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2014 Minerals Yearbook

STRONTIUM [ADVANCE RELEASE]

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Strontium

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Domestic apparent consumption of strontium increased by 9% in 2014 to 31,700 metric tons (t), mostly as the result of continued increases in imports of the strontium mineral celestite. Imports of celestite increased by 11% and imports of strontium compounds increased by 5%. Apparent consumption of strontium peaked in 1997 and then trended downward until 2011, when consumption began to increase again. The increased imports of strontium minerals since that time likely were the result of increased use of celestite in drilling muds (this is unconfirmed as the compositions of drilling muds are proprietary) or other unidentified end uses rather than as raw materials for strontium compound production. The last domestic strontium carbonate plant, which used celestite as a raw material, ceased production in 2006. Celestite imports were less than 1,000 t each year from 2005 through 2007 but increased to more than 55,000 t in 2014. Strontium minerals were not mined in the United States in 2014, although deposits have been identified and were mined in the past. World production of celestite decreased slightly to 343,000 t in 2014 from 351,000 t in 2013 (tables 1 and 4).

Strontium constitutes about 0.04% of the Earth's crust, ranking 15th in abundance among the elements (MacMillan and others, 2005). Owing to its high reactivity to air and water, strontium is not found in nature in metallic form. Two strontium-bearing minerals, 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 mining attractive.

Legislation and Government Programs

On October 20, 2014, the U.S. Environmental Protection Agency (EPA) announced a preliminary determination to regulate strontium in drinking water. The EPA made an initial determination that ingestion of strontium has adverse health effects, especially on infants, children, and adolescents, because it can replace calcium in bones and affect bone strength. After evaluating public feedback, the EPA was expected to issue a final determination of its intention to regulate strontium in drinking water during 2015. Strontium occurs naturally and has been detected in 99% of public water systems in the United States, 7% of which are at levels of concern (U.S. Environmental Protection Agency, 2014).

Production

Celestite has not been actively mined in the United States since 1959, though there are deposits in Arizona, California, Ohio, Texas, and Washington that were mined in the past. Domestic production of celestite correlated with the lack of availability of the mineral commodity from the United Kingdom during World War I and World War II (Schreck and Foley, 1959).

Although strontium carbonate was not produced in the United States in 2014, it was the principal strontium compound produced globally. Additionally, most other strontium compounds were derived from strontium carbonate. Domestic production of strontium carbonate ceased in 2006 with the closure of the Chemical Products Corp.'s strontium carbonate and strontium nitrate operations in Cartersville, GA. A few companies continued to produce small quantities of downstream strontium chemicals elsewhere in the United States.

Consumption

Consumption patterns for strontium materials have shifted substantially during the past few years, with more strontium in minerals being consumed than strontium in chemicals in 2012–14, which had not happened since 1992. In 2014, 24,200 t of strontium contained in celestite was consumed in the United States, and 7,600 t of strontium was consumed as various strontium chemicals (table 1). Because no strontium carbonate was produced domestically from imported celestite in 2014, imported celestite likely was used directly as an additive in drilling muds and underwent no chemical processing. Celestite, and thus strontium, consumption likely increased because of increased oil and natural gas well-drilling activity in the United States. Before 2006, nearly all imported celestite underwent chemical processes to be converted into strontium carbonate.

Strontium chemicals were mostly consumed by the ceramics, glass, and pyrotechnics industries, with smaller quantities consumed by a multitude of other industries. Strontium carbonate is used directly in some applications and also is converted into appropriate downstream chemicals such as strontium chloride, strontium hydroxide, or strontium nitrate. Celestite typically has been used as the raw material in strontium carbonate production and was consumed directly in small quantities as an alternative to barium sulfate as white filler in industrial products. Increased imports of celestite since 2010 most likely were the result of celestite being used in some drilling muds used in natural gas and crude oil wells.

