STRONTIUM

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Expectations for increased strontium carbonate demand for color television picture tube faceplate glass prompted strontium carbonate producers to expand capacity worldwide in the early 1990's. These expectations have proven to be overly optimistic. Even with additional consumption created with the completion of new television glass plants in North America, strontium carbonate production was only about 40% of installed capacity in 1998 with little prospect for improvement (Mineral Pricewatch, 1999). Increased celestite production in 1995 indicated that demand was beginning to grow, but since that time, celestite production has fallen back to about the same level as in 1994.

Chemical Products Corp. (CPC) of Cartersville, GA, was the only U.S. producer of strontium compounds from celestite. CPC produced strontium carbonate from imported Mexican ore; no celestite mines were active in the United States.

Strontium commonly occurs in nature, averaging 0.034% of all igneous rock; only two minerals, celestite (strontium sulfate) and strontianite (strontium carbonate), however, contain strontium in sufficient quantities to make its recovery practical. Of the two, celestite occurs much more frequently in sedimentary deposits of sufficient size to make development of mining facilities attractive. Strontianite would be the more useful of the two common minerals because strontium is used most commonly in the carbonate form, but few deposits have been discovered that are suitable for development. A mine in China was believed to be the only developed strontianite deposit in the world (Hong, 1993).

Legislation and Government Programs

Government stockpiling of celestite began in 1942 to provide a secure supply for the production of strontium compounds required for defense applications during World War II. Celestite purchase specifications issued in 1960 for the National Defense Stockpile established quality requirements at greater than 95% strontium sulfate content with less than 1.5% calcium sulfate and less than 2% barium sulfate (Department of Defense, 1960).

In 1963, Congress determined that the celestite stockpile was unnecessary, and the General Services Administration began selling stockpile material. All the stockpile-grade celestite was sold by 1973. The remaining material graded less than 91% strontium sulfate and more than 4% calcium sulfate and some with more than 10% barium sulfate (Defense Logistics Agency, 1998).

In 1998, the stockpile contained approximately 12,000 metric tons (t) of celestite, all of which were authorized by Congress for disposal. The low quality of the material remaining in the stockpile makes it undesirable as a raw material for strontium carbonate production. Reports issued by the Defense National Stockpile Center of the Defense Logistics Agency, the agency

now responsible for managing stockpile sales, listed the celestite as valueless.

Production

Although celestite mines have not been active in the United States since 1959, deposits have been identified nationwide. During World War II, celestite resources were mined in California and Texas; at that time, mines had been inactive since World War I, and strontium minerals were imported to satisfy domestic demand.

The sole U.S. strontium carbonate producer voluntarily provided domestic production and sales data to the U.S. Geological Survey (USGS). Production and stock data, however, have been withheld from publication to avoid disclosing company proprietary data (table 1). CPC was the only domestic company that produced strontium carbonate from celestite; the company also produced strontium nitrate. All the celestite CPC used in 1998 was imported from Mexico; CPC owned and operated a second strontium carbonate plant in Reynosa, Tamaulipas, Mexico. The company used the black ash method of strontium carbonate production at both of its facilities.

The black ash and the soda ash methods are the two most common recovery techniques. The black ash method, known alternatively as the calcining method, produces chemical-grade strontium carbonate, which contains at least 98% strontium carbonate. The soda ash, or direct conversion, method produces technical-grade strontium carbonate, containing at least 97% strontium carbonate.

The first step in the black ash process involves mixing the crushed and screened celestite with powdered coal. The mixture is then heated to about 1,100° C, expelling oxygen in the form of carbon dioxide from the insoluble strontium sulfate to form water-soluble strontium sulfide. Strontium sulfide is dissolved in water, and the resulting solution, filtered. Then either carbon dioxide is passed through the solution or soda ash is added, forming and precipitating strontium carbonate from solution. The precipitated strontium carbonate is filtered, dried, ground, and packaged. The byproduct sulfur from the process is recovered as elemental sulfur or other byproduct sulfur compounds (Chemical Products Synopsis, 1993). The black ash method is the preferred means of strontium carbonate production because it yields a higher grade product; most new production facilities employ black ash technology.

