical processing plant at Alwaye, Kerala State. Lanthanum oxide and misch metal were produced on a pilot plant scale in anticipation of eventual commercial-scale production at Alwaye.

**Japan.**—At the Nippon Yttrium Co. Ltd. plant in Mitaka, Tokyo, high-purity yttrium oxide monthly output was expected to be increased from 660 to

2,205 pounds by the installation of a solvent extraction process developed by The Rio Tinto Zinc Corp., Ltd. subsidiary, Thorium Ltd. In turn, Pyrites Co., a subsidiary of Rio Tinto Zinc, acquired a one-third interest in the Japanese firm which is a joint venture of Mitsui Mining & Smelting Co. and Tohoku Metal Industries. Operation of the new plant was expected in mid-1968. Shinetsu Chemical Industry Co. used a Japanese developed ion-exchange method to produce high-purity yttrium oxide at a plant at Takefu, Fukui Prefecture.

**Malagasy Republic.**—In 1966, Etablissements Tricot, a French lighter flint manufacturer, ceased concentrating monazite at its Isandravinang plant in the Manantenina district. Competition from Australian monazite was the reason given for closing the plant.

**Malawi.**—A private company was given a concession by the Malawi Government to prospect for and determine the feasibility of extracting monazite from the Kangankunde Hill carbonatite complex near Balaka and northwest of Zomba. Laboratory tests and pilot plant treatment of the material had been demonstrated previously.

**Malaysia.**—A rapid method for determining yttrium in xenotime was developed at Ipoh, Perak State. It was believed that this would save valuable time and prevent discarding the more valuable

xenotime in the mistaken belief that it was lower value monazite.

**Mauritania.**—Pechiney St. Gobain of France, one of Europe's largest producers of rare-earth oxides, explored recently discovered deposits of massive monazite at Bounaga, about 60 miles southwest of Akjoujt and about 220 miles east of Nouakchott. The material was said to contain an average of 3.8 percent yttrium oxide. Société d'Exploitation Minière et de Recherches de Mauritanie (SOMIREMA), a subsidiary of Pechiney, will mine and export the ores starting in early 1968. The ore concentrates will be processed in the Pechiney St. Gobain plant, La Rochelle, France.

**Spain.**—A deposit of bastnaesite was discovered at Pozoblanco near Córdoba, and it was believed to contain a useful percentage of europium.

**United Kingdom.**—Rio Tinto Zinc's rare-earth producing subsidiary, Thorium Ltd. opened a new laboratory at Widnes, Lancashire. The company gained a Queen's Award for Technological Innovation by developing an efficient solvent extraction process for separating and purifying rare-earth elements. The company was in the midst of an expansion program which would triple annual capacity for praseodymium oxide to 65,000 pounds by late 1968 and materially increase output of cerium, europium, lanthanum, and neodymium oxides. Subsequently, Thorium Ltd. joined with Johnson Matthey & Co. Ltd. in forming a new company, Rare Earth Products Ltd. Thorium Ltd. was scheduled to manage the plant starting on November 1, 1967.

## TECHNOLOGY

Although monazite is currently secondary to bastnaesite in this country as a source of rare-earth oxides, its history as the dominant rare-earth and thorium mineral reaches back to the 19th century. A recent U.S. Geological Survey publication is of maximum importance in making known the world distribution, types of geological environments, elemental contents, and relative abundance data on monazite.<sup>7</sup> In the event of immensely increased demand for some of the heavy rare-earth oxides it might be possible to recover these elements as a byproduct from "wet process" phosphoric acid used in producing fertilizers from marine phosphorites. The possible extraction processes which might be used for the byproduct recovery were discussed.<sup>8</sup>

Mining and concentrating bastnaesite and processing the concentrates to intermediate rare-earth products and others such as high-purity europium oxide were described. Two comprehensive flowsheets, showing the ore concentrating and the europium, cerium, and lanthanum circuits, were published.<sup>9</sup>

Bureau of Mines investigations reflected a varied interest in rare-earth

materials. Additions of small quantities of rare-earth elements were said to have little effect on the tensile properties of steel. Cerium metal was purified by solid-state electrolysis, and high-purity neodymium, praseodymium, and didymium metals were prepared by electrolysis of their oxides. Selective leaching of rare-earth values was facilitated by fusing euxenite with ammonium sulfate. Thermochemical data were published, and measurements were made of the reaction rate between yttrium metal and molten lithium fluoride. Yttrium was electrorefined and the electrical properties of yttrium compounds were discussed. Reconnaissance studies delineated an area of remote potential value as a source of

<sup>7</sup>Overstreet, William C. The Geological Occurrence of Monazite. Geol. Survey Prof. Paper 530, 1967, 327 pp.

<sup>8</sup>Altschuler, Z. S., Sol Berman, and Frank Cuttitta. Rare Earths in Phosphorites—Geochemistry and Potential Recovery. Geol. Survey Prof. Paper 575-B, 1967, pp. B1-B9.

<sup>9</sup>Harrah, H. W. Rare Earth Concentration at Molybdenum Corporation of America. Part II. Solvent Extraction Plant. Deco Trefoil, v. 31, No. 5, November-December 1967, pp. 9-16.

Johnson, N. L. Rare Earth Concentration at Molybdenum Corporation of America. Deco Trefoil, v. 30, No. 4, August-September-October 1966, pp. 9-16.



yttrium and related rare-earth elements.<sup>10</sup>

Investigations continued on fluorescence and luminescence phenomena of rare-earth materials, generated by their outstanding success in color television

phosphors.<sup>11</sup> Methods were studied to achieve the maximum economy in preparing phosphor coatings and in promoting maximum performance under a particular mode of excitation.<sup>12</sup>

<sup>10</sup> Barnard, P. G. Effects of Rare-Earth Additions on Plain-Carbon Steel. BuMines Rept. of Inv. 6907, 1967, 25 pp.

Driscoll, Timothy J., Jr., and Lindsay D. Norman, Jr. Thermoelectric Properties of Yttrium-Group V and Yttrium-Group VI Binary and Ternary Compounds. BuMines Rept. of Inv. 7025, September 1967, 14 pp.

Marchant, J. D., E. S. Shedd, and T. A. Henrie. Solid-State Electromigration of Impurities in Cerium Metal. BuMines Rept. of Inv. 6894, 1967, 13pp.

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