# STRONTIUM

By Joyce A. Ober

Prompted by the expected demand for additional strontium carbonate in the television glass industry, new strontium carbonate production facilities were completed in the early 1990's and celestite production increased, but not as dramatically as the earlier increases in strontium carbonate capacity. Significantly increased production of celestite beginning in 1995 indicates that the capacity utilization of strontium carbonate facilities is expanding in response to the additional demand for strontium carbonate required to supply newly completed television glass plants. Chemical Products Corp. (CPC) of Cartersville, GA, is the only U.S. producer of strontium compounds from celestite. CPC produces strontium carbonate from imported Mexican ore; no celestite mines are active in the United States.

Strontium occurs commonly in nature, averaging 0.034% of all igneous rock; however, only two minerals, celestite (strontium sulfate) and strontianite (strontium carbonate), 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 currently 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. Only one strontianite mine in China is believed to operate in the world.

## Legislation and Government Programs

Government stockpiling of celestite began in 1942 to provide a secure supply of celestite for the production of strontium compounds required for defense applications during World War II. Celestite purchase specifications issued in 1960 for the U.S. 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.

In 1963, the celestite stockpile was determined to be unnecessary, and the General Services Administration began selling stockpile material. All the stockpile-grade celestite was sold by 1973, with the remaining material grading less than 91% strontium sulfate and more than 4% calcium sulfate and some with more than 10% barium sulfate.

The stockpile currently contains approximately 12,000 tons of celestite, all of which have been authorized 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 Logistics Agency, Defense National Stockpile Center—the agency now responsible for managing stockpile sales—list the celestite as valueless.

## Production

There have been no active celestite mines in the United States since 1959, but domestic celestite deposits have been identified. During World War II, celestite was mined in California and Texas. U.S. celestite mines had at that time been inactive since World War I, and strontium minerals were imported to satisfy domestic demand.

The sole U.S. strontium carbonate producer voluntarily provides domestic production and sales data to the U.S. Geological Survey (USGS). Production and stock data, however, are withheld from publication to avoid disclosing company proprietary data. *(See table 1.)* CPC is the only domestic company that produces strontium carbonate from celestite; the company also produces strontium nitrate. All the celestite CPC used in 1997 was imported from Mexico. CPC owns and operates a second strontium carbonate plant in Reynosa, Tamaulipas, Mexico. The company uses the black ash method of strontium carbonate production at both of its facilities.

The black ash method and the soda ash method 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. Carbon dioxide is then passed through the solution or soda ash is added, forming and precipitating strontium carbonate from solution. The precipitated strontium carbonate is then filtered, dried, ground, and packaged. The byproduct sulfur from the process is recovered as elemental sulfur or as other byproduct sulfur compounds.

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. The black ash method is the preferred means of strontium carbonate production due to the higher grade product, and most new production facilities employ black ash technology.

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 basis for the end-use estimates shown in table 2.

In 1997, more than 85% of all strontium was consumed in ceramics and glass manufacture, primarily in television faceplate glass with smaller quantities in ceramic ferrite magnets and other ceramic and glass applications. Over the past 20 years, production of faceplate glass for color television picture tubes has become 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, increasing the brilliance and improving the quality of the picture.

Permanent ceramic magnets are another large end use for strontium compounds, in the form of strontium ferrite. These magnets are used extensively in small direct current motors used in automobile windshield wipers, loudspeakers, other electronic equipment, toys, and magnetically attached decorative items. Strontium ferrite magnets have high coercive force, high thermal and electrical resistivity, 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.

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 strontium compound used most frequently in pyrotechnic devices was strontium nitrate. Strontium carbonate, strontium oxalate, strontium sulfate, and strontium chlorate can be used in pyrotechnic applications, but strontium nitrate is used in significantly larger quantities than any of these. Pyrotechnic devices are used in military and nonmilitary applications. Military pyrotechnic applications that contained strontium included tracer ammunition, military flares, and marine distress signals. Nonmilitary applications include warning devices and fireworks.

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.

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.

Strontium metal is 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 is currently gaining popularity in the automotive industry because the weight reduction of the automobile from using cast aluminum parts instead of steel improves gas mileage.

Other end uses consume only small amounts of strontium and strontium compounds. As mentioned previously, 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, with limits for some of them 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. *(See table 2.)*

## Prices

The average customs value for celestite imported from Mexico was about $72 per ton, 7% higher than the average value in 1996. The average unit customs value of imported strontium carbonate was $0.62 per kilogram, about the same as that in 1996. The corresponding value for strontium nitrate was $3.75 per kilogram, an increase of about 89%.