In the soda ash method, ground celestite is washed, and most of the water, removed. The thickened mixture is combined with soda ash and treated with steam for 1 to 3 hours. During this time, celestite and soda ash react to form strontium carbonate and sodium sulfate. Sodium sulfate is water soluble, making it possible to separate the insoluble strontium carbonate by centrifuging.

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Several U.S. companies produced strontium compounds from strontium carbonate. Mallinkrodt Inc. of St. Louis, MO, produced strontium chloride, and Rockwood Pigments Corp. of Beltsville, MD, produced strontium chromate. A few other companies produced downstream strontium compounds but on a limited scale.

Consumption

The USGS estimated the distribution of strontium compounds by end use. Of the eight operations to which a survey request was sent, all responded. The information collected from this survey and the information provided by the U.S. Bureau of the Census on strontium trade were the bases for the end-use estimates shown in table 2.

In 1998, more than 85% of all strontium was consumed in ceramics and glass manufacture, primarily in television faceplate glass and secondarily in ceramic ferrite magnets and other ceramic and glass applications. Since 1970, production of faceplate glass for color television picture tubes has been the major consumer of strontium.

All color televisions and other devices containing color cathode-ray tubes (CRT's) sold in the United States are required by law to contain strontium in the faceplate glass of the picture tube to block x-ray emissions. Major manufacturers of television picture tube glass incorporate about 8%, by weight, strontium oxide in their glass faceplate material. Added to the glass melt in the form of strontium carbonate, it is converted to strontium oxide. In addition to blocking x-rays, the strontium improves the appearance of the glass and the quality of the picture and increases the brilliance (Wagner, 1986).

Permanent ceramic magnets were another large end use for strontium compounds, in the form of strontium ferrite. These magnets were used extensively in small direct current motors for automobile windshield wipers, loudspeakers, other electronic equipment, toys, and magnetically attached decorative items. Strontium ferrite magnets have high coercive force and high thermal and electrical resistivities and are chemically inert. They retain their magnetism well, are not adversely affected by electrical currents or high temperatures, do not react with most chemical solvents, resist demagnetization, and have a low density (Haberberger, 1971).

One of the most consistent and continuing applications for strontium has been in pyrotechnic devices. Strontium burns with a brilliant red flame, and no other material has been found to be better in this application. The compound used most frequently in these devices was strontium nitrate. Although strontium carbonate, strontium oxalate, strontium sulfate, and strontium chlorate can also be used, strontium nitrate is used in significantly larger quantities. Pyrotechnic devices are used in military and nonmilitary applications. Military pyrotechnic applications included tracer ammunition, military flares, and marine distress signals. Nonmilitary applications included warning devices and fireworks (Conkling, 1981).

Strontium is used to remove lead impurities during the electrolytic production of zinc. The addition of strontium carbonate in sulfuric acid to the electrolyte reduces the lead content of the electrolyte and of the zinc that is deposited on the cathode (Bratt and Smith, 1963).

Strontium chromate is an additive to corrosion-resistant paint. It is an effective coating for aluminum, most notably on

aircraft fuselages and ships. These paints are used, to some degree, on aluminum packaging to prevent package corrosion (Roskill Information Services Ltd., 1992).

Strontium metal was a very limited part of total strontium consumption. Small amounts of strontium are added to molten aluminum to improve the castability of the metal, making it more suitable for casting items that have been traditionally made from steel. The addition of strontium to the melt improves the machinability of the casting. The use of cast aluminum parts has been gaining popularity in the automotive industry because the weight reduction—by using cast aluminum parts instead of steel—improves gas mileage (Lidman, 1984).

