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Created in 1849, the Department of the Interior—a Department of Conservation—is concerned with the management, conservation, and development of the Nation's water, fish, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States—now and in the future.

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Foreword

This edition of Mineral Facts and Problems marks the second revision of this widely used reference work. Events have shown that the 5-year interval between editions was well chosen. For many commodities there have been significant shifts in the past 5 years in the world supply-demand position and the production-consumption pattern, resulting both from political and social changes and from advances in science and technology. Despite such major shifts for some commodities, much of the background information presented in the 1960 edition of Mineral Facts and Problems remains pertinent. Hence, substantial portions of the carefully prepared and reviewed material from the previous edition remain unchanged in this edition.

The initial edition of Mineral Facts and Problems, published early in 1956, was an outgrowth of a Bureau of Mines commodity program statement series. The statements, revised periodically to reflect the rapidly changing positions of individual commodities in relation to national demands, provided broad basic and background information from which the Bureau could generate and evaluate ideas for mineral resource development and research investigations. This orderly presentation of mineral information proved useful to other Government organizations, commercial analysts, and educators and students. The Bureau hopes that this edition, Bulletin 630, also will prove as worthwhile a reference and as helpful in understanding and attacking the problems encountered in developing world mineral resources to meet mankind's material needs.

Like its predecessors, this edition represents the work of Bureau specialists—but it depends heavily on information from industry and reviews by critics in both industry and Government for which the Bureau is deeply appreciative. Technical editing of the volume was carried out by Paul Yopes and statistical editing by Kathleen J. D'Amico, both of the Division of Minerals.

PAUL ZINNER
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ASBESTOS

By Timothy C. May[1]

ALTHOUGH asbestos has been known and used for at least 2,000 years, it was not until the end of the 17th century that it began to be regarded as something other than an object of superstition. It possesses some of the characteristics of the animal, vegetable, and mineral kingdoms. Although crude asbestos is naturally a dense mineral, it can be processed into a material as light, buoyant, and feathery as thistledown, which can be woven like cotton or wool.

Asbestos is a name applied to a group of naturally fibrous minerals. The largest producers of asbestos are Canada and the U.S.S.R. The United States is the largest consumer but produces only a small part of its requirements. The major part of the U.S. supply of chrysotile is imported from Canada. Most crocidolite and all amosite used in the United States are produced in the Republic of South Africa. Low-iron long-fiber chrysotile and amosite are important in defense purposes. Crocidolite has important industrial uses that are less directly related to defense problems. During World War II and several years thereafter, most grades of good quality asbestos were in short supply. The discovery of a large deposit of suitable low-iron chrysotile in British Columbia, Canada, relieved the short supply situation. The production and consumption of asbestos should continue to increase. The principal suppliers of U.S. markets—Canada and the Republic of South Africa—appear to have adequate reserves of asbestos to meet requirements for many years at current rates of consumption.

An important problem in asbestos is the complete dependence of the United States on foreign sources of supply. Other problems are the lack of a commercially satisfactory substitute for amosite, current lack of interchangeability of the various types of asbestos, waste disposal, and biological effects of asbestos upon the industrial employee.

BACKGROUND

SIZE, ORGANIZATION, AND GEOGRAPHIC DISTRIBUTION OF THE INDUSTRY

The United States leads in manufacturing asbestos products and consumes 23 percent of the world asbestos production; however, domestic sources furnish only 9 percent of the raw asbestos needed. Most of the supply is obtained in Canada, but important quantities, particularly of special kinds and grades, originate in the Republic of South Africa (*4–5*).[2]

The Province of Quebec, Canada, has the largest mines and mills in the world. The U.S.S.R. rivals Canada as an important producer. The Republic of South Africa, Southern Rhodesia, Swaziland, Italy, and the United States are substantial producers, and smaller supplies originate in many countries. The variety chrysotile constitutes about 95 percent of the world supply, and unless otherwise designated the data herein relate to chrysotile.

Total world production in 1963 was 3.2 million short tons of all grades and varieties. Of this total, Canada produced about 40 percent, the U.S.S.R. 38 percent (estimated), the Republic of South Africa 6 percent, Southern Rhodesia 4 percent, the United States 2 percent, Italy 2 percent, and Swaziland 1 percent.

Prior to 1962, the only large production of asbestos in the United States was from a deposit in Eden and Lowell Townships, Vt., in what is regarded as a southern extension of the

[1] Commodity specialist.
[2] Italicized numbers in parentheses refer to items in the list of references at the end of this chapter.

Quebec deposits. In 1963, deposits in the Copperopolis, Coalinga, and Napa areas in California began production, and in the next few years their combined production is expected to exceed that of Vermont. Several operators have small chrysotile mines in an area about 60 miles long and 25 miles wide in the Salt River and Cherry Creek basins of Gila County, north of Globe, Ariz. These are the only sources of chrysotile asbestos that have been developed in the United States. Chrysotile deposits are known in Montana, Wyoming, and other States, but production has been negligible. In addition, amphibole asbestos is produced sporadically in North Carolina and Georgia (*6–8, 16, 20–21, 25–27*).

The largest known asbestos deposits in the free world are in an area 75 miles long by 5 or 6 miles wide between Danville and the Chaudière River Valley, in the Province of Quebec, Canada. Eight companies are actively engaged in mining in this area. Six of these are subsidiaries of companies that operate large asbestos-products plants in the United States. Deposits occur elsewhere in Canada. Asbestos was mined in Munro Township, 12 miles east of Matheson, Ontario, from 1950 until the mine closed down on July 31, 1964. Asbestos has been mined continuously in northern British Columbia since 1953. In mid-1963 a new mine began operating at Baie Verte in Newfoundland. An important deposit in the northern Ungava region of Quebec is being examined and may be considered a prospective producer. Canadian production in 1963 was valued at Can-$135 million, whereas U.S. production had a sales value of about $5 million.