## Foreign Trade

According to reports from the U.S. Bureau of the Census, exports of strontium compounds decreased about 18% from the levels reported in 1996. Imports of celestite—all from Mexico—were 28,500 tons, an increase of about 8% from the 1996 level. Although celestite import figures vary significantly from year to year, this appears to be attributable to a 2-year cycle of celestite imports; however, during the past 3 years, trade data indicate a developing trend toward lower celestite imports. Over the past 5 years, annual celestite imports averaged about 29,000 tons (13,000 tons contained strontium) per year.

Mexico continued as the most important source for imported strontium compounds; Germany was second. Imports of strontium carbonate in 1997 were 27% higher than in 1996, with imports from Mexico comprising 92% of total carbonate imports. Imports of strontium nitrate were 106% higher than those in 1996; strontium nitrate imports vary significantly from one year to the next, but represent less than 1% of total strontium imports. *(See tables 3 and 4.)*

## 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, notably in Mexico, Spain, and Turkey. 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, current strontium chemical producers require material to contain at least 90% strontium sulfate. Most of the currently 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 are Mexico, Spain, Turkey, and Iran, in decreasing order of importance. Significant quantities of celestite are produced in China and the former U.S.S.R.; however, not enough information is available to make any estimate of location, number, or size of mines. Celestite is produced in smaller quantities in Algeria, Argentina, and Pakistan.

Detailed information on most world resources is not readily available and very little information on exploration results has been published. Some deposits are well identified but are in countries from which specific mineral information is not easily obtained.

Until World War II, practically all celestite produced worldwide was from the United Kingdom, and for several years following the end of the war, the United Kingdom maintained its importance. Depleted reserves, encroaching civilization, and the discovery of vast deposits in other countries resulted in the cessation of production in the United Kingdom. Any reported United Kingdom celestite production since 1992 was due to the reprocessing of mine tailings from an exhausted mine. *(See table 5.)*

Production facilities for strontium compounds and/or metal are located in Canada, China, Germany, Japan, the Republic of Korea, Mexico, Poland, the United States, and the former U.S.S.R.

## Outlook

Sales of televisions and computer monitors in the United States continues at a high rate. U.S. consumption of strontium increases to meet the demand for strontium carbonate for faceplate glass for these devices. Worldwide growth in demand for strontium carbonate may be moderated by the poor economic condition in parts of Asia.

As long as CRT's are the preferred display type for televisions and computers, long-term trends are expected to be positive. Growth in television sales is expected to continue and larger screens should increase 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 their current, slower rate.

Development of a technology to produce affordable flat television displays may severely reduce the demand for strontium carbonate. Although an affordable, high-quality, large, flat screen is not yet available, small models are, and research continues 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. Initial devices are expected to find application in military hardware and other sophisticated medical and scientific instrumentation. Flat screen display systems are likely to replace CRT's, and, at that point, strontium producers could experience a serious setback.

## 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.[1]

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.

[1]Prior 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/)

| | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|
| United States: | | | | | |
| Production, strontium minerals | -- | -- | -- | -- | -- |
| Imports for consumption: 3/ | | | | | |
| Strontium minerals | 11,600 | 16,000 | 12,700 | 11,600 | 12,500 |
| Strontium compounds | 15,300 | 20,000 | 20,800 | 20,500 | 26,000 |
| Exports (compounds) 3/ | 260 | 1,120 | 1,160 | 712 | 599 |
| Shipments from Government stockpile excesses | -- | -- | -- | -- | -- |
| Price, average value of mineral imports at port of exportation, dollars per ton | $73 | $68 | $71 | $67 | $72 |
| World production 4/ (celestite) | 201,000 | 274,000 r/ | 311,000 r/ | 306,000 r/ | 306,000 e/ |

e/ Estimated. r/ Revised.
1/ Data are rounded to 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 | 1996 | 1997 |
|---|---|---|
| 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 |

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

| | 1996 | | 1997 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value 2/ | Quantity (kilograms) | Value 2/ |
| Strontium carbonate precipitated: | | | | |
| Canada | 339,000 | $304,000 | 392,000 | $372,000 |
| Germany | 1,300 | 12,700 | -- | -- |
| Israel | 4,740 | 4,500 | -- | -- |
| Japan | 402 | 6,010 | 6,330 | 6,010 |
| Korea, Republic of | 250 | 4,000 | -- | -- |
| Mexico | 23,700 | 22,500 | -- | -- |
| Singapore | 11,600 | 11,000 | 200 | 3,680 |
| United Kingdom | 274 | 2,520 | -- | -- |
| Total | 381,000 | 368,000 | 398,000 | 382,000 |

See footnotes at end of table.

