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2018 Minerals Yearbook

STRONTIUM [ADVANCE RELEASE]

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Strontium

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Strontium minerals were not mined in the United States in 2018, although deposits have been identified and were mined in the past. Domestic apparent consumption of strontium contained in compounds and minerals increased by 29% in 2018 to 23,200 metric tons (t), mostly as the result of the increase in imports of celestite (table 1). Celestite imports increased in 2018 to 16,900 t from 11,300 t in 2017 (table 1). Imports of strontium compounds, in strontium content, decreased by 5% in 2018 to 6,350 t. In 2018, world production of celestite, in gross weight, was 219,000 t, essentially unchanged from the revised quantity for 2017 (tables 1, 4).

Strontium constitutes about 0.03% of the Earth's continental crust, ranking 17th in abundance among the elements (Wedepohl, 1995, p. 1220). 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

In May, the U.S. Department of the Interior, in coordination with other executive branch agencies, published a list of 35 critical mineral commodities, which included strontium. The list was developed to serve as an initial focus, pursuant to Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals" (U.S. Department of the Interior, 2018).

Under section 301(b) of the Trade Act of 1974, as amended, the Office of the U.S. Trade Representative (USTR) determined that acts, policies, and practices of China related to technology transfer, intellectual property, and innovation were discriminatory or unreasonable and those actions burdened or restricted United States commerce (83 FR 14906). An initial list of 818 tariff lines became subject to an additional import duty of 25% in July 2018. In August, the USTR imposed an additional 25% import duty on a second list of 279 tariff lines. A third list of 5,745 full and partial tariff lines, including nonfuel mineral ores and concentrates and forms, became subject to an additional 10% import duty in late September. Strontium-containing materials subject to the section 301 actions included the following Harmonized Tariff Schedule of the United States (HTS) codes: 2805.19.10, strontium metal; 2816.40.10, strontium oxide, hydroxide, peroxide; 2834.29.20, strontium nitrate; and 2836.92.00, strontium carbonate (Office of the U.S. Trade Representative, 2018).

In October, the U.S. International Trade Commission announced in a preliminary determination that a reasonable indication existed that strontium chromate, under HTS codes 2841.50.91 and 3212.90.00, from Austria and France was being sold in the United States at less than fair value. In the same document, the Commission announced the commencement of the final phase of investigation, which was not completed at yearend (U.S. International Trade Commission, 2018).

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 had been detected in 99% of public water systems in the United States, 7% of which were 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 (U.S. Environmental Protection Agency, 2016). On October 12, 2018, the EPA approved alternative testing methods for measurements of contaminants in drinking water, which included strontium-89 and strontium-90 (U.S. Environmental Protection Agency, 2018).

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 2018, 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. 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 2016, this trend had reversed with more strontium in chemicals being consumed than in minerals. Beginning in 2017 and continuing throughout 2018, more strontium in minerals was again consumed than in chemicals (table 1). Because no strontium carbonate was produced domestically from imported celestite in 2018, 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 (4.10 to 4.20 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 (Miller, 2010; McRae, 2015, 2019).

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 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 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.

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 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 carbonate 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.

Historically, strontium chromate was incorporated into paints as a corrosion inhibitor, effectively coating aluminum used in the construction of aircraft fuselages and ships. However, since being classified as a carcinogen in humans because of its hexavalent chromium content, strontium chromate has increasingly been replaced by safer alternatives in the paint industry. 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 several 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) and the use of strontium chloride in toothpastes to treat temperature- and pressure-related sensitivity.

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 has also 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 $76 per metric ton (table 3). Imports from Germany and Madagascar were reported in 2018, but the high average unit values (about $2,500 per ton and $4,800 per ton, respectively) and low tonnages indicated that those imports were likely mineral specimens rather than for use as industrial additives or raw materials. The average unit values in 2018 of imported strontium carbonate, metal, and nitrate increased by 5%, 17%, and 11%, respectively, compared with those in 2017.

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, were 38,400 t by gross weight (16,900 t by strontium content) in 2018, an increase of 50% compared with those of 2017. Celestite imports were only 1,230 t in 2007 but increased to 55,800 t in 2015 before decreasing in 2016 to 10,100 t. Celestite imports again increased in 2018 to 38,400 t, from 28,700 t in 2017 (table 1). The recent fluctuations in celestite imports may have resulted from increased use of celestite in drilling muds when barite prices were high and oil and natural gas drilling activity was booming. Since 2007, imported celestite most likely was used directly without undergoing chemical transformation.

Imports of strontium compounds (includes strontium chemicals and metal) were 11,200 t by gross weight (6,350 t by strontium content) in 2018, a decrease of 6% compared with that of 2017 (table 3). Imports of strontium compounds into the United States were sourced predominantly from Mexico, 52%; Germany, 37%; and China, 8%. Strontium carbonate exports were 55 t by gross weight (32 t by strontium content) in 2018, a decrease of 9% compared with that of 2017 (table 2).