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 the chemical and physical properties that are ideal for use in these applications, such as effectiveness at high temperatures, low densities, and resistance to corrosion and demagnetization. Strontium oxide and strontium carbonate are used as frits in ceramic glazes as a nontoxic alternative to barium and lead. Strontium oxide is used as a glass modifier to enhance optical

glass properties, increase hardness and strength, and intensify light refraction. Strontium glass is colorless and absorbs ultraviolet and x-ray radiation, an ideal glass for cathode-ray-tube (CRT) faceplates, although flat panel displays have almost completely replaced CRTs. The fiberglass, lab glass, and pharmaceutical glass industries consume strontium in smaller quantities.

Strontium nitrate is used most commonly as a coloring agent in pyrotechnic applications to produce a bright red and, in combination with a copper compound, purple. Strontium carbonate, strontium chloride, strontium oxalate, and strontium sulfate can also be used. Strontium pyrotechnic applications include civilian and military flares, fireworks, and tracer ammunition.

In metallurgical applications, strontium metal is added to aluminum alloys to improve the strength and ductility of castings used in aerospace and automotive applications. Addition of even a few hundred parts per million strontium causes the microscopic structure of the alloys to transform from a coarse, plate-like texture to a fine, fibrous network (Timpel and others, 2012). 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.

Strontium chromate was incorporated into paints as a corrosion inhibitor, effectively coating aluminum used in the construction of aircraft fuselages and ships. Strontium chromate, however, was classified as a carcinogen in humans because of its hexavalent chromium content, leading many in the paint industry to seek safer alternatives. The European Chemical Agency proposed strict regulations for its use, although achieving comparable corrosion resistance proved difficult using more environmentally friendly materials. A mixed metal calcium-strontium-phosphate complex on a silicate core provides excellent corrosion resistance (Hodges and others, 2010; European Chemical Agency, 2012; Koleske and others, 2014, p. 50). Other strontium chemicals were used as catalysts to accelerate the drying of oils, paints, and printing inks (Koleske and others, 2014, p. 55).

The prescription drug strontium ranelate has been shown to reduce the incidence of fractures in osteoporotic patients by promoting the uptake of calcium into bones. No rigorous clinical studies have been completed that prove whether strontium dietary supplements, such as strontium carbonate and strontium citrate, are effective treatments for osteoporosis (Johannes, 2013). Further studies, however, have shown that strontium ranelate may present cardiovascular risks that outweigh its benefits (Price, 2014a). Although the European Medicines Agency considered withdrawing the drug from the market, strontium ranelate remained on the market in Europe, but only for patients that were unable to take other osteoporosis medication (Price, 2014b). 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 some toothpastes 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. Research also was conducted on the use of strontium in superconductors and radiation detectors. As the technology improves and costs decrease, high-tech industries may consume more strontium (McCoy, 2009; McIntosh, 2009; Physorg, 2010; Walter, 2010; Singh and others, 2011).

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 $50 per metric ton, virtually the same as that of 2013 (table 3). The average unit customs value of imported strontium carbonate was $0.84 per kilogram, slightly higher than that in 2013. In 2014, the unit value of imported strontium metal decreased by 10% to $7.47 per kilogram from $8.28 per kilogram. In 2014, the unit value for strontium nitrate was $1.31 per kilogram, 9% higher than the $1.20 per kilogram in 2013. Strontium compound and mineral prices can vary widely from year to year, and reasons for significant changes are difficult to determine.

Foreign Trade

Strontium exports from and imports into the United States have become unpredictable from year to year. Adequate information to explain the variations is unavailable. Imports of strontium minerals, all of which were celestite from Mexico, were 55,100 t by gross weight in 2014, 11% more than those of 2013. The increase was most likely the result of expanded use of celestite in drilling muds. By gross weight, total strontium compound imports were 13,600 t in 2014, 5% more than those of 2013 (table 3).

Strontium carbonate exports by gross weight were 174 t in 2014—nearly three times those in 2013. Exports to China and Hong Kong accounted for 71% of total strontium exports (table 2). Export and import data in table 1 represent only the strontium content of the imported celestite and strontium compounds. Strontium chemicals imported from China, Germany, and Mexico accounted for nearly 99% of total strontium chemical imports into the United States by gross weight, with Mexico accounting for 58%; Germany, 35%; and China, 6%.

