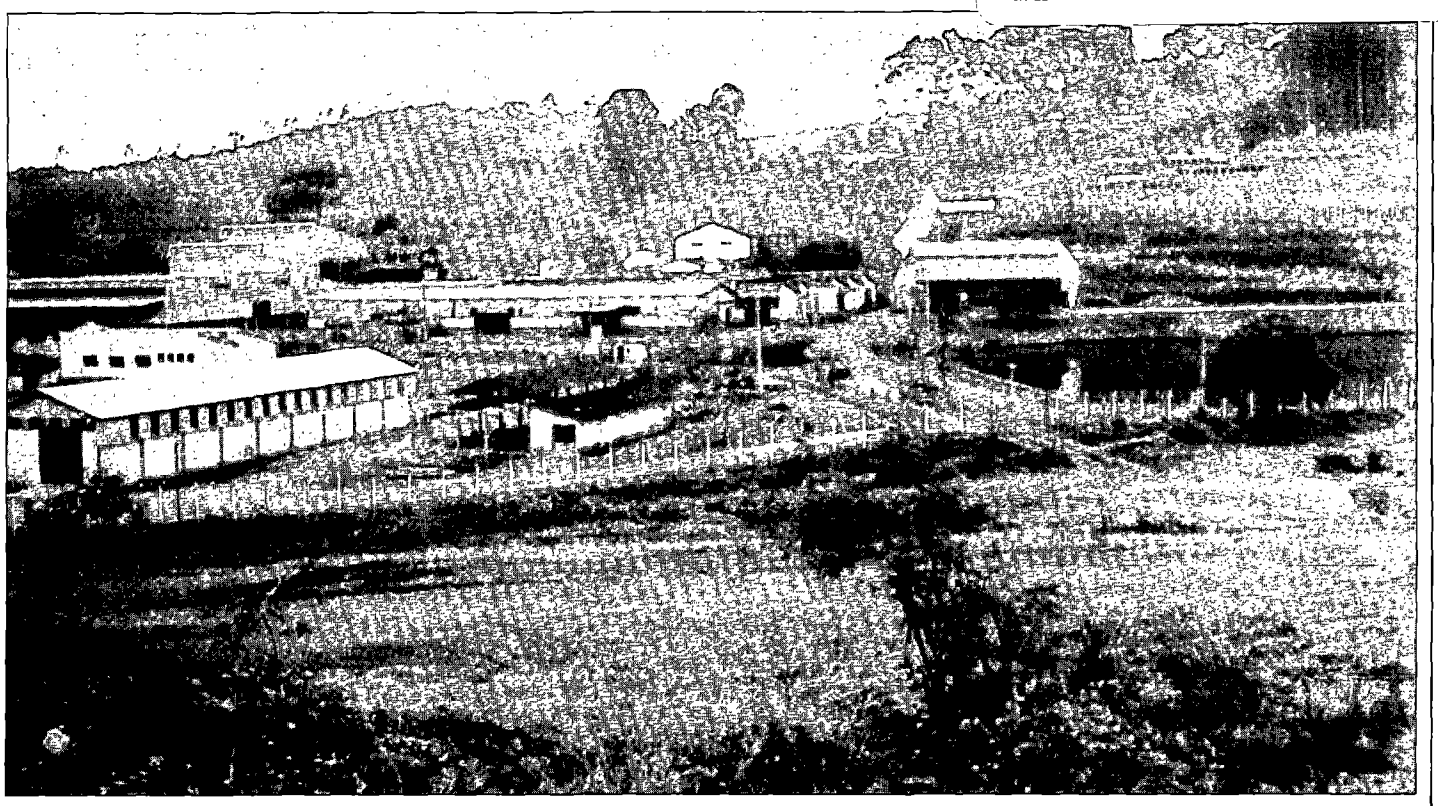

GRAPHITE

By Harold A. Taylor, Jr.

1993

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Bruce Babbitt
Secretary

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COVER PHOTO:
Crystalline flake graphite beneficiation plant in Minas Gerais State, Brazil. (Photo by author.)

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GRAPHITE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 27 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for graphite since 1980. Domestic survey data were prepared by William Field, statistical assistant; and international data tables were prepared by Amy Durham, international data coordinator.

Amorphous graphite was not mined domestically in 1993. Graphite supplies again exceeded industrial demand. Most prices of the major kinds of graphite dropped somewhat or remained unchanged from those of 1992. Quoted prices mostly reflected the existing oversupply. Production of manufactured graphite and graphite fibers decreased slightly and increased 21%, respectively.

DOMESTIC DATA COVERAGE

Domestic production data for synthetic graphite are developed by the U.S. Bureau of Mines from a voluntary survey of domestic producers. Of the 29 operations polled, 100% responded. This represented 100% of the total production data shown in table 4. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Graphite, a soft crystalline form of carbon, has been called plumbago and black lead. It crystallizes in a lamellar hexagonal system, has a gray to black metallic luster, and is greasy to the feel. It is anisotropic in its physical properties and has a weak plane of cleavage parallel to the lamellae.