The Soviet deposits, situated in the Bajenova district of the Urals, are extensive. The mines and mills are large, and most of the fiber is used within the country in the manufacture of various asbestos products.

Southern Rhodesia is an important producer of chrysotile asbestos, particularly in the Shabani area. The fiber from these deposits has such a low iron content that it can be made into the excellent electrical insulating material that is required in the construction of electric cables for use on shipboard. Most of the other deposits of the world, except the comparatively small ones in Arizona and the recently discovered large one in British Columbia, have a substantially higher iron content, making them unsuitable for electrical insulation. Swaziland and the Republic of South Africa also produce chrysotile in substantial quantities. The Republic of South Africa produces two special types of asbestos—amosite, found commercially nowhere else, and crocidolite (blue asbestos), produced also in Australia and Bolivia. Most of the African production is exported (*24*).

Smaller operations are in Cyprus, Italy, Finland, France, Australia, Bolivia, Brazil, Japan, and several other countries.

DEFINITION OF TERMS, GRADES, AND SPECIFICATIONS

Asbestos is a name applied to a group of naturally fibrous minerals. The principal variety is *chrysotile*, a hydrous magnesium silicate having the theoretical formula $3MgO \cdot 2SiO_2 \cdot 2H_2O$. Other commercial varieties are *amosite*, a complex iron-magnesium silicate, $(FeMg)SiO_3 \cdot$ 1–5 pct. H_2O; and *crocidolite*, a sodium-iron hydrous silicate, $NaFe(SiO_3)_2 \cdot FeSiO_3 \cdot H_2O$. Of minor importance are *tremolite*, $Ca_2Mg_5Si_8O_{22}(OH)_2$, and *anthophyllite*, $(MgFe)_7Si_8O_{22}(OH)_2$ (*3*)

Chrysotile, the principal variety of commerce, is graded according to fiber length. Fibers three-eighths of an inch long or longer are classed as the spinning grades suitable for use in making fabrics. According to the Canadian classification, the crudes (hand-cobbed long fibers) and spinning fibers comprise groups 1, 2, and 3. The succeeding groups are of progressively shorter fibers. Group 4 is designated as shingle stock; group 5, paper stock; group 6, waste stucco and plaster; and group 7, refuse or shorts. Most of these groups are divided into several subgroups. Such groupings comprise the commercial specifications. The consumer designates the grade desired, such as 3R or 4K. Grades may be blended to satisfy special needs. For some uses the chemical composition is important. Thus, for electric insulation an upper limit for the iron content may be specified. The methods of classification used in the principal producing countries are discussed in detail in a Bureau of Mines publication (*4*).

TECHNOLOGY

Most chrysotile asbestos deposits, including those of Vermont and California in the United States, Canada, Southern Rhodesia, Swaziland, the Republic of South Africa, and the U.S.S.R., consist of irregular cross-fiber veins (closely packed fiber set at a right angle to the faces of the rock fractures) or slip-fiber zones (shear planes in rock filled with fiber matted together parallel to the seam) in massive serpentine. Such deposits commonly extend to unknown depths. Those of Arizona, however, consist of more or less horizontal asbestos-bearing serpentine zones in thin-bedded limestone. Such deposits are generally less extensive and less persistent than those in massive serpentine. The amosite and crocidolite of the Republic of South Africa occur in banded ironstones that are so folded and contorted that the veins are very irregular (*16, 24–27*).

In Vermont, the fiber-bearing rock is removed from an open pit, which is worked on three 125-foot-high benches. Similar methods are employed in the Copperopolis district in California; but in the Coalinga district the highly sheared ore is simply "plowed" and allowed to air-dry, and the coarse fraction is screened out from the millfeed. The usual practice in Arizona is to drive a 5- to 6-foot heading in barren limestone beneath the fiber zone, which is later blasted down and hand-cobbed. The Canadian mines were originally open pits, but there has been a gradual transition to underground mines using block-caving methods. The chrysotile of Southern Rhodesia, the Republic of South Africa, and Swaziland is obtained from underground mines. Amosite is obtained chiefly from large underground workings, and blue asbestos from small open pits and shallow mines. The Soviet deposits are worked both in open pits and underground. Cyprus has large open-pit workings (*5, 17, 21, 24*).

Asbestos milling is a complex operation involving primarily the separation of fiber from rock and classification of the fiber by length. Asbestos, unlike the metals, is not a single commodity, but comprises a series of grades depending upon the length of individual fibers. The operator has little control over the proportions of the various grades, as they are fixed in nature, but he has the important task of minimizing fiber damage. He must mill the rock with as little fiber breakage as possible, because short fibers are worth much less than long ones. Special types of rock disintegrators have been developed, and reduction is accomplished in stages with fiber removal by air suction at each stage (*14*).

In Arizona the hand-cobbed rock is reduced in jaw crushers and the fiber separated by screening. Fiber which remains on a ½-inch screen is classed as No. 1; that which passes a ½-inch mesh and remains on a ¼-inch mesh, No. 2; through ¼-inch mesh and on ⅛-inch mesh, No. 3; and that which passes through the ⅛-inch mesh, No. 4. Nos. 1 and 2 are classed as spinning grade if the fibers are not too harsh. Some spinning fiber is obtainable from No. 3.

Special milling techniques have been developed for the matted short fiber chrysotile of the Coalinga district of California, including grinding and wet-milling processes.

In Vermont and Canada the mills are large and complex. The fiber is classified in many grades, such as spinning, cement stock, and paper stock.

USES

The uses of asbestos fibers of all varieties are numerous and range from floor tile to rockets. The longer fibers—Canadian groups 1, 2, and 3, and their equivalents from other countries—are used for making textile products such as cloth, yarn, tape, and rovings. The asbestos is spun and woven in much the same way as cotton, silk, or wool. Asbestos fabrics are used extensively for lagging cloth, brakeband linings, clutch facings, safety clothing, packings, gaskets, and various other appliances. Low-iron fiber is used in cable insulation (*2, 13*).

