

STRONTIUM

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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 often 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 of 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 stockpiled 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 1999, the stockpile contained approximately 12,000 metric tons (t) of celestite, all of which was 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 1999 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 is 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.

Several U.S. companies produced strontium compounds from strontium carbonate. Mallinkrodt Chemical Inc. of St. Louis, MO, and Laporte Pigments Corp. of Beltsville, MD, were strontium chloride and strontium chromate producers,

respectively. 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 six operations to which a survey request was sent, five 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 user 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 is 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 can be 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 Limited, 1992, p. 76).

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 using cast aluminum parts instead of steel reduces the weight of the vehicle and 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 \$72 per ton, 21% higher than that of 1998. The average unit customs value of imported strontium carbonate was \$0.58 per kilogram, about the same as in 1998. The corresponding value for strontium nitrate was \$3.89 per kilogram, an increase of about 10% from that of 1998.

Foreign Trade

Exports of strontium compounds were 3.5 times higher than the levels reported in 1998 (table 3). This tremendous increase in exports was a result of a surge of strontium carbonate exports to Asia. In 1998, U.S. strontium carbonate exports to Asian countries were 24 t; 1999 exports to Japan, Singapore, Taiwan, and Thailand totaled 3,500 t. This astounding increase was due in part to decreased production in Japan that resulted from plant closures and was coupled with strong demand for strontium carbonate at TV glass operations in Asia.

Imports of celestite from Mexico were 31,300 t, an increase of nearly 30% from those of 1998. Small quantities of celestite—totaling less than 1 t—were imported from Madagascar and the Netherlands. The low tonnage and high unit value (nearly \$20,000 per ton) of the material indicate 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 5 years, annual celestite imports averaged

about 27,800 t (12,200 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 1999 were 7% higher than those of 1998; imports from Mexico were 94% of total carbonate imports. Imports of strontium nitrate were 56% higher than those of 1998; strontium nitrate imports vary significantly from one year to the next but represent less than 1% of total strontium imports.

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.

Germany.—Solvay Barium Strontium GmbH, a subsidiary of Belgium's Solvay S.A., expanded its capacity at its Bad Hönningen plant. The plant had the capacity to produce 150,000 t of barium and/or strontium carbonate. The capacity for barium carbonate was to increase 50%; an incremental increase in strontium carbonate capacity was planned through debottlenecking. Solvay produced strontium carbonate at the Bad Hönningen plant from imported Spanish celestite. The company had other strontium carbonate plants in Italy, the Republic of Korea, and Mexico (Industrial Minerals, 1999b).

Turkey.—A long-time celestite producer for the export market, Barit Maden Turk AS sells most of its production to the Republic of Korea and China. The company planned to use its celestite to begin strontium carbonate production in 2000. In preparation for its expansion into carbonate production, Barit Maden built a carbon dioxide plant, which proved

profitable for the company even before the strontium carbonate facilities were complete. Its high-quality celestite resources and in-house carbon dioxide supply contributed to Barit Maden's confidence that its strontium carbonate would be high-quality and cost-competitive with other producers (Houssa, 1999).

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. Glass and ceramic applications for strontium carbonate are expected to grow at 3% to 5% per year for the near future (Industrial Minerals, 1999a). As long as CRT's are the preferred display type for televisions and computers, 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. Ferrite magnet markets are expected to be strong; growth in other markets will probably continue at the current slower rate. Improved economic conditions worldwide will spur growth in demand for strontium carbonate.

Flat screen display systems for televisions and computer monitors have threatened to replace CRT's for many years, but low-cost technology has been elusive. Improvements have increased the likelihood that the large flat screens using either liquid crystal displays (LCD) or plasma technology will replace bulkier CRT's. LCD's, which are smaller and use less energy than plasma display systems, seem to be filling the market for relatively small flat displays such as those required for portable computers. This market has experienced remarkable growth since 1997, and this trend is expected to continue. Plasma technology is more common for large, high-definition televisions with screens up to 60 inches wide; and significant growth is expected in this area also (Tremblay, 1999, p. 19-21). Neither of these developing technologies requires strontium carbonate in the glass.

Although still expensive in comparison to CRT's, improvement of the technology to reduce the costs of flat panel displays for televisions and computers is likely to reduce the demand for strontium carbonate. When a new display system that is economically attractive to the general public is developed, CRT's will become obsolete, and with them, this major market for strontium carbonate.

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TABLE 1
SALIENT STRONTIUM STATISTICS 1/

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

	1995	1996	1997	1998	1999
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption: 3/					
Strontium minerals	12,700	11,600	12,500	10,600	13,700
Strontium compounds	20,800	20,500	26,000	25,000	26,800
Exports (compounds) 3/	1,160	712	599	875	2,890
Shipments from Government stockpile excesses	--	--	--	--	--
Price, average value of mineral imports at port of exportation, dollars per ton	\$71	\$67	\$72	\$60	\$73
World production (celestite) 4/	311,000	320,000 r/	288,000 r/	272,000 r/	269,000 e/

e/ Estimated. r/ Revised. -- Zero.