The term "amorphous" when applied to graphite is a misnomer. The term "microcrystalline" is more descriptive. The definition of amorphous, as applied to graphite, has been complicated further by longstanding industrial application of the term to very fine particles of crystalline flake graphite that can be sold only for low-value use such as foundry facings. Fine-grained varieties of lump graphite that are easily reduced to fine particle size by grinding are called amorphous lump to distinguish them from the tough, platy and acicular varieties, known as crystalline lump, that can be reduced in particle size only with extreme difficulty.

Crystalline flake graphite is well defined in paragraph 214 of the Tariff Act of 1930 as follows:

"The term crystalline flake means graphite, or plumbago, which occurs disseminated as a relatively thin flake throughout its containing rock, decomposed or not, and which may or has been separated therefrom by ordinary crushing, pulverizing, screening, or mechanical concentration process, such flake being made up of a number of parallel laminae, which may be separated by mechanical means."

Under the foregoing definition, finely divided particles of crystalline flake graphite would be classified as crystalline graphite. The Court of Customs Appeals, however, has held that commercial designations and not scientific terms must govern classification, and when a commercial meaning differs from the technical meaning, the commercial designation must govern. Therefore, quantities of fine crystalline flake graphite are imported under the amorphous classification.

Sri Lankan lump graphite is classified as amorphous or crystalline. Each type is divided into a number of grades, depending on the size (such as lump, ranging from the size of walnuts to that of peas; chip, from that of peas to about that of wheat grains; and dust, finer than 60 mesh), graphitic carbon content, and degree of consolidation.

Amorphous graphite is graded primarily on graphitic carbon content. Commercial ore contains about 75% to 93% carbon, depending on the source.

Crystalline flake graphite from Madagascar is divided into two main grades, "flake" (coarse flake) and "fines" (fine flake). Madagascan crucible flake must have a minimum of 85% graphitic carbon and be essentially all minus 20 plus 80 mesh in particle size. Other crystalline flake graphites are also graded according to graphitic carbon content and particle size.

Natural graphite is marketed in the form of crystalline graphite as flake, lump, chip, and dust and in the form of amorphous graphite in sizes from fine powder to lumps up to the size of walnuts. It is common practice to blend different graphite to obtain a product having certain desired physical and chemical properties. In many instances, the composition of these blends is retained as a trade secret.

Geology-Resources

The three principal types of natural graphite—lump, amorphous, and crystalline flake—are based on physical characteristics that are the result of major differences in geologic origin and occurrence. A variety of silicate minerals are generally associated with graphite in the ore.

Lump graphite occurs as fissure-filled veins. It is typically massive, ranging in particle size from extremely fine grains (amorphous) to coarse, platy intergrowths

of fibrous to acicular aggregates (crystalline). The origin of vein-type graphite deposits is believed to be hydrothermal.

Amorphous graphite is formed by metamorphism of coalbeds by nearby intrusives. Its purity depends on the purity of the original coalbeds. Amorphous graphite usually is associated with sandstones, shales, slates, and limestones.

Flake graphite commonly occurs disseminated in regionally metamorphosed sedimentary rocks, such as gneisses, schists, and marbles. It is believed that the graphite was formed under the same conditions that caused the metamorphism of the rocks—from carbon deposited with the sediments.

Although the flake graphite deposits of certain countries conform to this description, most of the commercial deposits that are exploited are the result of weathering of these metamorphic rocks, with the graphite being found in lateritic clays that have accumulated at the surface. Graphite, quartz, and other resistant minerals have been freed by weathering of the feldspars, thus lessening the amount of crushing necessary before beneficiation.

World graphite reserves totaled 21 million metric tons. Detailed breakouts are given in the 1988 Minerals Yearbook chapter. All tonnages are reported in metric tons, unless otherwise noted.

Technology

Mining.—In Sri Lanka, lump graphite is mined underground from narrow, steeply dipping veins. The ore is mined principally by overhand stoping and filling, using temporary stulls when necessary to support the walls. Hand drilling is used in most stoping to achieve selective mining and to avoid unwanted fines and product contamination. Drills are used in developing headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds are usually mined underground. However, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, hand-loaded into cars, and hauled to the surface by conventional methods.

Flake graphite deposits have been mined by underground and surface methods. Underground deposits are usually unweathered and require drilling and blasting. Most surface mining is confined to the weathered part of the deposit, and normal excavating equipment such as power shovels, bulldozers, and rippers is used with a minimum of drilling and blasting. The ore is usually trucked to the mill.

Milling.—Sri Lankan amorphous lump graphite and crystalline lump graphite are refined by hand cobbing and hand sorting and wiping lumps on wet burlap to remove fines. Light hand sorting and cleaning operations are done by women, while the heavier duties are performed by men.

Most amorphous graphite that requires beneficiation is not worth mining. Preparation for most uses requires grinding only, and coarse impurities are removed by screening or air separation methods.

Flake graphite from disseminated deposits must be concentrated to meet market requirements. Virtually every known concentrating device and combination of separating principles have been tried. The mineral has gained a reputation of being difficult to concentrate, and probably in no other industry has such a large proportion of the mills failed to make commercial recoveries. Graphite actually is one of the easiest minerals to segregate into a rough concentrate, but one of the most difficult to refine.