Shorter fibers such as Canadian group 4, and to some extent 5 and 6, are used widely for asbestos-cement products such as roofing shingles and flat and corrugated siding. These products consist of about 80 percent portland cement and 20 percent asbestos. Canadian groups 4 and 5 and African amosite are used extensively for making 85 percent magnesia block and pipe insulation. They consist of about 85 percent basic magnesium carbonate and 15 percent asbestos. Canadian group 5 is suitable for asbestos paper and millboard manufacture. Such products are made on standard papermaking machines. An important use of asbestos paper is for making the so-called air-cell pipe covering. The shortest fibers are used for boiler and roofing cements and as filler in asphalt floor tile and various other products.

Amosite is used for felted insulation in blanket form for high-temperature service up to 900° F. A loosely compacted form is applied as a covering for marine turbines, jet engines, and similar applications. Amosite is also used as a constituent of 85 percent magnesia insulation and lightweight, fire-resistant marine partition board.

Long-fiber crocidolite (blue asbestos) is woven into fabrics used for locomotive boiler lagging (in Great Britain) and for acid-resistant packings and gaskets. The principal use of the shorter crocidolite fibers is in making asbestos-cement pipe. Bolivian crocidolite has been found useful for making gas-mask filters.

Tremolite and anthophyllite are used for chemical-resistant filters, as welding-rod coating, and as fillers in various products.

BYPRODUCTS

There are virtually no commercial byproducts at asbestos mines and mills. The fiber comprises a small part ranging commonly from 5 to 7 percent of the rock mined, and the waste rock consists of pulverized serpentine for which very little commercial use has been found. In

Vermont, however, an appreciable amount is used for road metal. The possibility of recovering magnesia from it has been proposed, but no practical method has been developed.

ALTERNATE MATERIALS

Fiberglass is used as a substitute for asbestos in some applications, chiefly in the field of heat insulation. Fabrics woven with a plied yarn having one strand each of glass and asbestos yarn are advantageous for some uses where light weight and high strength are needed. Glass filaments in submicron sizes made by highly refined processes involving the use of platinum dies are technically satisfactory substitutes for amosite in blanket insulation, but the cost is five or six times as great as that of amosite. Fiberglass is not a satisfactory substitute for asbestos in friction materials or asbestos-cement products.

Silicone products, organic compounds, and plastics are used as substitutes in certain limited applications. The use of calcium silicate, diatomite, and magnesia in some instances reduces asbestos requirements in end products.

Aluminum sheets are being used as a partial substitute for asbestos where insulation against radiant heat is required.

Synthetic asbestos has not yet been made commercially. Its current status is covered later in the section devoted to research. New types of heat-resistant plastics are being substituted for chrysotile in some forms of electrical insulation. Substantial progress has been made in substitution of Novabestos and Quinterra papers for electrical insulation. There is, however, no satisfactory complete substitute for strategic grades of chrysotile in some forms of dielectric insulation.

Fibrous glass and chrysotile asbestos are substitutes for amosite, but they are not as resistant to steam, seawater, and alkalies under all working conditions. For 85 percent magnesia and calcium silicate insulation, textile grades of chrysotile may be substituted for amosite.

Experimentation on materials that may be substituted for asbestos indicate that fiberglass can replace asbestos for some types of heat-insulating products. Cloth of good quality is made using alternate strands of fiberglass and asbestos yarn. Such substitution extends the supply of spinning-grade asbestos. Fiberglass cannot be used successfully in friction materials such as brake band linings, nor in some of the highly specialized electrical insulation uses. Recent advances in the manufacture of glass fibers offer opportunities for wider substitution. Organic plastics and silicone products have limited substitute applications.

RESERVES

In Vermont, a reserve of at least 1 million tons of chrysotile fiber appears to be assured. A small proportion of this quantity is of spinning grade. In California, measured and indicated reserves totaling more than 1 million tons are reported for the Copperopolis area; these reserves consist chiefly of types and grades similar to those in Quebec, Canada. Reserves of several hundred million tons of rock that will yield matted short-fiber chrysotile asbestos are reported for the Coalinga area in California (*20*). The Arizona reserve is difficult to estimate but is probably small.

The world appears to have an adequate asbestos reserve for at least 25 to 30 years at current or moderately enlarged rates of output. The chief suppliers of U.S. markets—Canada and the Republic of South Africa—appear to have adequate reserves for long-range planning. It is difficult to calculate South African reserves owing to the intensive folding encountered in nearly all the asbestos areas. The duplication of the asbestos bands through folding has resulted in large reserves (*18*). The U.S.S.R. reserve is probably large enough to supply its domestic economy for many years.

SOURCES OF STATISTICAL INFORMATION

Annual data on the production and shipments are obtained from domestic producers and consumption of strategic grades are reported by consumers to the Bureau of Mines.

World production and trade data also are compiled by the Bureau of Mines, and U.S. imports and exports are obtained from the U.S. Department of Commerce.

The Bureau of Mines publishes the principal statistics annually in the "Asbestos" chapter in the Minerals Yearbook.

PRODUCTION, CONSUMPTION, AND TRADE

World production of asbestos by country of origin is given in table 1. Most of the asbestos production is chrysotile asbestos, but 160,000 to 200,000 tons of the world's production each year consists of amosite and crocidolite. Table 2 shows the production of these two varieties of asbestos by country of origin.

The United States is the largest consumer of asbestos in the world. Table 3 shows U.S. asbestos consumption and imports from 1954 to 1963. Table 4 shows imports of special grades of asbestos.