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 more than 99% of the estimated 219,000 t total celestite production in 2018. Some celestite was also produced in Argentina, Tajikistan, and Turkey. Many large deposits are not economic to mine owing to high levels of barium and calcium, which are impurities that require cost-prohibitive and energy-intensive methods for separation. Most strontium producers require a minimum of 90% strontium sulfate content to achieve profitability. For ore processing, 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.

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 decrease, drilling activity would likely also 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 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)

	2014	2015	2016	2017	2018
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[2]					
Strontium compounds[3]	7,600	7,100	6,420	6,660	6,350
Strontium compounds, gross weight	13,600	12,700	11,500	11,800	11,200
Celestite[4]	24,200	24,500	4,420	11,300	16,900
Celestite, gross weight	55,100	55,800	10,100	25,700	38,400
Exports:[2]					
Strontium carbonate	104	86	91	36	32
Strontium carbonate, gross weight	174	145	154	60	55
Apparent consumption[5]	31,700	31,500	10,800	17,900	23,200
Price, average customs value of celestite imports	50	51	78	74	78
World, production of celestite, gross weight	285,000	286,000	207,000 r	219,000 r	219,000 e

[e]Estimated. [r]Revised. -- Zero.
[1]Table includes data available through August 15, 2019. 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%); strontium oxide, hydroxide, and peroxide (70.00%); strontium carbonate (59.35%); and strontium nitrate (41.40%). These factors were used to convert units of strontium compounds to strontium content.
[4]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]

	2017		2018	
Country or locality	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
British Virgin Islands	--	--	2,650	$3,130
Canada	19,700	$18,000	35,400	33,900
China	2,000	6,500	--	--
Japan	5,600	10,700	--	--
Korea, Republic of	32,700	37,100	--	--
United Kingdom	--	--	16,700	15,900
Total	60,100	72,300 r	54,700	52,900

[r]Revised. -- Zero.
[1]Table includes data available through August 15, 2019. 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]

	2017		2018	
Compound and country or locality	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Celestite:				
Brazil	29,400	$16,100	--	--
Germany	--	--	21,300	$52,200
Madagascar	2,870	9,470	9,480	45,800
Mexico	25,700,000	1,850,000	38,400,000	2,900,000
South Africa	573	13,300	--	--
Total	25,700,000	1,890,000	38,400,000	3,000,000
Strontium carbonate:				
China	258,000	396,000	114,000	153,000
Germany	4,320,000	3,510,000	4,090,000	3,490,000
Italy	41,300	53,600	9,400	50,100
Mexico	3,740,000	2,920,000	4,200,000	3,520,000
Russia	--	--	30	3,600
Spain	39,300	40,200	138,000	140,000
United Kingdom	--	--	56,600	52,800
Total	8,400,000	6,920,000	8,600,000	7,420,000
Strontium metal:				
China	162,000	1,410,000	225,000	2,270,000
Japan	120	3,440	2,880	35,100
Mexico	20,800	199,000	8,730	83,900
United Kingdom	1	3,030	4,640	104,000
Total	183,000	1,610,000	241,000	2,500,000
Strontium nitrate:				
Canada	4,670	5,820	--	--
China	517,000	659,000	503,000	742,000
India	21,500	27,300	3,720	35,700
Mexico	2,090,000	2,570,000	1,630,000	2,160,000
Norway	--	--	1,010	15,200
Poland	--	--	407	5,100
Russia	--	--	5	2,450
Spain	142,000	164,000	114,000	137,000
Total	2,780,000	3,430,000	2,250,000	3,100,000
Strontium oxide, hydroxide, peroxide:				
China	20,000	18,900	--	--
France	36,100	76,800	19,800	29,600
Germany	975	14,800	1,550	25,700
Japan	180,000	229,000	--	--
Korea, Republic of	252,000	422,000	72,000	141,000
United Kingdom	100	6,700	--	--
Total	489,000	768,000	93,300	197,000

-- Zero.
[1]Table includes data available through August 15, 2019. 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]	2014	2015	2016	2017	2018 e
Argentina	700	700 e	700 r, e	700 r, e	700
China	50,600	53,200	50,000 e	50,000 e	50,000
Iran	41,050	36,760	37,000 r, e	37,000 r, e	37,000
Mexico	64,931	79,022	33,230	40,699 r	40,000
Spain	128,077	116,765	85,599 r	90,000 e	90,000
Turkey	-- r	-- r	-- r	1,000 r	1,000
Total	285,000	286,000	207,000 r	219,000 r	219,000

[e]Estimated. [r]Revised. -- Zero.
[1]Table includes data available through May 1, 2019. 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.