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STRONTIUM [ADVANCE RELEASE]

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Strontium

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Domestic apparent consumption of strontium increased by 66% in 2017 to 17,900 metric tons (t), mostly as the result of the 155% increase in imports of celestite (table 1). Imports of strontium compounds, in strontium content, also increased, in this case by 4%. Apparent consumption of strontium peaked in 1997 and then trended downward until 2008, when consumption began to increase again. The increased imports of celestite, especially since 2011, were likely the result of its increased use in petroleum industry drilling muds, although this is unconfirmed because drilling mud compositions are proprietary. Alternatively, the imported celestite could have been used for other unidentified end uses. In either case, it is unlikely that the imported celestite was being used as raw material for strontium compound production because the last domestic strontium carbonate plant, which used celestite as a raw material, ceased production in 2006. Celestite imports were, in gross weight, less than 2,000 metric tons per year (t/yr) from 2005 to 2007 but increased to 55,800 t (24,500 t of strontium) in 2015 before decreasing to 10,100 t (4,420 t of strontium) in 2016 and then increasing to 25,700 t (11,300 t of strontium) in 2017 (table 1). The recent decrease and increase in celestite imports in 2016 and 2017, respectively, was likely a result of the changing price of crude oil and drilling activities. Strontium minerals were not mined in the United States in 2017, although deposits have been identified and were mined in the past. World production of celestite, in gross weight, increased by 17% to 255,000 t in 2017 from 218,000 t in 2016 (tables 1, 4).

Strontium constitutes about 0.03% of the Earth's continental crust, ranking 17th in abundance among the elements (Wedepohl, 1995). 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. 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). After evaluating public feedback, the EPA announced on January 4, 2016, that it would delay its determination until additional data were considered as to whether treatment systems would inadvertently remove beneficial calcium along with the strontium in drinking water (U.S. Environmental Protection Agency, 2016). There was no update on this topic in 2017.

In 2017, India's Supreme Court banned the sale of fireworks, one of the primary end uses of strontium, in Delhi during the Diwali festival in October in an attempt to reduce air pollution. Diwali is the Hindu festival of lights and includes many fireworks displays throughout the multiday event. The 2017 ban in Delhi was a test run to determine how pollution levels were affected by the restrictions and has the potential to result in future restrictions during the festival elsewhere in the country (McCarthy, 2017).

Production

Celestite has not been actively mined in the United States since 1959, although deposits in Arizona, California, Ohio, Texas, and Washington were mined in the past. Additionally, deposits have been identified in Colorado, Kansas, Michigan, New York, Pennsylvania, Tennessee, Virginia, and West Virginia (Culin, 1916; Mitchell and Pharr, 1960). In the past, domestic production of celestite correlated with the difficulty in obtaining the mineral commodity from former import sources, especially 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 2017, 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 continue 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. From 2012 to 2015, more strontium in minerals was consumed than strontium in chemicals, which had not happened since 1992, although at that time, the strontium minerals were used to produce strontium chemicals. In 2017, more strontium in minerals (11,300 t) was again consumed than in chemicals (6,660 t); in 2016, this trend had reversed with more strontium in chemicals (6,420 t) being consumed than in minerals (4,420 t) (table 1). Because no strontium carbonate was produced domestically from imported celestite in 2017, imported celestite likely was used directly as an additive in drilling muds and underwent no chemical processing. Before 2006, nearly all imported celestite underwent chemical processing to be converted into strontium carbonate.

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. However, 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. Celestite may be used as a substitute for barite in these muds owing to the similar specific gravities of the two minerals (4.1 to 4.2 for the American Petroleum Institute specification for barite in drilling muds and an average of 3.95 for celestite). The possible use of celestite as a substitute for barite or as an additive in drilling muds is likely because of the increase in the price of barite beginning in 2008 (McRae, 2015, 2018).

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 to produce permanent ceramic ferrite magnets, which are used extensively in small direct current motors for automobile windshield wipers, loudspeakers, magnetically attached decorative items, toys, and other electronic equipment. These magnets are produced by several U.S. companies and possess 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 nontoxic alternatives 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. Additionally, with future development in holography, strontium barium niobate could be a significant storage medium for three-dimensional color holograms (Ketchel and others, 1999).

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 also can 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 of 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 Chemicals 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).