From 1949 to 1953 the United States consumed on an average about 50 percent of the total world production. Domestic consumption more than doubled from 1945 to 1951, but thereafter it remained fairly constant, except for 1955, while world production continued to increase. In 1963 the United States consumed about 23 percent of the total world production.

Domestic sources furnish only a small percentage of U.S. asbestos requirements. Arizona, the only present natural source of low-iron chrysotile in the United States, has rarely produced more than 600 tons per year of the spinning grades, and the output usually has been considerably lower than that figure. A large part of the production of crudes No. 1, No. 2, and No. 3 since 1953 was purchased by the U.S. Government for stockpiling. The purchase program terminated at the end of 1962.

TABLE 1.—*World production of asbestos, unmanufactured, by principal countries*

[Thousand short tons]

Country	1954–58 (average)	1959	1960	1961	1962	1963
Australia	10	18	16	17	18	18
Canada (sales)	994	1,050	1,118	1,174	1,216	1,272
China (estimate)	33	90	90	100	100	110
Cyprus	15	14	23	16	22	22
Finland	9	10	11	10	11	10
France	15	23	29	31	25	26
Italy	57	53	61	63	61	63
Japan	10	14	17	19	16	18
South Africa, Republic of	140	182	176	195	221	206
Southern Rhodesia	113	120	134	162	142	142
Swaziland	30	25	32	31	33	33
U.S.S.R. (estimate)	475	600	660	860	1,100	1,200
United States (sales)	44	45	45	63	53	67
Other countries (estimate)[1]	15	16	25	19	35	16
Total (estimate)	1,940	2,260	2,440	2,770	3,055	3,200

[1] Includes small production in about 20 countries.

TABLE 2.—*World production of amosite and crocidolite*

[Thousand short tons]

	1954–58 (average)	1959	1960	1961	1962	1963
Amosite: South Africa, Republic of	55	72	69	69	75	78
Crocidolite:						
South Africa, Republic of	62	81	78	94	116	99
Australia	8	16	14	16	17	12
Bolivia	(1)	(1)	(1)	(1)	(1)	(1)

[1] Less than 200 tons.

TABLE 3.—*U.S. consumption and imports of asbestos*

[Thousand short tons]

	1954–58 (average)	1959	1960	1961	1962	1963
Apparent consumption	729	754	709	666	726	734
Imports:						
Australia	4	9	5	2	8	(1)
Canada	637	665	617	570	624	619
Southern Rhodesia	10	6	2	3	4	4
South Africa, Republic of	32	39	41	35	35	37
Other countries	4	6	4	7	3	8
Total	687	718	669	617	676	668

[1] Less than 100 tons.

TABLE 4.—*Special grades of asbestos imported for consumption*

[Thousand short tons]

	1954–58 (average)	1959	1960	1961	1962	1963
Low-iron chrysotile (spinning lengths)	5	7	7	6	5	6
High-iron chrysotile (spinning lengths)	17	16	13	12	10	11
Amosite	14	17	20	16	20	22
Crocidolite	20	18	20	18	17	11

Vermont and the Copperopolis district of California are the only consistent U.S. producers of Quebec-type asbestos. Both are predominantly producers of short fiber, but the Vermont asbestos mines produce about 500 to 700 tons per year of spinning length fiber. Most of it is applied to nonspinning uses.

On a tonnage basis Canada furnished 90 percent of the U.S. imports (1959–63), but most of this material (97 percent) was of the shorter grades. The comparatively small quantities received from Africa are more important than would appear on a tonnage basis, because they consist largely of special kinds and qualities unobtainable elsewhere. Under emergency conditions imports of spinning fibers are of primary importance. Imports of spinning fibers from Canada average about 17,000 tons per year. The longer fibers of chrysotile suitable for spinning purposes represent a small fraction of the total production. Shortages of spinning-grade fibers have previously occurred.

The spinning grades of asbestos produced in Southern Rhodesia were of great importance during World War II and the early postwar years, because they constituted the principal source of low-iron chrysotile suitable for shipboard electric-cable construction. Production began from the new source of supply of low-iron chrysotile in northern British Columbia in 1953, and in 1962 over 5,000 tons of spinning fibers was imported from that source.

Production of amosite in the Republic of South Africa has increased from an average of 20,000 tons per year during the 1940's to 78,000 tons in 1963.

Imports of amosite into the United States from 1959 to 1963 averaged about 19,000 tons per year. Part of the imported material has been placed in the national stockpile; hence industrial consumption has been somewhat lower than the aforementioned figures. Probably larger quantities would have been used had they been obtainable, because there has been and still is a stringency of supply.

Most crocidolite originates in the Republic of South Africa, but substantial tonnages are received from Australia and small quantities from Bolivia. The commercial demand for Bolivian blue is very small. African production of crocidolite has increased from an annual average of 10,000 tons during the 1940's to almost 100,000 tons in 1963. Imports of crocidolite advanced from 12,000 tons in 1954 to 18,000 tons in 1959 and dropped to 11,000 tons in 1963.

About 10,000 tons of unmanufactured asbestos was exported from the United States in 1963. The exports consist chiefly of Canadian fibers blended and prepared in various ways to suit the needs of Latin American and European buyers.

Unmanufactured asbestos enters the United States duty free.

STRATEGIC CONSIDERATIONS

Asbestos kinds and grades of greatest strategic importance are being stockpiled. The national stockpile items are spinning-grade chrysotile and amosite. Bolivian blue crocidolite is no longer considered strategic. On June 30, 1964, the maximum stockpile objective for chrysotile was 13,700 short tons. Government inventories totaled 9,287 tons, of which 6,224 was in the national (strategic) stockpile, 724 in Commodity Credit Corp. (CCC) stocks, and 2,339 tons in the supplemental stockpile. The stockpile objective for amosite was 40,000 short tons, and inventories totaled 65,838 tons, of which 11,705 was in the national (strategic) stockpile, 23,196 in CCC stocks, and 30,937 in the supplemental stockpile.