Other end uses consumed only small amounts of strontium and strontium compounds. As mentioned above, the presence of strontium in glass applications improves the brilliance of the glass. It also improves the quality of certain ceramic glazes, as well as eliminates the toxicity that may be present in glazes containing lead or barium. Strontium titanate is sometimes used as substrate material for semiconductors and in some optical and piezoelectric applications. Strontium chloride is used in toothpaste for temperature-sensitive teeth. For this application, impurities must be strictly controlled; some limits are in the parts-per-million range. Strontium phosphate is used in the manufacture of fluorescent lights, and the entire range of strontium chemicals is used in analytical chemistry laboratories.

Prices

The average customs value for celestite imported from Mexico was about \$60 per metric ton, 17% lower than that 1997. The average unit customs value of imported strontium carbonate was \$0.59 per kilogram, about 5% lower than that of 1997. The corresponding value for strontium nitrate was \$3.54 per kilogram, a decrease of about 6% from that of 1997.

Foreign Trade

Exports of strontium compounds increased by about 4% from the levels reported in 1997 (table 3). Imports of celestite from Mexico were 24,200 t, a decrease of about 15% from those of 1997. A small quantity of celestite—less than 1 t—was imported from Madagascar. The low tonnage and high unit value (more than \$8,000 per ton) of the material indicates that it was probably specimen- or gem-quality material. Although celestite import figures vary significantly from year to year, this appeared to be attributable to a 2-year cycle of celestite imports; during the past 3 years, however, trade data indicate a developing trend toward lower celestite imports. During the past 5 years, annual celestite imports averaged about 29,000 t (13,000 t contained strontium).

Mexico continued to be the most important source for imported strontium compounds; Germany was second (table 4). Imports of strontium carbonate in 1998 were 6% lower than those of 1997, imports from Mexico were 93% of total carbonate imports. Imports of strontium nitrate were 35% higher than those of 1997; strontium nitrate imports vary significantly from one year to the next but represent less than 1% of total strontium imports.

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World Review

In most instances, celestite deposits occur in remote, undeveloped locations far from population centers in areas where inexpensive labor is available for mining. Huge deposits of high-grade celestite have been discovered throughout the world. Strontium commonly occurs along with barium and calcium, two elements with chemical properties very similar to strontium, thus making separation difficult. Because removing many impurities from celestite is difficult and energy intensive, strontium chemical producers require material to contain at least 90% strontium sulfate. Most operating celestite facilities can produce sufficient supplies with only minimal processing necessary to achieve acceptable specifications. Hand sorting and some washing are all that are necessary at many strontium mines; a few operations use gravity separation, froth flotation, or other methods to beneficiate ore.

Leading celestite producers were, in decreasing order of importance, Mexico, Spain, Turkey, and Iran. Significant quantities of celestite were produced in China and the former Soviet Union (FSU); not enough information was available, however, to make any estimates of location, number, or size of mines. Celestite was produced in smaller quantities in Algeria, Argentina, and Pakistan.

Detailed information on most world resources was not readily available because very little information on exploration results has been published. Other deposits may be well identified but are in countries from which specific mineral information is not easily obtained (table 5). Production facilities for strontium compounds and/or metal were located in Canada, China, FSU, Germany, Japan, the Republic of Korea, Mexico, Poland, and the United States.

Outlook

Sales of televisions and computer monitors in the United States will continue at a high rate and will continue to influence U.S. strontium consumption significantly.

As long as CRT's are the preferred display type for televisions and computers, long-term trends should remain steady with some small increases. Growth in television sales is expected to continue, and larger screens are increasing in popularity. Likewise, the market for personal computers is expanding, and the average size of monitors is increasing. These factors are driving increased demand for strontium carbonate for CRT's. Growth in other markets will probably continue at the current slower rate. Worldwide growth in demand for strontium carbonate may be moderated by the poor economic condition in other parts of the world.

Development of a technology to produce affordable flat panel displays for televisions and computers is likely to reduce the demand for strontium carbonate. Although an affordable, high-quality, large, flat screen is not yet available, small models are already in commercial production, and research will continue to seek improvements in the technology. The question remains as to when a new display system that is economically attractive to the general public will be developed, but there is little doubt

that flat panels will eventually replace CRT's. Initial devices are expected to find application in military hardware and other sophisticated medical and scientific instrumentation. When flat

panel display systems become more common, strontium producers are expected to experience serious setbacks.

