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STRONTIUM

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Domestic apparent strontium consumption increased in 2009, attributed primarily to an increase in imported celestite. The 11,800 metric tons (t) of strontium content consumed in 2009 is dramatically lower than the nearly 38,000 t consumed at its peak in 1997. The decline in consumption during this period is a direct consequence of the decline in color television faceplate glass production, strontium's major end use since the early 1970s. Demand has increased for flat panel technology as an alternative to cathode-ray tubes (CRTs) for television displays, which requires little to no strontium carbonate. World production of celestite decreased by about 39% as a result of reduced production in Mexico, Spain, and Turkey, which also was attributed to the shift to flat panel technology.

Strontium composes about 0.04% of the Earth's crust, ranking 15th among elements in abundance (MacMillan and others, 2005). Only two minerals, however, celestite (strontium sulfate) and strontianite (strontium carbonate), contain strontium in sufficient quantities to make recovery practical. Of the two, celestite occurs much more frequently in sedimentary deposits of sufficient size to make development of mining facilities attractive. Neither mineral is mined in the United States, although deposits have been identified and were mined in the past.

Legislation and Government Programs

Strontium may be found in trace amounts in drywall, but the occurrence of foul odor, electrical corrosion, and illness associated with many Florida homes fitted with Chinese-manufactured drywall led State and Federal investigators to suspect the presence of elevated strontium sulfide levels. Strontium sulfide can react with moist air to produce hydrogen sulfide emitting a foul odor and causing corrosion. An initial study conducted by the Florida Department of Health found trace amounts of strontium sulfide in Chinese drywall and none in domestic drywall. The Environmental Protection Agency (EPA) found elevated strontium and sulfur levels in Chinese drywall. The U.S. Consumer Product Safety Commission (CPSC) conducted an air quality study on 51 affected homes and found high levels of hydrogen sulfide. The EPA and CPSC were conducting expanded studies and results were expected in the summer of 2010 (Florida Department of Health, 2009a, b; U.S. Consumer Product Safety Commission, 2009; U.S. Environmental Protection Agency, 2009).

Production

Although strontium carbonate was not produced in the United States in 2009, strontium carbonate was the principal strontium compound produced globally in 2009, and most other strontium compounds were derived from strontium carbonate. Domestic production of strontium carbonate ceased in 2006 when Chemical Products Corp. (CPC) of Cartersville, GA, closed its strontium carbonate and strontium nitrate operations. A few companies produced small quantities of downstream strontium chemicals elsewhere in the United States.

Consumption

Celestite is typically used as the raw material in strontium carbonate production and is consumed directly in small quantities as an alternative to barium sulfate as white filler in industrial products. Strontium carbonate is used directly in some applications and is also converted into appropriate downstream chemicals such as strontium chloride, strontium hydroxide, or strontium nitrate.

With the closure of CPC's strontium operations, an accurate estimation of domestic end uses has become difficult to obtain. The entire strontium consumption scenario has been reconfigured because television faceplate glass is no longer produced in the United States; thus, what was once the dominant end use is no longer a factor. At its peak, as much as 75% of all strontium consumption in the United States was used in faceplate glass for CRTs.

Even without strontium carbonate consumption in CRT displays, ceramics and glass manufacturing remained one of its top end uses. Permanent ceramic ferrite magnets are used extensively in small direct current motors for automobile windshield wipers, loudspeakers, magnetically attached decorative items, toys, and other electronic equipment. Strontium ferrite magnets possess chemical and physical properties ideal for use in these applications. They retain their magnetism well, are not adversely affected by electrical currents or high temperatures, do not react with most chemical solvents, and have a low density (Haberberger, 1971). Strontium oxide and strontium carbonate are used as frits in ceramic glazes as a nontoxic alternative to barium and lead (Yunpeng, 2009). Strontium oxide is used as a glass modifier to increase hardness and strength, enhance optical glass properties, and increase light refraction. Strontium glass is colorless and absorbs ultraviolet and x-ray radiation, an ideal glass for CRT faceplates. The fiberglass, lab glass, and pharmaceutical glass industries consume strontium in smaller amounts (Solvay S.A., 2010b).