The United States is dependent upon foreign sources for 90 to 93 percent of its requirements for all grades of asbestos. The principal source of low-iron spinning grade chrysotile asbestos is British Columbia, Canada. The former chief source was Southern Rhodesia, from which our essential needs were supplied until the end of the Korean war. A small amount of low-iron long-fiber chrysotile is available from Arizona. The only source of commercial grades and quantities of amosite is a limited area in Transvaal, Republic of South Africa. The United States is also completely dependent on foreign sources for crocidolite.

GOVERNMENT PROGRAMS

During World War II controls were in effect to restrict exports of asbestos needed in the military program. These controls were removed by executive order on September 10 1945. During the Korean war the supply situation again became acute, and in 1950 and 1951 controls were invoked that required licenses for export of all grades of asbestos. The license requirement was removed for the nonspinning grades in 1953, and for the spinning fibers in 1954; however, export licenses are required for shipments to Communist nations.

The allocation of asbestos supplies effected during World War II has been deemed unnecessary since the Korean war, but the National Production Authority (NPA) issued an order (M-96 dated January 17, 1952) that gave priority to military and essential civilian uses of the limited supply of spinning grades of chrysotile asbestos. It prohibited the use of certain grades of spinning fiber for other than certain specified end uses. As supplies of spinning-grade chrysotile had become adequate for all commercial and military needs early in 1953, order M-96 was revoked by the NPA May 12, 1953.

The discovery and development of new asbestos deposits have always been a most urgent necessity. To assist in discoveries the Office of Minerals Exploration (OME), and the Defense Minerals Exploration Administration which was abolished in 1958 and whose functions were assumed by OME approved 19 asbestos exploration contracts as of December 1963. Only five contracts led to certification of discovery and none of these were significant to the overall supply situation.

A government depot in Globe, Ariz., was opened for the purchase of domestically produced asbestos meeting certain specifications. Under Public Law 733 (1956), a government purchase program at premium prices for domestic low-iron chrysotile asbestos was established which was terminated on December 31, 1958. In 1959 the stockpile objectives for low-iron chrysotile were raised, and a barter program was established to acquire the additional fiber needed through exchange of agricultural surpluses. The U.S. Department of the Interior recommended purchase of 500 tons of low-iron chrysotile from domestic mines to assist the domestic industry and to establish a domestic mobilization base for production.

Amosite and chrysotile have been acquired for the stockpile by purchase and barter, and crocidolite has been acquired by barter.

PRICES

Although asbestos has had an erratic price history, prices during the past 5 years have remained relatively stable. Quebec chrysotile fiber prices in 1963, f.o.b. mine, ranged from Can$40 per short ton for 7T, which is the shortest of the regular fiber grades generally produced, to Can$875 for the longest of the milled fibers. Crude No. 1 sold for Can$1,410 or more per ton. British Columbia fibers sold from Can$142 for AX to Can$1,522 per ton for crude No. 1.

Vermont chrysotile is produced in grades similar to those of Canada and ranged in price in 1963 from $40 for group 7 to $402 for group 3, f.o.b. mine. Arizona fibers ranged in price from $58 for group 7 to $1,650 for crude 1, f.o.b. Globe, Ariz. (*1*).

As sales of African and Australian asbestos are negotiated separately, market quotations are not available.

TAXES

There are no special taxes on the asbestos industry. Producers are granted a depletion allowance of 23 percent on domestic production and 10 percent on foreign production.

TRANSPORTATION

The Quebec and Vermont deposits are within easy rail haul to most of the plants manufacturing asbestos products in the industrial areas of the Eastern United States. The African deposits are remote from the principal markets and have high transportation expenses. Transportation from British Columbia is difficult and costly, but a shorter route is in prospect. The Arizona miners have difficult transportation problems. The mines are in the vicinity of Globe, the nearest railhead, at distances ranging from a few miles to 104 miles, with an average haul to the railroad of about 50 miles. The major consumption centers are in the Northeastern United States, and are much closer to Quebec, Canada, than to Arizona. Consumption of asbestos is growing along the west coast of the United States. Comparable growth of the industry has taken place in other areas where fiber from California would be competitive, in terms of freight rates, with that from Quebec.

RESEARCH

Research on production has been conducted by companies operating mines in Canada. Substantial research has been conducted on utilization of the more plentiful shorter grades in applications where longer grades are preferred. For instance, it has been found that more complete fiberization, permitting better contact of cement and fiber, will allow groups 5 and 6 to be blended in increasing proportions with group 4 in making asbestos-cement products.

Two companies have developed processes for reducing the iron content of Quebec asbestos to make it suitable for electrical uses. The Johns-Manville Corp. manufactures Quinterra paper from such fibers. Raybestos-Manhattan, Inc., has developed a process for making a low-iron product known as Novabestos. Both Quinterra and Novabestos papers may be interlaminated with a fiberglass fabric or grid to give additional strength. These products are now manufactured commercially and are used extensively in cable construction and for other nonferrous applications.

The Cape Asbestos Company Ltd., London, has investigated tensile testing of crocidolite and amosite, their chemical resistance, and their behavior in solutions of various chemicals and surface active agents. The only laboratory in the world devoted entirely to fundamental research on asbestos fibers was recently constructed by Turner and Newall Ltd., Manchester, England. New types of equipment were developed to sort asbestos fibers according to diameter and length (*19*).

In this country, the Naval Research Laboratory has conducted experimental work on the possible use of a papermaker's Vortrap to remove iron minerals from Canadian chrysotile. The Bureau of Mines conducted similar experimental work with its own equipment. The tests indicated that the magnetic iron content of ordinary Quebec asbestos can be reduced to satisfy the requirements of 2 percent or less stipulated in the national stockpile specification for nonferrous chrysotile.