1/ Data are rounded to no more than three significant digits.

2/ 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	1998	1999
Electrolytic production of zinc	2	2
Ferrite ceramic magnets	10	10
Pigments and fillers	3	3
Pyrotechnics and signals	5	6
Television picture tubes	76	75
Other	4	4
Total	100	100

TABLE 3
U.S. EXPORTS OF STRONTIUM COMPOUNDS, BY COUNTRY 1/

	1998		1999	
	Gross weight (kilograms)	Value 2/	Gross weight (kilograms)	Value 2/
Strontium carbonate precipitated:				
Brazil	18,100	\$15,200	--	--
Canada	547,000	489,000	254,000	\$220,000
Germany	5,630	47,600	10,800	89,300
Japan	21,000	33,800	2,480,000	1,470,000
Korea, Republic of	2,990	2,840	--	--
Mexico	90,200	59,500	51,200	44,900
Singapore	200	3,680	577,000	342,000
South Africa	--	--	38,800	34,300
Taiwan	--	--	228,000	134,000
Thailand	--	--	213,000	129,000
United Kingdom	907	3,200	907	3,200
Total	686,000	655,000	3,860,000	2,470,000
Strontium oxide, hydroxide, peroxide:				
Australia	212,000	117,000	--	--
Brazil	--	--	124,000	48,300
Canada	55,700	30,600	272,000	150,000
Germany	16,000	8,800	19,600	9,500
Italy	9,820	5,400	--	--
Japan	66,400	36,500	176,000	96,900
Korea, Republic of	5,820	3,200	82,800	51,000
Malasia	--	--	21,600	11,900
Mexico	136,000	97,100	127,000	85,500
Norway	16,800	9,240	20,100	11,100
Portugal	4,830	2,660	--	--
Singapore	7,410	4,070	--	--
Sweden	10,700	5,880	--	--
United Kingdom	96,500	53,100	10,600	5,840
Total	639,000	373,000	854,000	470,000

-- Zero.

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Customs value.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY 1/

	1998		1999	
	Gross weight (kilograms)	Value 2/	Gross weight (kilograms)	Value 2/
Strontium carbonate:				
Canada	3,650	\$4,820	--	--
China	166,000	83,500	425,000	\$191,000
Germany	2,530,000	1,560,000	2,380,000	1,260,000
India	560	2,230	--	--
Italy	12,400	49,600	6,000	24,000
Japan	800	13,400	100	2,060
Mexico	38,400,000	22,600,000	41,100,000	24,200,000
United Kingdom	950	32,600	35	8,090
Total	41,100,000	24,400,000	44,000,000	25,700,000
Strontium metal:				
Canada	114,000	1,480,000	88,400	882,000
China	83,700	493,000	123,000	662,000
Germany	8	1,500	10	2,050
Japan	120,000	283,000	104,000	227,000
Total	318,000	2,260,000	315,000	1,770,000
Strontium nitrate:				
China	67,300	373,000	195,000	256,000
France	82,700	557,000	174,000	1,150,000
India	11,000	34,800	--	--
Japan	12,900	97,700	98,700	771,000
Mexico	204,000	275,000	122,000	114,000
Switzerland	--	--	50	2,370
Total	378,000	1,340,000	590,000	2,290,000
Strontium oxide, hydroxide, peroxide:				
China	20,000	14,000	66,700	52,300
Germany	32,700	131,000	60,000	54,300
Italy	500	1,930	--	--
Japan	3,030	24,300	90,500	421,000
Mexico	75,200	130,000	30,300	57,300
Switzerland	--	--	20,000	15,600
United Kingdom	516	12,600	--	--
Total	132,000	314,000	267,000	600,000

-- Zero.

1/ Data rounded to no more than three significant digits; may not add to totals shown.

2/ Customs value.

Source: Bureau of the Census.

TABLE 5
CELESTITE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country 3/	1995	1996	1997	1998	1999 e/
Algeria e/	5,400	5,400	5,400	5,400	5,400
Argentina	9,325	3,775	3,049 r/	3,100 r/ e/	3,000
Iran e/ 4/	20,000	20,000	20,000	20,000	20,000
Mexico	138,342	143,892	134,707	118,230	120,000
Pakistan	1,625	2,500 e/	3,000 r/ e/	598 r/	600
Spain	105,868 r/	114,829 r/	92,000 r/ e/	95,000 r/ e/	95,000
Turkey e/	30,000	30,000	30,000	30,000	25,000
Total	311,000	320,000 r/	288,000 r/	272,000 r/	269,000

e/ Estimated. r/ Revised.

1/ World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

2/ Table includes data available through May 19, 2000.

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.