One of the most consistent and continuing applications for strontium is its use in pyrotechnics as a coloring agent. While undergoing combustion, strontium emits a brilliant red hue. Strontium nitrate is used most often as a coloring agent, but strontium carbonate, strontium chlorite, strontium oxalate, and strontium sulfate can also be used. Strontium pyrotechnic applications include civilian and military flares, fireworks, and tracer ammunition (Conkling, 1981).

Recent research suggested that using nitrogen-base instead of carbon-base oxidizers reduced the amount of smoke emitted when deploying pyrotechnic products. By minimizing smoke, lower quantities of coloring agents were required to produce the same color intensities. The new technology could reduce the amount of coloring agents from 30% to 5%, by weight. Although the cost associated with this technology was high, these products found niche markets in indoor or environmentally friendly fireworks displays. If the cost fell and new environmental regulation was enacted, the consumption of strontium in this market was likely to decrease (Halford, 2008).

Strontium is used in a few metallurgical applications. Small quantities of strontium metal can be added to molten aluminum to improve the machinability of castings used in automotive engine blocks and wheels (Lidman, 2002). Strontium can be used to remove lead impurities during the electrolytic production of zinc. The addition of strontium carbonate dissolved in sulfuric acid reduces the lead content of the electrolyte and of the zinc deposited on the cathode (Solvay S.A., 2010a).

Small quantities of strontium and strontium compounds were consumed by other industries. Strontium chromate was incorporated into paints as a corrosion inhibitor, effectively coating aluminum used in the construction of aircraft fuselages and ships (Roskill Information Services Ltd., 1992, p. 76). Strontium chromate, however, was classified as a carcinogen in humans, leading many in the paint industry to seek safer alternatives (Raurell and others, 2010). Other strontium compounds were used as catalysts to accelerate the drying of oils, paints, and printing inks (Springate and others, 2009).

The drug strontium ranelate, a strontium salt of ranelic acid, has been used to reduce the incidence of fractures in osteoporotic patients by promoting the uptake of calcium into bones (Nielsen, 2004). The isotope strontium-89 has been used successfully in medical trials for the treatment of pain associated with advanced metastatic cancer (Porter, 1994). Strontium chloride is used in toothpaste to treat tooth-sensitivity caused by temperature and pressure.

Strontium exhibits a high dielectric constant, making it an attractive material for use in wireless devices and memory chips. Strontium titanate is sometimes used as a substrate material for semiconductors and in some optical and piezoelectric applications. As the technology improves and costs decrease, high-tech industries are likely to consume more strontium (McCoy, 2009; McIntosh, 2009).

Strontium oxide aluminate is used as a phosphorescent (glow-in-the-dark) pigment in applications such as emergency exit signs that glow brighter and longer than those using more-common photoluminescent pigments (Merit Lighting, LLC, 2008). Strontium phosphate is used in the manufacture of fluorescent lights, and the entire range of strontium chemicals is used in analytical chemistry laboratories.

Prices

Based on data published by the U.S. Census Bureau, the average customs unit value for celestite imported from Mexico was $47.11 per metric ton, a decrease of 26% compared with that of 2008. The average unit customs value of imported strontium carbonate was $0.65 per kilogram, a decrease of 3% from $0.67 per kilogram in 2008. In 2009, the unit value of imported strontium metal increased to $8.05 per kilogram from $4.66 per kilogram. In 2009, the corresponding value for strontium nitrate was $1.00 per kilogram, which was 12% lower than that of 2008.

Foreign Trade

With the modification of the domestic strontium market—strontium carbonate consumption for CRTs production shifting to Asia and the continued consumption of strontium compounds for ceramics, glass, and pyrotechnics—strontium exports from and imports into the United States became erratic from year to year. Adequate information to explain the variations is unavailable; however, trends have appeared during the past 5 years. Imports of celestite from Mexico were 14,600 t in 2009, more than 3 times the amount imported in 2008 and 11 times the amount imported in 2007 (table 1). Imports of strontium metal in 2009 were 70 t, exhibiting a steady decrease since reaching its peak of 770 t in 2005. Imports of strontium nitrate in 2009 decreased by 29% after 4 consecutive years of increases from 2005 to 2008, but were more than four times the imports of 2004, when CPC was still producing strontium nitrate at its Georgia plant. Imports of strontium carbonate have decreased steadily since 2005, and exports remained relatively low compared with their peak of 49,000 t in 2000.