Strontium is absorbed and processed in the human body in the same manner as calcium owing to the chemical similarities of the two elements. As a result, strontium has a number of medical applications including the use of the isotope strontium-89 for the treatment of pain related to certain types of bone cancer (Porter, 1994; Q BioMed Inc., 2017), the use of strontium chloride in toothpastes to treat temperature- and pressure-related sensitivity, and the recent development of the prescription drug strontium ranelate used 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, 2014). In August 2017, Laboratoires Servier (France) ceased the manufacture of Protelos (strontium ranelate) on the basis of commercial grounds arguing that the drug has limited uses and was being prescribed too infrequently (National Osteoporosis Society, 2017).

Strontium exhibits a high dielectric constant, making it an attractive material for use in wireless devices and memory chips (McCoy, 2009; McIntosh, 2009). Strontium titanate is sometimes used as a substrate material for semiconductors and in some optical and piezoelectric applications (Singh and others, 2011). Research also has been conducted on the use of strontium in superconductors and radiation detectors (Physorg, 2010; Walter, 2010). Promising developments in the use of lead halogen perovskite solar cells may also pertain to strontium because its substitution for lead represents a more environmentally friendly alternative to the toxic, water-soluble lead currently used (Jacobsson and others, 2015). Strontium niobate can split water into oxygen and hydrogen when in contact with water and under solar irradiation, which could have significant ramifications for harvesting hydrogen for use in clean energy (Physorg, 2017). As technologies improve and costs decrease, high-tech industries may use more strontium.

Strontium oxide aluminate is used as a phosphorescent (glow-in-the-dark) pigment in applications, such as emergency exit signs, which 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 $72 per metric ton (table 3). Imports from Brazil, Madagascar, and South Africa were reported in 2017, but the high unit values ($549, $3,300, and $23,100 per metric ton, respectively) and low tonnages indicated that those imports likely were as mineral specimens not industrial additives or raw materials. The average customs unit value of imported strontium carbonate was $824 per metric ton, slightly more than that in 2016. In 2017, the unit value of imported strontium metal increased by 42% to $8,820 per metric ton from $6,210 per metric ton, and the unit value for strontium nitrate was essentially unchanged.

Foreign Trade

Strontium exports from and imports into the United States have become unpredictable from year to year. Adequate information to explain the variations was unavailable. Imports of strontium minerals, all of which were celestite, were 25,700 t by gross weight (11,300 t by strontium content) in 2017, an increase of 155% compared with those of 2016. Imports of strontium compounds (includes strontium chemicals and metal) were 11,800 t by gross weight (6,660 t by strontium content) in 2017, 3% more than those of 2016 (table 3). Imports of strontium compounds into the United States were sourced predominantly from Mexico, 49%; Germany, 37%; and China, 8%.

Strontium carbonate exports were 60 t by gross weight (36 t by strontium content) in 2017, a 61% decrease compared with those of 2016 (table 2). Export and import data in table 1 represent only the strontium content of the celestite and strontium compounds.

World Review

Large deposits of high-grade celestite have been discovered throughout the world, but active mines were primarily in China, Iran, Mexico, and Spain. These countries accounted for 98% of total celestite production in 2017. Some celestite also was produced in Argentina and Tajikistan. Many large deposits are not economic to mine owing to high levels of barium and calcium, which are impurities that require energy-intensive and cost-prohibitive methods for separation. Most strontium producers require a minimum of 90% strontium sulfate content to achieve profitability. In terms of processing ore, 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 of strontium chemicals in 2017 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. In addition, if barite prices remain high, strontium could continue to be used as a partial substitute in drilling muds. However, if gas and oil prices remain low, drilling activity likely will continue to decline, leading to lower imports of celestite for use in drilling muds. Forthcoming EPA determinations to regulate strontium in drinking water are unlikely to affect the domestic use of strontium because most strontium in drinking water is naturally occurring, not from industrial facilities (Roberts, 2016). 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 specified)

	2013	2014	2015	2016	2017
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[2]					
Strontium compounds[3]	7,190	7,600	7,100	6,420 r	6,660
Strontium compounds, gross weight	12,900	13,600	12,700	11,500	11,800
Celestite[4]	21,900	24,200	24,500	4,420	11,300
Celestite, gross weight	49,800	55,100	55,800	10,100	25,700
Exports:[2]					
Carbonate	37	104	86	91	36
Carbonate, gross weight	63	174	145	154	60
Apparent consumption[5]	29,000	31,700	31,500	10,700 r	17,900
Price, average value of mineral imports at port of exportation	50	50	51	78	74
World, production of celestite, gross weight	286,000 r	285,000 r	286,000 r	218,000 r, e	255,000 e

eEstimated. rRevised. -- Zero.