Because of the premium placed on the mesh size of flake graphite, the problem in milling is one of grinding to free the graphite without reducing the flake size excessively. This is difficult because, during grinding, the graphite flakes are cut by quartz and other angular gangue minerals, thus reducing flake size rapidly. However, if most of the quartz and other angular minerals are removed, subsequent grinding will usually reduce the size of the remaining gangue, with little further reduction in the size of the flake.

Because graphite floats readily and does not require a collector froth, flotation has become the accepted method for beneficiating disseminated ores. The chief problem lies with depressing the gangue minerals. Relatively pure grains of quartz, mica, and other gangue minerals inadvertently become smeared with the soft, fine graphite, making them floatable and resulting in the necessity for repeated cleaning of the concentrates to attain high-grade products.

Substitutes

Some interchange of the various types and grades of natural graphite and between manufactured and natural graphite takes place, but the degree is difficult to determine. Manufactured graphite does not compete with natural graphite in most uses because of its greater cost. Manufactured graphite is not substitutable for natural flake graphite in clay-bonded graphite crucibles, although some crucibles are machined from manufactured graphite for special uses. Calcined coke and other carbons are satisfactory substitutes for graphite for certain foundry core and mold washes and are used when they can compete in terms of price and supply. Other carbons with high purity can be used in batteries.

Economic Factors

The price structure of graphite is quite complex because of the wide variety of products and the lack of standard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller and sometimes do not reflect the real market. Quotations are available in Industrial Minerals and the U.S. Bureau of Mines Annual Report. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from U.S. Bureau of the Census data.

The cost for domestically produced graphite from new mines would be much higher than that for graphite from the major foreign sources for the same type and purity. The high cost of production

results from high labor costs and the low graphite content of the ore.

Taxes.—Graphite producers are granted a 22% depletion allowance for tax purposes on domestic lump and amorphous and 14% on domestic flake and on foreign operations.

Tariffs.—Duties on graphite items imported from most favored nations (MFN) are minimal. Graphite from a few former Soviet republics (not Ukraine or Russia) and certain other nations are subject to a higher duty.

Operating Factors

Environmental Issues.—Because there was no mining of graphite this year, there were no environment-related issues. Future mining of graphite is highly improbable; there are no domestic reserves and resources are low grade and expensive to recover. Natural graphite is an inert nontoxic substance, and environmental requirements are limited to dust control and certain organic vapors arising from ingredients blended with it to manufacture products.

Postconsumer waste mostly returns to the environment in simple and nonpolluting ways. Graphite products that have contact with molten iron and steel slowly dissolve in it during use. This applies to refractories crucibles, foundry facings, and electrodes, plus a few less important uses, which combine to account for about 75% of total usage. Other important products such as pencils and brake linings slowly dissipate as they are used, almost on an atom-by-atom basis.

Employment.—Production and marketable natural graphite requires little hand labor, except for the graphite mined in Sri Lanka. Even in areas of low-cost labor, mechanical methods are used to mine and concentrate flake graphite.

Because of the very small size of the domestic natural graphite industry, no publishable employment data are available. Because there is only one small mine open intermittently and the product is beneficiated and processed to a minimal extent, employment probably does not exceed 50. Much of the imported graphite requires grinding, perhaps further refining, mixing with other grades to meet consumer specifications, bagging, and shipping. The total number of persons engaged in these operation, including marketing, probably does not exceed 500.

ANNUAL REVIEW

Legislation and Government Programs

No acquisitions of graphite for the strategic and critical materials stockpile occurred in 1993. *(See table 2.)*

Production

United Minerals Co. continued its suspension of production of its amorphous graphitic material from its Montana mine in 1993. Output of manufactured graphite decreased slightly to about 241,000 tons, at 29 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth increased 13% to 4,080 tons. *(See tables 3 and 4.)*

Consumption and Uses

Reported consumption of natural graphite decreased slightly to about 40,865 tons, according to a survey of more than 230 users. The three major uses of natural graphite were refractories, brake linings, and in packings, which together accounted for 53% of reported consumption. *(See table 5.)*

Nonclay refractories are represented by two important use categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizable part of the demand in the past 5 years, mainly as amorphous graphite. Crucibles, shrouds, nozzles, stopper heads, and retorts, used in hot-metal processing operations such as the continuous casting of steel, use significant amounts of crystalline flake. Coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower value. The newest important refractory use for graphite in steelmaking is in carbon magnesite brick, where large amounts of crystalline flake are now used.

Graphite is used in brake and clutch linings. More graphite is being used as brake and clutch producers change over from asbestos. The graphite lubricates, transfers the heat of friction away from the part, and leads to a lower rate of wear. Graphite is more commonly used in heavier duty nonautomobile lining. Low-quality crystalline flake and amorphous graphite are suitable for foundry facing use. The graphite is mixed with a small amount of clay, suspended in an adhesive material, and applied as a thin coating to mold surfaces to provide for clean and easy mold release of the metal castings.