Strontium exports from the United States have been decreasing every year since 2006. Total strontium exports in 2009 decreased to 773 t, an 11% decrease from the revised exports of 2008. Exports to Belgium, Germany, and the Republic of Korea represent 64% of total strontium exports by gross weight (table 2).

Strontium imports increased during the past 2 years, although total strontium imports decreased substantially from 2002 to 2007. Imports totaled 25,300 t (gross weight) in 2009 (table 3), an increase of 18% from that of 2008 and a 56% increase from that of 2007. Mexico continued to be a major source of imported strontium compounds, contributing more than 91% to total imports. Chinese strontium imports decreased from 2,480 t in 2008 to 719 t in 2009, driven in large part by a 70% decrease in strontium carbonate imports. With uncertainty surrounding the Spanish strontium production owing to the closure of the Montevive celestite mine in Granada and the global economic recession affecting the Spanish industrial minerals market, Spanish strontium imports decreased by 17% in 2009 (O'Driscoll, 2009; Moores, 2010).

World Review

Large deposits of high-grade celestite have been discovered throughout the world, but active mines are primarily in China, Iran, Mexico, Spain, and Turkey. Smaller operations are in Argentina, Morocco, and Pakistan. Many large deposits are not economically feasible to mine owing to high levels of barium and calcium, impurities requiring energy-intensive and cost-prohibitive methods for separation. Most strontium producers require a minimum of 90% strontium sulfate content to achieve profitability. Hand sorting and some washing are all that are

necessary at many strontium mines; a few operations use froth flotation, gravity separation, or other methods to beneficiate ore.

The leading celestite-producing countries were, in decreasing order of output, China, Spain, and Mexico comprising 96% of total celestite produced worldwide. Turkey had been another leading celestite producer but has experienced significant declines in production in recent years, and no celestite was produced in 2009. Celestite was produced in small quantities in Argentina, Morocco, Iran, and Pakistan (table 4). Production facilities for strontium compounds and metal were located in Canada, China, Germany, Japan, the Republic of Korea, Mexico, and the United States, although the current status of some of these operations is unknown.

Owing to decreased demand for CRTs and increased competition in the Chinese market, the Montevive celestite mine in Granada (operated by Bruno SA) closed in late 2009. The Belgian chemical producer Solvay Minerales SA was the only remaining Spanish producer of celestite. Spanish celestite production decreased significantly in 2009 and further production decreases were expected in coming years. The Iranian celestite industry was expected to expand during the next 3 years owing to strong Chinese demand, low cost of container freight, and government subsidies. Production was expected to reach between 2,000 and 20,000 tons per year (O'Driscoll, 2009).

Outlook

The production of CRT televisions and computer monitors is expected to cease as flat screen devices, requiring little or no strontium, become more accessible. Faceplate glass and smaller televisions with CRTs still are produced in Asia and Mexico, where they now are being built for local consumption and export. Strontium demand for CRTs has begun to decline in Asia and Mexico, and newer display technology is likely to replace CRTs in those markets as well.

Strontium use in pyrotechnics is expected to continue; however, the strontium consumption in pyrotechnics is likely to decline slowly as substitutes are developed that enable less strontium nitrate to be used to achieve the same color intensities. Ferrite magnet markets are expected to be strong, and demand for strontium is likely to continue for this use. As technologies improve, consumption of strontium in new applications may increase. Improved economic conditions worldwide could spur growth in demand for strontium carbonate in more traditional applications, but it is unlikely that television and monitor glass will ever represent the dominant end use for strontium that it once did.

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TABLE 1

SALIENT STRONTIUM STATISTICS[1]

(Metric tons of contained strontium and dollars per metric ton unless otherwise noted)[2]

	2005	2006	2007	2008	2009
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[3]					
Strontium compounds	11,700	8,860	8,550	9,420	5,860
Strontium minerals	799	671	541	2,030	6,420
Exports, compounds[3]	211 r	699 r	688 r	594 r	532
Shipments from Government stockpile excesses	--	--	--	--	--
Apparent consumption[4]	12,300	8,830	8,400 r	10,900 r	11,800
Price, average value of mineral imports at port of exportation	56	64	67	64	47
World, production of celestite, gross weight	509,000	524,000 r	518,000 r	656,000 r	402,000 e

eEstimated. rRevised. -- 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 of celestite.

[3]Source: U.S. Census Bureau.

[4]Production plus imports minus exports.