The Naval Research Laboratory has developed a fiberglass gas mask filter said to be superior to those made of Bolivian blue asbestos. Bolivian crocidolite is, therefore, no longer regarded as essential.

Much work has been done on the synthesis of asbestos, but limited progress has been made. The Bureau has synthesized amphibole asbestos, but the fibers made are weak and brittle. The Bureau also has synthesized asbestiform compounds not found in nature that have some of the properties of asbestos. Chrysotile, the type of asbestos most in demand, is difficult to synthesize. Fibers of submicroscopic length only have been made (*9–12*, *15*, *22–23*). The Bureau has performed core drill tests on various properties to determine the occurrence of asbestos, and the Geological Survey has studied the geology of asbestos deposits in various parts of the country (*6–8*, *16*, *25–27*).

OUTLOOK

The trends in the consumption of asbestos will follow those of industrial production and building construction. Asbestos will continue to find wide industrial use in friction materials, pipe insulation, packings, gaskets, plastics, and many other products. Also, large quantities of asbestos will be used for asbestos-cement pipe, roofing and siding products, floor tile, insulation, moulding compounds, and millboards. The demand in the United States for all types and grades of asbestos should increase 3 to 5 percent annually. Annual consumption of asbestos should reach 900,000 tons in 1965–70, and may exceed 1 million tons by 1975 in the absence of an industrial recession. Domestic production should increase annually and attain 95,000 tons per year during 1965–70; consequently, domestic mines will supply 10 percent of the Nation's overall requirements. Most of the supply, however, will consist of nonspinning, low-unit-value fiber.

As new markets come into being and old markets grow, world production of asbestos fibers will rise. As worldwide demand for asbestos increases, there is much interest in exploring new areas. New occurrences in Ireland, Australia, and Mexico have been examined. Additional mills in Quebec, and others in prospect, assure rising availability of supplies. Newly discovered deposits undergoing exploration and development, in northern Newfoundland, Quebec, Ontario, and British Columbia, promise further expansion and output. Expansions have also taken place in the U.S.S.R., Southern Rhodesia, and the Republic of South Africa where all types of asbestos are produced. Utilization of short-fiber grades is growing throughout the world. Deposits rich in short-fiber chrysotile, being developed in California, will add substantially to domestic production as markets are found. No spinning-grade fiber is expected from these deposits. Imports are expected to increase from Canada, Southern Rhodesia, and the Republic of South Africa. Supplies of asbestos apparently will be adequate for both short-term (5-year) and long-term (10-year) requirements. World production has doubled over the past 10 years to the present 3.2 million tons. World demand is expected to require world output of 4 to 5 million tons within the next decade.

U.S. requirements for low-iron chrysotile of spinning-grade quality have been greatly reduced because of the decline in military usage and the substitution of other electrical insulation materials, such as fibrous glass, plastics, and silicone rubber. Some Quebec fibers are now processed in such a manner that their iron content is reduced sufficiently to make tl suitable for some electrical insulation. H ever, the United States still needs about 2. tons per year of low-iron fiber. Beneficin chrysotile imported from Quebec is being u in the manufacture of low-iron fibers. Imp of low-iron chrysotile from British Colum will be adequate to meet special needs and p vide a surplus for general-purpose uses. L iron tapes and papers using beneficiated chr tile imported from Quebec are suitable for sc electrical insulation, thereby relieving part the demand for low-iron fibers. Arizona mi will remain a small factor in industrial sup

High-iron spinning-grade chrysotile requi ments for the short-term are estimated at most 20,000 tons per year, increasing over a year period to 25,000 tons. Most of the sup comes from Canada, with small amounts p duced in Vermont and imported from Afr and other overseas sources. Information fr the Canadian Department of Mines and Tech cal Surveys indicate that Canadian product of spinning grades is about 30,000 tons per ye The industry could produce about double t quanitity if the market so required. Appro mately 50 percent of the supply is curren exported to the United States. From this appears that Canada is an adequate source all foreseeable requirements.

Amosite requirements of the United Sta are increasing steadily. Imports reached ne ly 22,000 tons in 1963 and will probably incre to 30,000 tons per year within the next years. Mining and milling facilities are bei expanded in the Republic of South Africa a are expected to remain above the short-term a long-term requirements. Amosite is partic larly suitable for use in heat-insulati materials.

Crocidolite requirements have increased su stantially during the past 5 years. The lon fiber grades are in relatively small demand, b use of the shorter fibers in asbestos-cement pi manufacture is increasing rapidly. With e panding facilities for pipe manufacture in t United States, demand for crocidolite may rea 30,000 tons per year within 10 years. Lar deposits of crocidolite are known only in t Republic of South Africa and Australia. Af can production facilities are being expanded new fiber-bearing zones are discovered and d veloped. Production of crocidolite in Austr lia increased 30 percent during 1958–62. R serves are said to be extensive.

The outlook for successful synthesis of co mercial asbestos remains uncertain.

PROBLEMS

The complete dependence of the United States on foreign sources for some types of asbestos is an important problem that concerns the national economy and defense needs. Export duties and other controls by producing countries could increase costs to U.S. consumers.

The disposal of surplus inventories of asbestos in the Government stockpiles is of concern to the producing industry. The absence of any clearly defined and predictable long-term disposal program has heightened this concern.

More data are needed on the fundamental characteristics of asbestos to serve both as a foundation for future research on synthesis and as a guide to new and improved usage of all varieties of fiber.

Information is needed on the interchangeability of the many types of asbestos in manufactured products. Development of substitutes for scarce types and grades or asbestos fiber is a difficult problem because of the superiority of asbestos to other materials for special use.