Graphite is important as a lubricant; when used as a lubricant, it can be a dry powder or mixed with oil or water. It is used with materials that must withstand extreme conditions, such as very high temperatures. Material for this use must be free of abrasive-type impurities.

Graphite is used in packings, which includes expanded graphite and graphite foil. While this category includes uses in ammunition and seed coatings, in addition to packings, most of the tonnage was used to make expanded graphite and graphite foil and final products resulting from them.

Prices

Natural graphite prices are often negotiated between the buyer and seller and are based on purity and other criteria. Therefore, published price quotations such as those in Industrial Minerals are given as a range of prices. Another source of information for graphite prices is the average customs value per ton of the different imported classes. These mainly represent shipments of unprocessed graphite. A third source for natural graphite prices is the amount paid per ton at the point of consumption.

The price for crystalline graphite at the point of consumption—mostly crystalline flake, some crystalline dust, and a little lump graphite—dropped slightly to $1,469 per ton from $1,481. The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) rose slightly to $683 per ton from $677.

The index of unit value for high-modulus fiber produced in the United States (1973=100) was 42 in 1993, compared with 44 the previous year. *(See table 6.)*

Foreign Trade

Total exports of natural graphite decreased 4%. Exports of graphite electrodes totaled 86,369 tons valued at $178.8 million, of which 49,244 tons ($93.3 million) went to Canada, 3,394 tons ($8.5 million) to Venezuela, 6,613 tons ($10.0 million) to Brazil, 3,469 tons ($11.1 million) to Japan, and the balance to other destinations.

Imports of natural graphite increased 5% from those of 1992. *(See tables 7, 8, and 9.)*

World Review

The world graphite market moved a little closer to balance in supply and demand in 1993. This was observed mostly on the supply side, in the form of drops in production in Madagascar and Romania, or in the form of small increases in production in Canada instead of the large increases that might have been expected. Projects in Namibia and Australia (Munglinup) were dropped. Sales of Malagasy crystalline flake from the U.S. stockpile continued at a moderate rate. Commercial production of crystalline flake graphite from graphite-containing kish waste is not imminent, although progress was made at the kish pilot plant in Chicago. While U.S. apparent consumption of graphite increased moderately, the U.S. price of crystalline flake was unchanged and the price of lump decreased. The market could have been a bit worse, as it was in 1991-92.

Early this year, Industrial Minerals published a major examination of graphite supply-demand. This study delineated the overcapacity and oversupply of the past few years and indicated that any significant improvement would not occur before midyear 1993. It discussed new and proposed projects in detail, such as the coming on-stream of the Uley graphite deposit in Australia at a rate of 5,000 to 10,000 tons of product per year. Demand for ordinary grades of graphite dropped as graphite consumers, particularly the makers of brake linings and expandable graphite, insisted on graphite that is 94% carbon or above. The most damage to demand from the recession occurred in the refractories industry. It concluded that the new projects nearing production face unpleasant prospects.[1]

Brazil.—Nacional de Grafite will bring a new mine and pilot plant on-stream in March 1994, at Salto da Divisa, about 250 kilometers from its major mine at Pedra Azul, and very near the Bahia-Minas Gerais State line. The firm has stated that this crystalline flake graphite deposit is the largest in the world, has more than 100 years of ore supply averaging 5% to 6% graphite at the desired production level, and is capable of producing 40,000 tons per year of 95% graphite product. This production level will hopefully be reached in two years after a $20 million investment. The product is expected to be entirely exported, with the other two mines maintaining their current domestic or export markets. (The Pedra Azul expansion has been suspended.)

Vesuvius Co. has brought a new refractories plant on-stream in Rio de Janeiro among whose products will be some alumina graphite items.

Canada.—Quinto Mining Corp. previously announced the discovery of a large deposit containing graphite, probably amorphous, near Lumby, British Columbia. The graphite would be a byproduct of a sericitic gold ore and is low grade and widely disseminated. Laboratory work has shown it will be difficult to separate the graphite from the mica (sericite) because they are so fine grained. The firm hopes to avoid the problem by selling a mica-graphite final product.

Stratmin Inc. has signed an agreement with St. Genevieve Resources Co. to allow it to use a newly developed method for purifying graphite and use a new method to produce flexible laminated graphite sheets.

China.—According to official trade statistics, China exported a total of 145,000 tons of natural graphite in 1993, 155,000 tons in 1992, 150,000 tons in 1991, and 140,000 tons in 1990. Official statistics indicate that 40,000 tons of natural graphite was added to stocks in 1991. Probably a similar amount was added to stocks in 1992 and a much larger amount in 1990. Domestic consumption of natural graphite is believed to be very large, much larger than Japanese consumption, because of waste during consumption and much shorter product life than is common in industrially advanced countries.

France.—Pechiney signed a letter of intent to merge its synthetic graphite operations in Belgium, France, and Spain into Sigri Great Lakes Carbon Corp. in return for a 10% to 12% stock interest in the new enlarged firm, second largest in the world. Pechiney had only about 4% of the currently oversupplied world market.