World Review

Large deposits of high-grade celestite have been discovered throughout the world, but active mines were primarily in China, Mexico, and Spain. These countries accounted for 96% of total celestite produced in 2014. Smaller mines operated in Argentina

and Morocco. Many large deposits are not economic 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. Major global producers for strontium chemicals and metal in 2014 were in China, Germany, and Mexico.

Outlook

Improved economic conditions worldwide could spur increased demand for strontium carbonate in more traditional applications. Use of strontium by the ceramics, glass, and pyrotechnics industries is expected to continue, with continued demand for strontium used in ferrite magnets. With developments in advanced applications, consumption of strontium in new end uses may increase.

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TABLE 1
SALIENT STRONTIUM STATISTICS[1]

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

	2010	2011	2012	2013	2014
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[3]					
Strontium compounds	8,640	10,000	8,150	7,190	7,600
Strontium minerals	2,370	7,320	8,660	21,900	24,200
Exports, carbonate[3]	72	18	71	37 r	104
Shipments from Government stockpile excesses	--	--	--	--	--
Apparent consumption[4]	10,900	17,300	16,700	29,000	31,700
Price, average value of mineral imports at port of exportation	45	46	50	50	50
World, production of celestite, gross weight	325,000 r	381,000 r	378,000 r	351,000 r	343,000 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 CARBONATE, BY COUNTRY[1]

	2013		2014	
Country	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Canada	26,200	$31,900	10,600	$11,700
China	--	--	61,100	58,100
Hong Kong	500	9,350	63,600	60,400
Japan	1,870	3,390	--	--
Korea, Republic of	29,600	28,200	7,960	9,500
Mexico	--	--	181	2,850
United Kingdom	4,460	11,300	31,100	43,600
Total	62,600	84,000	174,000	186,000

-- 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]

Compound and country	2013 Gross weight (kilograms)	2013 Value[2]	2014 Gross weight (kilograms)	2014 Value[2]
Celestite, Mexico	49,800,000	$2,490,000	55,100,000	$2,760,000
Strontium carbonate:				
China	129,000	406,000	234,000	368,000
Germany	4,600,000	3,520,000	4,790,000	3,900,000
Italy	8,000	54,300	11,500	124,000
Mexico	4,880,000	3,920,000	5,690,000	4,460,000
Spain	109,000	87,800	40,000	41,300
United Kingdom	6	8,080	1,030	128,000
Total	9,730,000	8,000,000	10,800,000	9,020,000
Strontium metal:				
China	111,000	915,000	77,500	569,000
France	7,320	60,200	11,000	91,500
Taiwan	5,400	48,300	--	--
Total	124,000	1,020,000	88,500	661,000
Strontium nitrate:				
China	435,000	588,000	483,000	666,000
France	--	--	800	7,520
Hungary	--	--	615	13,300
India	--	--	500	4,630
Japan	13,000	36,800	33,500	40,200
Mexico	2,470,000	2,890,000	2,160,000	2,790,000
Spain	130,000	146,000	41,300	48,500
Total	3,050,000	3,660,000	2,720,000	3,570,000
Strontium oxide, hydroxide, peroxide:				
Brazil	2,660	8,260	--	--
China	40,000	44,000	--	--
Japan	151	17,400	225	13,200
Total	42,800	69,600	225	13,200

-- Zero.
[1]Data rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.

Source: U.S. Census Bureau.

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

(Metric tons)

Country[3]	2010	2011	2012	2013	2014[e]
Argentina	8,512	1,056	22,750	10,000 [e]	10,000
China[e]	200,000	200,000	190,000	180,000	170,000
Iran[e]	--	40,000	20,000	--	--
Mexico	31,429	40,669	46,192	67,778 [r]	70,000
Morocco[e]	2,500	2,500	2,500	2,500	2,500
Spain	83,035 [r]	97,102 [r]	96,888 [r]	90,972 [r]	90,000
World total	325,000 [r]	381,000 [r]	378,000 [r]	351,000 [r]	343,000

[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]Includes data available through June 28, 2016.
[3]In addition to the countries listed, Tajikistan was thought to produce celestite, but information was not available to make reliable estimates of output levels.