The biological effects of asbestos are a serious health problem in the industry. The hazards are recognized, however, and adequate filtering and ventilation are provided in processing plants. The extensive use of asbestos in a variety of industrial applications has drawn attention to the medical problems associated with this use. These problems include pulmonary asbestosis and neoplasia associated with occupational exposure to asbestos.

Other problems include occasional shortages of spinning-grade fiber, utilization of waste from asbestos plants, and the development of potential large-scale uses for the widespread resources of actinolite, anthophyllite, and tremolite varieties that are in little demand.

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U. S. Bureau of Mines

Mineral Facts and Problems

Bulletin 630 (1965)

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improved". It appears that if the regulations are more widely and more stringently applied than at present, the number of cases should inevitably fall.

The panel indicates that crocidolite has a special significance in relation to mesothelial tumours. It recommends that other types of fibre should be substituted for crocidolite wherever possible, and, where this is impossible, special precautions should be taken to reduce the risks of inhaling the material. The panel admits that at the moment the level of exposure below which the risk may be negligible is not known. The quantity of crocidolite (blue asbestos) imported into the country is much less than the other varieties of asbestos, and it has remained at about 7,000 tons per year for the last few years. But time may show that other fibres are also implicated in the development of mesothelial tumours.

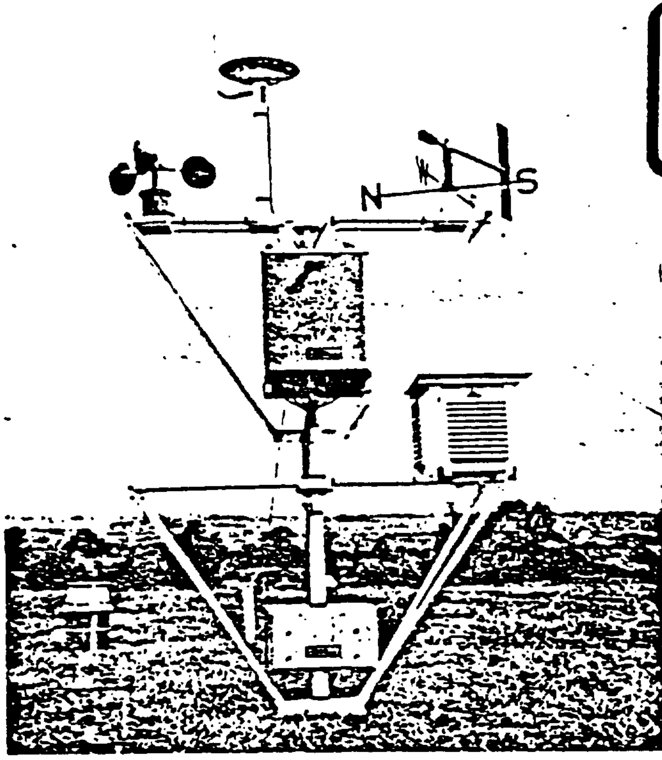
Finally, the report suggests that action should be taken to control the discharge of dust-laden air from asbestos factories and the dispersal of dust from waste dumps. It emphasizes, however, that the problem of mesothelioma in association with asbestos exposure should be kept in a proper perspective. Even though the incidence is increasing, the total number of cases of mesothelioma in Britain over several years is very small when compared with the annual total of deaths from cancers of the trachea, bronchus and lung.

Recording Weather

AN automatic weather recording station which can operate unmanned for at least three months has been produced by the Plessey Company Ltd. This station, which can make and record more than 82,500 measurements in a three month period, is available from the Marine Systems Division of the Plessey Electronics Group at Ilford. The value of automatic weather stations was recognized by a recent report from the World Meteorological Organization (*Nature*, 215, 1324; 1967). They are important because modern developments in weather forecasting require information about climate from all over the world—sometimes from uninhabited areas—and it is becoming increasingly hard to persuade amateur meteorologists to provide accurate data day by day. Professionals cost money, and so there should be a real market for automatic stations which can do the job reliably for long periods without attention.

The Plessey station is virtually self-contained and can monitor parameters such as rainfall, humidity, wind speed and direction, air, soil and water temperatures, barometric pressure, pH, solar radiation and water level and flow. The basic design was evolved in co-operation with the British Water Resources Board, the Meteorological Office and the National Physical Laboratory. By adding various instruments to the basic design, it has been possible to produce a family of stations including hydrometeorological, climatological, water level, water quality and recording rainfall stations. Each can be arranged for automatic operation, and the recorded data can be sent by telemetry to a control centre on demand.

Each station is supplied as a complete system with sensors, recorder, power supply, 'Stevenson' screens and a stayed aluminium mast which supports the sensors. The memory of the station samples up to eight sensors in turn, recording their outputs in ten-bit



binary code on standard quarter-inch magnetic tape. It samples at intervals of 5, 10, 20, 30 or 60 minutes and is accurate to within 0·1 per cent.

Discomforts of Space

by Angela Croome

THE next moves in manned spaceflight may be uncertain, but in both the United States and the USSR, background experiments for the longer flights of the future are going ahead. This month the McDonnell Douglas Corporation of California, contractors to the Office of Advanced Research and Technology of NASA (National Aeronautics and Space Administration), is to start on a two-month-long test of a closed system space chamber. The Soviet Union has recently completed a 70-day confinement experiment involving three men. American and Soviet trials have relevance both for survival in space and for the operation of manned submersibles under the sea.

In the case of the American closed life-support trial, four college students of the University of the City of Los Angeles are acting as experimental subjects. For a period of 60 days, they will exist on reclaimed water and oxygen from their own metabolic wastes. The test is believed to be the longest so far attempted under flight conditions using a closed water-oxygen loop. The closed water system consists of an evaporation unit, a charcoal filter and a condenser that reclaims moisture directly from the crew and from the air in the cabin. Oxygen will be reclaimed through a process of mixing hydrogen and carbon dioxide and then converting them to water and methane gas. The oxygen is recovered from the water by electrolysis and the methane gas is expelled. Atmospheric pressure within the cabin will be at 7 p.s.i. (half that at sea-level) and will consist of 3·1 p.s.i./oxygen and 3·9 p.s.i./nitrogen. The simulation of space conditions will not, of course, be complete, for the trial will take place on the ground where both men and system will operate under normal gravity.