Mozambique.—Kenmare Resources PLC completed the financing for its large-flake crystalline flake graphite project at Ancuabe, 100 kilometers from the port of Pemba. The financing is by the Commonwealth Development Corp. and the European Investment Bank. The deposit will be mined by open pit, and the firm stated proven reserves were 1 million tons averaging 11% graphite. Pilot plant testwork has been completed, and the final design specifies a modular flotation plant with a 5,000-ton-per-year capacity for concentrate. The engineering

design has been sent out for tender. The plant may be on-stream about yearend.

Sweden.—Norbotten Grus och Grafit AB (NGG) has acquired state-owned graphite claims in the north. The two most promising deposits are at Raitajaervi and Lehtoselkae with ores running 10% to 22% carbon and 19% to 23% carbon, respectively.

Anro Graphite AB expects to have its Kringelgruvan Mine on-stream by early 1995. *(See table 10.)*

Current Research and Technology

The U.S. Bureau of Mines kish process moved closer to implementation. The small pilot plant run by Inland Steel produced about 10 tons of product in 1993 and is expected to produce about 20 tons in 1994. The product almost always has been well received where it has been used, although the price has been 5% to 10% above that for crucible-grade crystalline flake. Some drying equipment still has to be installed in the plant, and other equipment has been modified to make it work better.

Natural fullerenes have been discovered in carbon-containing lightning-seared rocks (fulgurites) from Colorado. The fullerenes are complex configurations of approximately 60 or more carbon atoms, the best known configurations being shaped like a soccer ball. Evidently these fullerenes must have originated under conditions radically different from the natural fullerenes found in coal-like shungite, discovered last year.

The following applications for fullerenes in medicine were discovered this past year: A water-soluble fullerene has been found to block an enzyme the AIDS virus uses to cut up proteins. Fullerenes also can ferry electrons across cell membranes even more efficiently than natural porphyrins can.

Fullerene microtubes now can be filled with lead or other metals to form microscopically thin wires. The fullerene microtubes have natural caps that are destroyed by heating in air, which then allows molten lead to be drawn inside by strong capillary forces. The material inside the microtube may or may not be pure lead.

Other notable applications for fullerenes also were discovered. Coating superconducting metal-containing fullerenes with polystyrene preserved them from decomposition by moisture, which allows them to be used as room-temperature superconductors. Fullerene films will polymerize when exposed to visible or ultraviolet light, the fullerene molecules directly linking together without a bridge.

OUTLOOK

Projected demand for crystalline flake graphite totaled 30,000 tons for 1995 and 35,000 tons for the year 2000. Demand for other graphite, mostly amorphous, totaled 15,000 tons for 1995 and 13,000 tons for the year 2000. This very slow growth rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick. Production capacity is unlikely to increase from the present level while the overcapacity exists.

[1]Harries-Rees, K. Graphite Prices Flaking Away. Industrial Minerals (London), No. 305, Feb. 1993, pp. 27-45.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Graphite. Ch. in Mineral Commodity Summaries, annual.
Graphite. Ch. in Annual Report, annual.
Graphite. Reported annually in Mineral Industry Surveys.

Other Sources

Chemical Week.
European Chemical News.
Industrial Minerals (London).
Materials Engineering.
Wall Street Journal.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS

		1989	1990	1991	1992	1993
United States:						
Production	metric tons	W	—	—	—	—
Apparent consumption[1]	do.	50,867	38,676	14,170	29,527	34,814
Exports	do.	11,452	11,537	19,374	20,217	17,358
Value	thousands	$7,421	$9,481	$11,345	$12,244	$11,149
Imports for consumption	metric tons	62,319	50,213	33,544	49,744	52,172
Value	thousands	$33,707	$35,222	$21,662	$25,538	$29,850
World: Production	metric tons	r1,005,417	r945,462	r771,189	r755,905	e741,040

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Domestic production plus imports minus exports.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1993, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	(1)	15,156
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	(1)	1,754
Nonstockpile-grade, all types	(1)	846

[1]This commodity no longer has a goal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of Dec. 31, 1993.

TABLE 3
PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1993

Company	Plant location	Product[1]
Amoco Performance Products Co.	Greenville, SC	Cloth, high-modulus fibers.
BASF Structural Materials Inc.	Rock Hill, SC	High-modulus fibers.
Carbone of America	St. Marys, PA	Motor brushes; unmachined shapes; other.
Fiber Materials, Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	
Fortafil Fibers Inc.	Rockwood, TN	High-modulus fibers.
BF Goodrich Co., Engineered Systems Div., Super-Temp Operations	Santa Fe Springs, CA	Other.
Grafil Inc.	Sacramento, CA	High-modulus fibers.
Hercules Inc.	Salt Lake City, UT	Do.
HITCO Materials Group, British Petroleum Co.Ltd.	Gardena, CA	Cloth.
Minerals Technology, Inc.; Specialty Minerals Corp.	Easton, PA	Other.
National Electrical Carbon Co.	Fostoria, OH	Unmachined shapes; high-modulus fibers.
NAC Carbon Products, Inc.	Punxsutawney, PA	Other.
Polycarbon, Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes; other.
SIGRI Great Lakes Carbon Corp.		
Do.	Hickman, KY	Anodes; crucibles; electrodes; unmachined shapes; other.
Do.	Morganton, NC	Do.
Do.	Niagara Falls, NY	Do.
Do.	Ozark, AR	Do.
Superior Graphite Co.	Russellville, AR	Electrodes.
Do.	Hopkinsville, KY	Other.
Textron Specialty Materials	Lowell, MA	High-modulus fibers.
The Carbide/Graphite Group, Inc.; Graphite Specialties	Niagara Falls, NY	Anodes; crucibles; motor brushes; electrodes; unmachined shapes; refractories; other.
Do.	St. Marys, PA	Do.
The Carborundum Co., Metallics Systems Div.	Sanborn, NY	Unmachined shapes.
UCAR Carbon Company, Inc.	Clarksburg, WV	Anodes; electrodes; unmachined shapes; other.
Do.	Clarksville, TN	Do.
Do.	Columbia, TN	Do.
Zoltek Corp.	St. Charles, MO	High-modulus fibers.