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

| | 1996 | | 1997 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value 2/ | Quantity (kilograms) | Value 2/ |
| Strontium oxide, hydroxide, and peroxide: | | | | |
| Australia | 255,000 | $140,000 | -- | -- |
| Belgium | 19,400 | 17,100 | -- | -- |
| Canada | 21,400 | 11,800 | 7,430 | $5,090 |
| Colombia | -- | -- | 189,000 | 104,000 |
| Dominican Republic | -- | -- | 28,100 | 15,500 |
| Germany | 84,400 | 46,400 | 134,000 | 73,800 |
| Haiti | -- | -- | 28,100 | 15,500 |
| Hong Kong | -- | -- | 100,000 | 55,200 |
| Israel | 26,400 | 14,500 | 148,000 | 81,500 |
| Italy | -- | -- | 30,500 | 16,800 |
| Japan | 165,000 | 149,000 | 52,500 | 49,300 |
| Korea, Republic of | -- | -- | 9,090 | 5,000 |
| Mexico | -- | -- | 72,800 | 40,000 |
| Norway | 24,800 | 13,700 | 11,600 | 6,400 |
| Panama | -- | -- | 19,000 | 10,400 |
| Russia | -- | -- | 37,900 | 20,800 |
| Taiwan | 88,300 | 48,600 | -- | -- |
| United Kingdom | 491,000 | 270,000 | 10,200 | 5,630 |
| Total | 1,170,000 | 711,000 | 879,000 | 505,000 |

1/ Data are rounded to 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/

| | 1996 | | 1997 | |
|---|---|---|---|---|
| | Quantity (kilograms) | Value 2/ | Quantity (kilograms) | Value 2/ |
| Strontium carbonate: | | | | |
| Canada | -- | -- | 13,000 | $3,550 |
| China | 377,000 | $215,000 | 173,000 | 99,700 |
| Germany | 3,360,000 | 2,230,000 | 3,330,000 | 2,190,000 |
| Italy | 3,000 | 6,870 | 3,000 | 7,200 |
| Japan | 5,780 | 78,800 | 385 | 7,800 |
| Mexico | 30,500,000 | 18,400,000 | 40,200,000 | 24,700,000 |
| United Kingdom | 762 | 18,700 | 1,180 | 28,800 |
| Total | 34,300,000 | 20,900,000 | 43,700,000 | 27,000,000 |
| Strontium nitrate: | | | | |
| Canada | -- | -- | 166 | 1,660 |
| China | 19,400 | 96,100 | 63,000 | 329,000 |
| France | 4,980 | 34,700 | 62,900 | 469,000 |
| Germany | -- | -- | 4 | 1,290 |
| Japan | -- | -- | 1,700 | 28,800 |
| Mexico | 111,000 | 138,000 | 152,000 | 220,000 |
| Switzerland | -- | -- | 1 | 1,350 |
| Total | 136,000 | 269,000 | 280,000 | 1,050,000 |

1/ Data rounded to 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/ | 1993 | 1994 | 1995 | 1996 | 1997 e/ |
|---|---|---|---|---|---|
| Algeria e/ | 5,400 | 5,400 | 5,400 | 5,400 | 5,400 |
| Argentina | 4,806 | 8,484 | 9,325 | 3,775 r/ | 4,000 |
| Iran e/ 4/ | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 |
| Mexico | 71,900 | 111,000 r/ | 138,342 | 143,892 | 145,000 |
| Pakistan | 1,684 | 2,320 | 1,625 | 2,500 e/ | 2,000 |
| Spain | 52,968 | 102,046 | 106,000 r/ | 100,000 r/ e/ | 100,000 |
| Turkey e/ | 43,700 | 25,000 | 30,000 r/ | 30,000 r/ | 30,000 |
| United Kingdom e/ | 1,000 | -- | -- | -- | -- |
| Total | 201,000 | 274,000 r/ | 311,000 r/ | 306,000 r/ | 306,000 |

e/ Estimated. r/ Revised.

1/ World totals and estimated data are rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through May 20, 1998.

3/ In addition to the countries listed, China and the former U.S.S.R. produce strontium minerals, 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.