TABLE 2

U.S. EXPORTS OF STRONTIUM COMPOUNDS, BY COUNTRY[1]

	2008		2009	
	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Strontium carbonate, precipitated:				
Canada	37,400	$40,100	30,900	$32,200
Germany	--	--	3,840	3,650
Japan	--	--	13,100	21,800
Korea, Republic of	62,600	59,500	--	--
Mexico	18,100	14,100	102,000	41,100
Netherlands	--	--	6,320	6,000
United Kingdom	--	--	2,780	2,640
Total	118,000	114,000	159,000	107,000
Strontium oxide, hydroxide, peroxide:				
Argentina	117,000	64,400	--	--
Belgium	29,300	16,100	215,000	121,000
Brazil	7,570 r	11,900 r	--	--
Canada	161,000	76,300	--	--
China	1,000	5,260	--	--
Colombia	30,700	16,900	--	--
France	189,000	297,000	--	--
Germany	19,100 r	10,500 r	176,000	97,000
Israel	63,300	34,800	11,000	6,070
Italy	37,000	42,400	--	--
Japan	12,100 r	6,630 r	25,600	14,100
Korea, Republic of	28,400	15,600	102,000	56,100
Norway	4,550	2,500	--	--
Spain	-- r	-- r	--	--
Sweden	22,900	12,600	18,400	10,100
Switzerland	--	--	27,900	15,300
Taiwan	18,000 r	24,100 r	38,000	34,700
Trinidad	--	--	747	3,240
United Kingdom	7,640	4,200	--	--
Total	749,000 r	641,000 r	615,000	358,000

rRevised. -- Zero.

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

[2]Free alongside ship value.

Source: U.S. Census Bureau; data adjusted by the U.S. Geological Survey.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY[1]

	2008		2009	
	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Celestite, Mexico	4,620,000	$295,000	14,600,000	$690,000
Strontium carbonate:				
China	2,000,000	2,890,000	600,000	693,000
Germany	1,490,000	877,000	1,240,000	703,000
Italy	7,000	34,900	20,400	124,000
Mexico	9,240,000	4,750,000	5,890,000	3,500,000
Spain	--	--	72,600	64,900
United Kingdom	25	13,400	25	9,720
Total	12,700,000	8,560,000	7,820,000	5,090,000
Strontium metal:				
Brazil	4,090	22,100	--	--
Canada	47	2,200	--	--
China	60,700	326,000	20,200	149,000
Japan	103,000	410,000	30,400	71,200
Korea, Republic of	2,340	22,500	--	--
Switzerland	16	8,660	19,500	344,000
Total	170,000	791,000	70,100	564,000
Strontium nitrate:				
Canada	--	--	1,700	5,700
China	312,000	310,000	93,600	115,000
Japan	256,000	726,000	58,000	178,000
Mexico	3,130,000	3,230,000	2,550,000	2,410,000
Spain	170,000	152,000	68,500	59,900
Taiwan	16,700	15,200	--	--
Total	3,890,000	4,430,000	2,770,000	2,770,000
Strontium oxide, hydroxide, peroxide:				
China	104,000	103,000	5,450	36,000
Germany	1,400	23,500	--	--
Japan	601	20,700	300	9,400
Korea, Republic of	200	5,150	974	5,370
Total	106,000	152,000	6,720	50,800

-- Zero.

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

[2]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 4
CELESTITE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2005	2006	2007	2008	2009[e]
Argentina	7,233	19,822	4,904	14,910 [r]	10,000
China[e]	180,000	180,000	190,000	200,000	210,000
Iran[e, 4]	672 [5]	1,000 [r]	2,000 [r]	2,000 [r]	2,000
Mexico	110,833	125,000	125,000 [e]	96,902	37,601 [5]
Morocco[e]	2,700	2,700	2,700	2,700	2,600
Pakistan	1,855	1,466	1,600 [e]	1,700 [e]	1,800
Spain[e]	188,000	188,000	188,000	336,000 [r, 5]	138,000 [5]
Turkey[e]	18,000	6,300	4,200	1,600	--
Total	509,000	524,000 [r]	518,000 [r]	656,000 [r]	402,000

[e]Estimated. [r]Revised. -- Zero.

[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 16, 2010.

[3]In addition to the countries listed, Tajikistan was thought to produce celestite, but information was not available to make reliable estimates.

[4]Data are for year beginning March 21 of that stated.

[5]Reported figure.