[1]Cloth includes low-modulus fibers; motor brushes include machined shapes; crucibles include vessels.

TABLE 4
U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY END USE

End use	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Anodes[1]	W	W	W	W
Cloth and fibers (low-modulus)	255	$22,599	37	$4,536
Crucibles and vessels and refractories[1]	W	W	W	W
Electric motor brushes and machined shapes	1,339	16,510	1,147	18,737
Electrodes	161,278	336,155	154,339	368,921
Graphite articles[2]	—	28,364	—	38,663
High-modulus fibers	3,345	145,622	4,045	158,343
Unmachined graphite shapes	3,152	23,752	4,238	27,643
Other	8,771	54,765	8,589	45,479
Total	178,140	627,767	172,395	662,322
Synthetic graphite powder and scrap[3]	69,762	34,808	69,072	36,388
Grand total[4]	247,902	662,575	241,468	698,711

W Withheld to avoid disclosing company proprietary data.
[1]Anodes, crucibles/vessels and refractories end products are included in the "Other" products category.
[2]Includes all items for which quantity data are usually unavailable.
[3]Includes lubricants (alone/in greases), steelmaking carbonraisers, additives in metallurgy, and other powder data.
[4]Data may not add to totals shown because of independent rounding.

TABLE 5
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Uses	Crystalline		Amorphous[1]		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991	20,482	$31,221	15,951	$11,274	[2]36,434	$42,495
1992:						
Batteries	146	303	—	—	146	303
Brake linings	2,221	3,016	5,145	4,307	7,366	7,323
Carbon products[3]	619	1,912	625	438	1,244	2,350
Crucibles, retorts, stoppers, sleeves and nozzles	W	W	W	W	1,029	1,434
Foundries[4]	864	936	1,888	1,006	2,752	1,942
Lubricant group:						
Lubricants	764	1,197	2,337	1,357	3,101	2,554
Packing; other[5]	3,759	5,402	143	247	3,902	5,649
Pencils	2,670	3,661	261	179	2,931	3,840
Powdered metals	1,739	3,426	225	204	1,964	3,630
Refractories	9,147	12,067	3,812	1,551	12,959	13,618
Rubber	100	235	491	397	591	632
Steelmaking	W	W	W	W	1,466	1,025
Other[6]	1,156	2,256	1,167	1,238	2,323	3,494
Withheld uses	1,083	1,538	1,412	921	—	—
Total	24,268	35,949	17,506	11,845	41,774	47,794
1993:						
Batteries	W	W	W	W	606	1,409
Brake linings	1,666	2,270	5,053	4,214	6,719	6,484
Carbon products[3]	561	1,621	493	331	1,054	1,952

See footnotes at end of table.

TABLE 5—Continued
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Uses	Crystalline		Amorphous[1]		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1993—Continued:						
Crucibles, retorts, stoppers, sleeves and nozzles	W	W	W	W	995	$1,020
Foundries[4]	720	$840	2,222	$1,206	2,942	2,046
Lubricant group:						
Lubricants	708	1,231	2,431	1,560	3,139	2,791
Packing; other[5]	4,222	6,045	86	134	4,308	6,179
Pencils	2,563	2,947	236	169	2,799	3,116
Powdered metals	1,996	4,124	372	302	2,368	4,426
Refractories	7,754	8,734	2,732	757	10,486	9,491
Rubber	189	287	424	375	613	662
Steelmaking	W	W	W	W	1,722	1,027
Other[6]	1,460	4,162	1,654	1,466	3,114	5,628
Withheld uses	1,464	1,976	1,859	1,480	—	—
Total	23,303	34,237	17,562	11,994	40,865	46,231

W Withheld to avoid disclosing company proprietary data; included with "Withheld uses" and "Total" where applicable.
[1]Includes mixtures of natural and manufactured graphite.
[2]Data do not add to total shown because of independent rounding.
[3]Includes bearings and carbon brushes.
[4]Includes foundries (other) and foundry facings.
[5]Includes packings; ammunition; and seed coating.
[6]Includes paint and polishes; small packages; antiknock and other compounds; soldering/welding; mechanical products; electrical/electronic devices; industrial diamonds; drilling mud; magnetic tape; and other end-use categories.