The Soviet experiment has already taken place and lasted the full period of 70 days during which a medical doctor, an engineer and a journalist remained shut up together under cramped and uncomfortable conditions. The exact dimensions of the isolation chamber are not given, but it is described as small. All three subjects were thoroughly instrumented for the measurement of their physical condition during the test. Their regime was to fulfil a daily routine of work, eating, sleep and medical examination up till about the halfway stage when they switched to a "free" routine, doing as they pleased. The journalist of the group recorded reactions in his log at the end of the first three weeks: "Watch-keeping, dinner, medical examination, sleep—our life has acquired a feverish though monotonous rhythm. There is almost no free time left. But we are already beginning to feel exhausted. Stanislav [the doctor] is getting thinner, there is a stubble of beard on his cheeks and dark rings under his eyes. Leonard's eyes have become red and anxious. I cannot escape the feeling that some pungent fog is creeping into our tiny room. While gradually poisoning our brains, it makes us more intolerant towards one another".

But during the later period when there was no set routine, things seemed even worse. There was no longer a work schedule, but the men could pass the time as they chose—playing chess, reading or presumably sleeping. (Food preparation did not amount to much of a task as their diet was a typical space diet of dehydrates, concentrates, and tinned foods.) Now, they reported, time passed more slowly and nervous tension increased. Sleep was troubled and they had hallucinations of sound. They dreamt of music, singing and the noise of aircraft. None the less, no member of the group "deviated from the programme or complained"—complaint presumably being defined as a request for release from the experiment. The experimenter in charge comments that the trial was above all a test of character and willpower, but much useful information was gleaned.

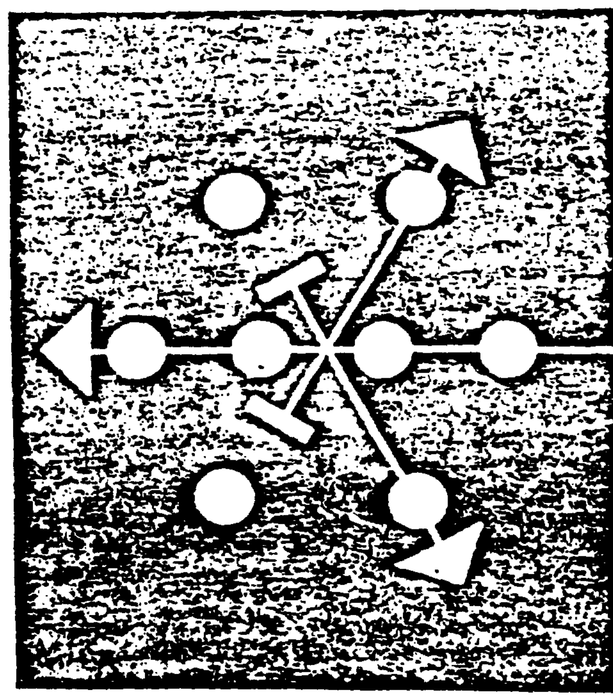
Mapping in Metric Units

ONE organization faced with a formidable task in changing to metric units is the Ordnance Survey. Among proposals which have so far been endorsed by the Joint Standing Committee in accomplishing this task are that heights will be shown in metres instead of feet on new and revised maps at 1 : 1,250 and 1 : 2,500 scales. Areas will be shown in hectares instead of acres on maps at 1 : 2,500 scale. Heights will be given in metres instead of feet on bench mark lists prepared from new levelling. Contours will be shown at a metric interval on new six-inch maps. Finally, the problems of changing the six-inch and one-inch maps to "rational" scales such as 1 : 10,000 and 1 : 50,000 will be reviewed. These proposals were circulated to 180 interested bodies, representing all classes of map users.

According to the annual report of the Survey for 1966–67 (HMSO, 7s. 6d.), in which these facts are published, the past year was marked by a change of ministry. In February the responsibility for the Ordnance Survey was passed from the War Office to the Minister of Housing and Local Government. Overall expenditure during the year was £5,715,000, about one third of which was recovered by revenue from sales of maps and from royalties. On the whole, however, there was a falling off in demand for maps, which the report suggests, is mainly due to the deferment of investment in development schemes in many parts of the country as a result of the Government's economic measures, together with an increase in the price of maps at certain scales. On March 31, the total number of staff was 4,090 non-industrial and 552 industrial compared with 4,008 and 540 a year earlier—a vigorous recruiting programme bringing in some 480 new staff.

Survey of the principal town areas on the scale of 1 : 1,250 is said in the report to be nearing completion and revision of the old 1 : 2,500 plans covering minor towns and rural areas has been speeded up, largely through the increased use of aerial photographs. Instead of the five-year re-levelling programme which was originally aimed at, subsidence areas will be levelled on a twenty-year cycle as in normal areas.

New Physics Symbol



THE Institute of Physics and the Physical Society hopes that this symbol, when correctly placed on a red ground, will soon become familiar to anyone who has any acquaintance with physics. The symbol has been designed to accompany all kinds of information produced in connexion with the four-day Physics Exhibition opening at the Alexandra Palace on March 11. It is based on the weight diagram for the irreducible representation D^8 (1,1) of the $SU(3)$ symmetry which has been successful in bringing order to the classification of subatomic particles. Mr D. Walter, who is organizing the exhibition, first thought of basing the symbol on $SU(3)$ symmetry and, after advice from Imperial College, the final representation was drawn by Mr M. R. Preston of the Science Museum.