[1]Table includes data available through May 30, 2018. Data are rounded to no more than three significant digits.

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

[3]Strontium compounds, with their respective strontium contents, include strontium metal (100.00%); oxide, hydroxide, and peroxide (70.00%); carbonate (59.35%); and nitrate (41.40%). These factors were used to convert units of strontium compounds to strontium content.

[4]In 2016, this label was changed from "Strontium materials" to "Celestite" to reflect that it includes only celestite. The strontium content of celestite is 43.88%, assuming an ore grade of 92%, which was used to convert units of gross weight celestite to strontium content.

[5]Production plus imports minus exports.

TABLE 2
U.S. EXPORTS OF STRONTIUM CARBONATE, BY COUNTRY OR LOCALITY[1]

	2016		2017	
Country or locality	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Canada	9,540	$9,500	19,700	$18,000
China	--	--	2,000	6,500
India	125	3,120	--	--
Japan	4,410	8,890	5,600	10,700
Korea, Republic of	36,900	35,000	32,700	37,100
Mexico	103,000	90,900	--	--
Total	154,000	147,000	60,100	72,300

-- Zero.

[1]Table includes data available through May 30, 2018. 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.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY OR LOCALITY[1]

Compound and country or locality	2016 Gross weight (kilograms)	2016 Value[2]	2017 Gross weight (kilograms)	2017 Value[2]
Celestite:				
Brazil	--	--	29,400	$16,100
Madagascar	1,670	$10,400	2,870	9,470
Mexico	10,100,000	772,000	25,700,000	1,850,000
Morocco	16,000	4,800	--	--
South Africa	--	--	573	13,300
Total	10,100,000	787,000	25,700,000	1,890,000
Strontium carbonate:				
China	184,000	224,000	258,000	396,000
Germany	4,190,000 r	3,390,000 r	4,320,000	3,510,000
Italy	34,900	35,400	41,300	53,600
Mexico	4,430,000	3,500,000	3,740,000	2,920,000
Spain	11,000	9,350	39,300	40,200
United Kingdom	97,500	93,900	--	--
Total	8,940,000 r	7,250,000 r	8,400,000	6,920,000
Strontium metal:				
China	70,800	409,000	162,000	1,410,000
France	1,350	9,570	--	--
Japan	7,000	56,700	120	3,440
Mexico	4,760	45,700	20,800	199,000
United Kingdom	--	--	1	3,030
Total	83,900	521,000	183,000	1,610,000
Strontium nitrate:				
Canada	--	--	4,670	5,820
China	493,000	557,000	517,000	659,000
Germany	12,900	25,700	--	--
India	3,000	27,800	21,500	27,300
Mexico	1,840,000	2,330,000	2,090,000	2,570,000
Spain	74,000	77,600	142,000	164,000
United Kingdom	5	2,170	--	--
Total	2,430,000	3,020,000	2,780,000	3,430,000
Strontium oxide, hydroxide, peroxide:				
China	1,030	12,500	20,000	18,900
France	34,100	51,200	36,100	76,800
Germany	937	13,200	975	14,800
Japan	1	3,000	180,000	229,000
Korea, Republic of	--	--	252,000	422,000
Peru	697	2,190	--	--
United Kingdom	--	--	100	6,700
Total	36,800	82,100	489,000	768,000

rRevised. -- Zero.
[1]Table includes data available through May 30, 2018. Data are 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 OR LOCALITY[1]

(Metric tons)

Country or locality[2]	2013	2014	2015	2016	2017[e]
Argentina	5,246	700 [r]	700 [r, e]	5,000 [e]	5,000
China	76,000	50,600	53,200 [r]	50,000 [e]	50,000
Iran	46,240 [r]	41,050 [r]	36,760 [r]	40,000 [r, e]	40,000
Mexico	67,778	64,931	79,022	33,230 [r]	70,000
Spain	90,972	128,077	116,765 [r]	90,000 [e]	90,000
Total	286,000 [r]	285,000 [r]	286,000 [r]	218,000 [r, e]	255,000

[e]Estimated. [r]Revised.
[1]Table includes data available through May 9, 2018. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
[2]In addition to the countries and (or) localities listed, Tajikistan may have produced celestite, but available information was inadequate to make reliable estimates of output.