TABLE 6
REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1992	1993
Industrial minerals:[1 2]		
Crystalline large flake, 85% to 90% carbon	$400- $800	$400- $600
Crystalline medium flake, 85% to 90% carbon	350- 750	300- 500
Crystalline small flake, 80% to 90% carbon	300- 550	250- 500
Amorphous powder, 80% to 85% carbon	220- 440	220- 440
Custom value, at foreign ports:[3]		
Flake	r708	710
Lump and chip, Sri Lankan	1,073	789
Amorphous, Mexican	125	127

rRevised.
[1]Prices are normally c.i.f. (cost, insurance, and freight) main European port.
[2]Source: Industrial Minerals, No. 303, Dec. 1992, p. 66, and No. 315, Dec 1993, p. 54.
[3]Source: Department of Commerce, Bureau of the Census.

TABLE 7

U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE,[1] BY COUNTRY

Country	Natural[2]		Artificial[3]		Total[4]	
	Quantity (metric tons)	Value[5]	Quantity (metric tons)	Value[5]	Quantity (metric tons)	Value[5]
1992:						
Canada	5,180	$3,389,714	14,833	$6,370,111	20,013	$9,759,825
France	29	94,717	1,051	1,688,774	1,080	1,783,491
Germany	71	188,884	721	646,165	792	835,049
Japan	260	432,090	4,539	10,167,361	4,799	10,599,451
Korea, Republic of	71	43,918	1,656	1,850,319	1,727	1,894,237
Mexico	9,430	3,643,596	1,279	726,634	10,709	4,370,230
Netherlands	118	42,040	3,381	1,688,756	3,499	1,730,796
Venezuela	659	951,675	671	472,197	1,330	1,423,872
Other	4,399	3,457,008	6,356	9,078,595	10,756	12,535,603
Total	20,217	12,243,642	34,487	32,688,912	54,705	44,932,554
1993:						
Canada	3,884	2,514,791	13,846	5,944,390	17,730	8,459,181
France	107	43,978	714	1,916,551	820	1,960,529
Germany	34	14,639	436	429,824	471	444,463
Japan	275	428,692	3,260	6,236,315	3,534	6,665,007
Korea, Republic of	38	41,922	4,498	2,838,470	4,536	2,880,392
Mexico	7,448	2,764,781	742	488,361	8,190	3,253,142
Netherlands	1	3,325	1,393	1,127,825	1,394	1,131,150
Venezuela	388	628,067	687	559,334	1,074	1,187,401
Other	5,183	4,708,917	9,463	11,310,237	14,646	16,019,154
Total[4]	17,358	11,149,112	35,039	30,851,307	52,397	42,000,419

[1]Numerous countries for which data were reported have been combined within the "Other" category under the "Country" list.
[2]Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified. The applicable "Harmonized Tariff Schedule" (HTS) nomenclature title and code(s) are: "Natural graphite in powder or in flakes"/"Other"; HTS Nos. 2504.10/.90.0000.
[3]Includes data from the applicable "Harmonized Tarif Schedule" (HTS) nomenclatures: "Artificial graphite" and "Colloidal or semi-colloidal graphite;" their respective HTS code Nos. are: 3801.10/.20.0000.
[4]Data may not add to totals shown because of independent rounding.
[5]Values are free alongside ship (f.a.s.).

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake[1]		Lump or chippy dust		Other natural crude and refined[1]		Amorphous		Total[2]	
	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
1991	12,301	$11,936	434	$626	9,229	$7,699	11,580	$1,401	33,544	$21,662
1992:										
Austria	—	—	—	—	—	—	20	10	20	10
Brazil	r810	r1,249	—	—	r810	r1,260	—	—	1,620	2,509
Canada	7,470	4,856	—	—	9,130	5,400	—	—	16,600	10,256
China	r3,380	r1,643	—	—	r3,416	r2,029	1,663	436	8,459	4,108
France	41	74	—	—	109	462	—	—	150	537
Germany	51	149	—	—	13	101	—	—	64	250
India	178	88	—	—	160	173	—	—	338	261
Japan	(4)	(4)	—		r3,190	r1,413	—	—	3,190	1,413
Macau	—	—	—	—	—	—	40	30	40	30
Madagascar	2,011	1,730	—	—	1,341	1,003	—	—	3,352	2,733
Mexico	—	—	—	—	387	259	13,970	1,752	14,357	2,011
Russia	—	—	—	—	15	35	—	—	15	35
Sri Lanka	—	—	492	528	—	—	—	—	492	528
United Kingdom	46	73	—	—	4	9	—	—	49	82
Zimbabwe	r497	r380	—	—	r497	r380	—	—	994	760
Other[5]	1	11	—	—	3	4	—	—	4	15
Total	r14,485	r10,253	492	528	r19,075	r12,528	15,693	2,228	49,744	25,538
1993:										
Austria	—	—	—	—	—	—	20	10	20	10
Brazil	328	453	—	—	2,952	4,079	—	—	3,280	4,532
Canada	8,050	4,689	—	—	9,838	5,730	—	—	17,888	10,419
China	2,818	1,246	—	—	6,485	2,892	91	14	9,394	4,152
France	76	182		—	57	435	—	—	133	617
Germany	136	1,743	—	—	21	114	—	—	157	1,857
Hong Kong	—	—	—	—	—	—	385	61	385	61
India	21	10	—	—	199	279	—	—	220	288
Japan	—	—	—	—	333	1,663	—	—	333	1,663
Madagascar	2,011	1,419	—	—	r1,341	946	—	—	3,352	2,365
Mexico	—	—	—	—	387	162	13,681	1,732	14,068	1,894
Namibia	16	9	—	—	—	—	—	—	16	9
Norway	56	23	—	—	—	—	—	—	56	23
South Africa, Republic of	74	111	—	—	—	—	—	—	74	111
Sri Lanka	—	—	712	562	—	—	—	—	712	562
Switzerland	(6)	7	—	—	10	117	—	—	11	124
Ukraine	—	—	—	—	16	60	—	—	16	60
United Kingdom	101	123	—	—	20	10	—	—	121	134
Zimbabwe	521	255	—	—	1,217	596	—	—	1,738	851
Other[5]	198	104	—	—	(6)	14	—	—	198	118
Total[2]	14,406	10,374	712	562	22,875	17,097	14,177	1,817	52,172	29,850