References Cited

Bratt, G.C., and Smith, W.N, 1963, The effects of strontium compounds and related materials in the electrolytic production of zinc, *in* Australian Conference On Electrochemistry, 1st, Sydney, New South Wales, Australia, 1963, Proceedings: New York, Pergamon Press, p. 939-948.

Chemical Products Synopsis, 1993, Strontium carbonate: Chemical Products Synopsis, May, 2 p.

Conkling, J.A., 1981, Chemistry of fireworks: Chemical and Engineering News, June 29, p. 24-32.

Defense Logistics Agency, 1998, Solicitation of offers for celestite (strontium sulfate): Defense Logistics Agency, DLA-Celestite-001, June 17, p. 30. Department of Defense, 1960, National Stockpile purchase specification:

Department of Defense, P-10-R2, September 28, 1 p. Haberberger, T.H., 1971, Ferrite applications ever changing and expanding:

Ceramic Industry Magazine, August, p. 29-32.

Hong, Wei, 1993, Celestite and strontianite—Review of ore processing and exploration: Industrial Minerals, no. 309, June, p. 55.

Lidman, W.G., 1984, Master alloys improve aluminum casting properties:
Foundry Management and Technology, v. 112, no. 8, August, p. 46-47.
Mineral Pricewatch, 1999, Celestite—No light at the end of the tunnel: Mineral Pricewatch, Issue 51, March, p. 12.

Roskill Information Services Ltd., 1992, The economics of strontium 1992: Roskill Information Services Ltd., London, 93 p.

Wagner, R.G., 1986, Glass as a CRT fabrication material: Glass, v. 63, no. 6, June, p. 191-192.

SOURCES OF INFORMATION

U.S. Geological Survey Publications

Evaporites and brines. Ch. in United States mineral resources, U.S. Geological Survey Professional Paper 820, 1973.

Strontium. Ch. in Mineral Commodity Summaries, annual. Strontium. Ch. in Minerals Yearbook, annual. 1

Other

American Ceramic Society Bulletin, monthly.

Chemical Market Reporter, weekly.

Engineering and Mining Journal, monthly.

Industrial Minerals (London), monthly.

Mining Annual Review (London).

Mining Engineering, monthly.

Mining Journal (London).

Mining Magazine (London).

Roskill Information Services Ltd. (London, last reported on strontium in 1992).

Strontium–Supply, demand, and technology, U.S. Bureau of Mines Information Circular 9213, 1989.

Strontium. Ch. in Mineral facts and problems, U.S. Bureau of Mines Bulletin 675, 1985.

World Mining, monthly.

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¹Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1 SALIENT STRONTIUM STATISTICS 1/

(Metric tons, of contained strontium, unless otherwise noted 2/)

1994	1995	1996	1997	1998
16,000	12,700	11,600	12,500	10,600
20,000	20,800	20,500	26,000	25,000
1,120	1,160	712	599	875
\$68	\$71	\$67	\$72	\$60
274,000	311,000	306,000	294,000 r/	276,000 e
	16,000 20,000 1,120	- 16,000 12,700 20,000 20,800 1,120 1,160 \$68 \$71	- 16,000 12,700 11,600 20,000 20,800 20,500 1,120 1,160 712 	-

- e/ Estimated. r/ Revised.
- $1/\,\text{Data}$ are rounded to three significant digits. $2/\,\text{The}$ strontium content of celestite is 43.88%, which was used to convert units to celestite.
- 3/ Source: Bureau of the Census.
- $4/\,Excludes$ China and the former U.S.S.R.