rRevised.
[1]The information framework from which data for this material were derived originated from Harmonized Tariff Schedule (HTS) base data.
[2]Data may not add to totals shown because of independent rounding.
[3]Customs values.
[4]Revised to zero.
[5]Includes Armenia, Australia (1993), Belgium, Finland (1992), Italy, and Poland (1993).
[6]Less than 1/2 unit.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF GRAPHITE ELECTRODES,[1] BY COUNTRY

Country	Quantity[2] (metric tons)	Value[3] (thousands)
1992:		
Canada	1,417	$1,696
Germany	3,884	7,280
India	1,358	2,299
Italy	4,466	7,425
Japan	5,678	9,940
Mexico	8,218	11,075
Spain	878	1,579
Other	1,489	2,446
Total	27,388	43,740
1993:		
Canada	5,407	8,318
Germany	2,175	5,894
India	1,983	3,571
Italy	5,729	9,009
Japan	6,374	12,237
Mexico	10,511	15,414
Spain	539	1,123
Other	1,271	2,212
Total	33,989	57,778

[1]The applicable "Harmonized Tariff Schedule" (HTS) code and nomenclature title are: (HTS 8545.11.0000); "Electric Furnace Electrodes."
[2]For both 1992 and 1993 data for countries reflecting less than 500 metric tons each for yearly imports have been combined under the "Other" category in the "Country" list.
[3]Customs values.

Source: Bureau of the Census.

TABLE 10
GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993e
Argentina e	[2]100	100	100	90	100
Austria	15,307	r22,705	r19,750	r19,547	19,500
Brazil (marketable)[3]	31,650	28,890	26,965	r29,414	29,000
Burma[4]	—	45	r36	—	—
Canada (exports of natural graphite)	6,000	10,200	6,200	17,400	18,800
China e	r490,000	r455,000	r289,000	r300,000	310,000
Czech Republic[5]	—	—	—	—	20,000
Czechoslovakia[6]	r66,000	r39,000	r47,000	r e20,000	—
Germany	r e15,800	r19,314	r15,807	r11,963	10,000
India (run-of-mine)[7]	58,000	61,000	69,922	e70,000	64,000
Korea, North e	35,000	35,000	35,000	38,000	38,000
Korea, Republic of:					
Amorphous	100,282	98,987	75,239	e75,000	72,000
Crystalline flake	1,186	703	1,552	r8,412	8,000
Madagascar	15,863	18,036	14,079	r8,910	8,000
Mexico:					
Amorphous	38,304	22,553	35,315	r47,053	49,440
Crystalline flake	1,942	2,365	1,943	r985	1,000
Namibia e	—	—	200	200	200
Norway	1,800	e5,000	6,930	r e5,000	5,000
Romania	10,000	r e6,000	r e6,000	2,300	2,000
Russia	—	—	—	e15,000	10,000
Sri Lanka	4,163	5,469	6,381	r3,307	4,000
Turkey (run-of-mine)[8]	11,873	18,712	25,867	r20,978	20,000
Ukraine	—	—	—	e50,000	40,000
U.S.S.R. e [9]	84,000	80,000	75,000	—	—
United States	W	—	—	—	—
Zimbabwe	18,147	16,383	12,903	r12,346	12,000
Total	r1,005,417	r945,462	r771,189	r755,905	741,040

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data.
[1]Table includes data available through May 31, 1994.
[2]Reported figure.
[3]Does not include the following quantities sold directly without beneficiation, in metric tons: 1989—13,005 (revised); 1990—8,400 (revised); 1991—7,298 (revised); 1992—8,957 (revised); and 1993—9,000 (estimated).
[4]Data are for fiscal years beginning Apr. 1 of that stated.
[5]Formerly part of Czechoslovakia.
[6]Dissolved Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from what is now the Czech Republic.
[7]Indian marketable production is 10% to 20% of mine production.
[8]Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.
[9]Dissolved in Dec. 1991.