TABLE 2 U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	1997	1998
Electrolytic production of zinc	2	2
Ferrite ceramic magnets	9	10
Pigments and fillers	3	3
Pyrotechnics and signals	9	5
Television picture tubes	73	76
Other	4	4
Total	100	100

 $\label{eq:table 3} \text{U.S. EXPORTS OF STRONTIUM COMPOUNDS, BY COUNTRY 1/}$

	1997		1998	
	Gross weight		Gross weight	
	(kilograms)	Value 2/	(kilograms)	Value 2/
Strontium carbonate precipitated:				
Brazil			18,100	\$15,200
Canada	392,000	\$372,000	547,000	489,000
Germany			5,630	47,600
Japan	6,330	6,010	21,000	33,800
Korea, Republic of			2,990	2,840
Mexico			90,200	59,500
Singapore	200	3,680	200	3,680
United Kingdom			907	3,200
Total	398,000	382,000	686,000	655,000
Strontium oxide, hydroxide, peroxide:				
Australia			212,000	117,000
Canada	7,430	5,090	55,700	30,600
Colombia	189,000	104,000		
Dominican Republic	28,100	15,500		
Germany	134,000	73,800	16,000	8,800
Haiti	28,100	15,500		
Hong Kong	100,000	55,200		
Israel	148,000	81,500		
Italy	30,500	16,800	9,820	5,400
Japan	52,500	49,300	66,400	36,500
Korea, Republic of	9,090	5,000	5,820	3,200
Mexico	72,800	40,000	136,000	97,100
Norway	11,600	6,400	16,800	9,240
Panama	19,000	10,400		
Portugal			4,830	2,660
Russia	37,900	20,800		
Singapore			7,410	4,070
Sweden			10,700	5,880
United Kingdom	10,200	5,630	96,500	53,100
Total	879,000	505,000	639,000	373,000

^{1/} Data are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

^{2/} Customs value.

 ${\bf TABLE~4} \\ {\bf U.S.~IMPORTS~FOR~CONSUMPTION~OF~STRONTIUM~COMPOUNDS,~BY~COUNTRY~1/}$

	199	97	1998		
	Gross weight		Gross weight		
	(kilograms)	Value 2/	(kilograms)	Value 2/	
Strontium carbonate:					
Canada	13,000	\$3,550	3,650	\$4,820	
China	173,000	99,700	166,000	83,500	
Germany	3,330,000	2,190,000	2,530,000	1,560,000	
India			560	2,230	
Italy	3,000	7,200	12,400	49,600	
Japan	5,780	7,800	800	13,400	
Mexico	30,500,000	24,700,000	38,400,000	22,600,000	
United Kingdom	762	18,700	950	32,600	
Total	43,700,000	27,000,000	41,100,000	24,400,000	
Strontium nitrate:					
Canada	166	1,660			
China	63,000	329,000	67,300	373,000	
France	62,900	469,000	82,700	557,000	
Germany	4	1,290			
India	<u> </u>		11,000	34,800	
Japan	1,700	28,800	12,900	97,700	
Mexico	152,000	220,000	204,000	275,000	
Switzerland	1	1,350			
Total	280,000	1,050,000	378,000	1,340,000	

^{1/} Data rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

 ${\bf TABLE~5}$ CELESTITE: WORLD PRODUCTION, BY COUNTRY ~ 1/~2/~

(Metric tons)

Country 3/	1994	1995	1996	1997	1998 e/
Algeria e/	5,400	5,400	5,400	5,400	5,400
Argentina	8,484	9,325	3,775	1,905 r/	2,000
Iran e/ 4/	20,000	20,000	20,000	20,000	20,000
Mexico	111,000	138,342	143,892	134,707 r/	118,230 5/
Pakistan	2,320	1,625	2,500 e/	2,000 e/	670
Spain	102,046	106,000	100,000 e/	100,000 e/	100,000 5/
Turkey e/	25,000	30,000	30,000	30,000	30,000
Total	274,000	311,000	306,000	294,000 r/	276,000

e/ Estimated. r/ Revised.

^{2/} Customs value.

^{1/}World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

^{2/} Table includes data available through May 20, 1999.

^{3/} In addition to the countries listed, China and the former U.S.S.R. produce strontium materials, but output is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.

^{4/} Data are for year beginning March 21 of that stated.

^{5/} Reported figure.