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MATERIALS SURVEY

TUNGSTEN

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U. S. DEPARTMENT OF COMMERCE

SINCLAIR WEEKS, Secretary

BUSINESS AND DEFENSE SERVICES ADMINISTRATION

H. B. McCOY, Administrator

DEPARTMENT OF COMMERCE
BUSINESS AND DEFENSE SERVICES ADMINISTRATION
WASHINGTON 25

December 1, 1956

OFFICE OF THE ADMINISTRATOR

Mr. George B. Beitzel
Assistant Director for Production
Office of Defense Mobilization
Washington 25, D. C.

Dear Mr. Beitzel:

Forwarded herewith are 325 copies of the "Materials Survey--Tungsten," prepared by the Business and Defense Services Administration for the Office of Defense Mobilization, successor to the National Security Resources Board.

This report, one of a series of basic surveys on various strategic and critical materials prepared at the request of the National Security Resources Board by selected Government agencies, conforms in contents and format with the working fund agreement between the Board and the Department of Commerce, and with the general outline proposed by the Board.

Manuscript revisions proposed by reviewing officials have been incorporated in the survey.

Sincerely yours,


H. B. McCoy
Administrator

Enclosures

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MATERIALS SURVEY--TUNGSTEN

PREFACE

This survey on tungsten is one in a series of materials surveys on certain strategic and critical materials prepared by various United States Government agencies. The series was initiated by National Security Resources Board, now the Office of Defense Mobilization.

Materials Survey--Tungsten was prepared by the Business and Defense Services Administration, United States Department of Commerce. The survey was written by Paul Sacharov, metallurgist, Ferroalloys Branch, Iron and Steel Division, except for Chapter II, Resources, which was prepared by Dwight M. Lerrmon and Donald C. Ross, geologists of the Geological Survey. Principal consultant was Joseph H. Brennan, chief metallurgist, Electrometallurgical Corporation.

In the course of preparation, free use was made of available technical publications and financial papers. An attempt has been made to give individual acknowledgment to all of these sources in the bibliography, Chapter XI.

The manuscript has been reviewed in whole or in part by specialists of the former Defense Materials Procurement Agency; the Geological Survey and the Bureau of Mines of the United States Department of the Interior; and editorially by John Croston, formerly consultant to Defense Materials Procurement Agency.

This survey attempts to present the pertinent aspects of the technical and economic position of tungsten in order that a proper evaluation of the commodity may be made with respect to both its intrinsic merits and its role in the national economy.

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CHAPTER I
HISTORY

CHAPTER I

HISTORY

Tungsten, also known as wolfram, enjoys a unique position among metals. It has the highest melting point, 3410 C. (6170 F.), of any metal. Its corrosion resistance is also one of the highest. When properly worked it is elastic and ductile, and tensils of up to 600,000 pounds per square inch can be obtained.

The word tungsten is derived from the Swedish words tung and sten, which mean "heavy stone." It was first used about 1758 by A. F. Cronstedt, who applied the term to the mineral scheelite because of its high density.

The origin of the word wolfram is more obscure. Lazarus Ercker described "wolf-eram" as early as 1574, but undoubtedly it was known long before that time. Georgius Agricola suggested that it stems from the early German words wolf and ram or rahm (froth), which mean literally "the foam of the wolf" and suggest that in some manner the ore has wolflike qualities. These qualities were connected by tin miners in England with the tendency of wolframite--frequently associated with tin ore but originally believed to be a mineral of tin--to "eat up" tin during the process of the smelting. It was not realized at the time that this detrimental impurity contained a new element.

In 1781 a Swedish chemist, Carl Scheele, pointed out that in tungsten ore (scheelite) there existed a peculiar acid, which he called tungstic acid, combined with lime. In recognition of his discovery the mineral now bears his name: scheelite. Torbern Bergman thought the base of the acid was a metal but was not able to isolate it. However, he as well as Scheele, suggested the possibility of extracting the element in a manner similar to that used in the recovery of arsenic from its oxide ores known centuries before, that is, with carbonaceous material.

J. J. & F. de Elhuyar found the same acid in wolframite and gave the first published account of isolating the metal in 1783. Their experimental procedure consisted merely of mixing tungstic acid and charcoal in a crucible and heating to bring about interaction between the two. The residue was a crumbly metallic button which upon close

examination revealed small globules of elemental metal which they called wolfram. The English called it tungsten. (Scheele probably had already prepared the metal but made no accounting of it.) The de Elhuyar brothers had further shown that in wolfram the metallic element was associated with iron and manganese instead of lime.

The first important use of tungsten commercially was in a tungsten-manganese steel which hardened upon air cooling from proper heat-treating temperatures. This steel was devised by Mushet in the middle of the 19th century. Several other European investigators experimented with steels containing tungsten.

The most notable achievement in the field of tungsten steels was made by Taylor and White, who developed the composition known today as high-speed steel. Their work was received with great enthusiasm when the first high-speed steel was exhibited by the Bethlehem Steel Company at the Paris Exposition in 1900. Its ability to hold a cutting edge at dull red heat promised to revolutionize the tool-steel industry. Many investigations were subsequently carried out with other compositions and the possibility of substituted elements was later considered when tungsten became a critical alloying element. At present, standard grades of high-speed steels include the use of tungsten, molybdenum, chromium, vanadium, and cobalt.

One of the more important applications of tungsten, because it contributes to man's comfort, is in the field of electric lamp filaments for lighting and for electronic tubes. Tonnagewise, the actual amount thus used is small--1 ton is enough to make over 10 million electric lamps. Progress in this field was slow for the first few years because of the difficulty of producing from tungsten metal powder a solid material possessing good ductility. Just and Hanaman in 1904-06 had some success in making filaments with a process of "squirting" into thread a mixture of fine tungsten powder and organic binder through appropriate-sized dies, and then volatilizing the binder in hydrogen to prevent oxidation. Tungsten particles were thus sintered to

form a conducting filament suitable for lamps. However, its lack of flexibility was a serious drawback.

The difficulty was overcome by Coolidge (General Electric Company) who, after several years of research, produced fine flexible wire by the application of high initial temperatures and judicious use of mechanical deformation in the initial stages of fabrication. Once deformation had occurred, subsequent mechanical working below the recrystallization temperature permitted the material to be drawn into very fine wire even at room temperature. Coolidge's efforts had produced fine wire of commercial importance by 1906 and by 1911 incandescent lamps using coiled filaments were on the market. Filaments as fine as .0004 inches in diameter are now commercially available.

Tungsten carbide, recognized by H. Moissan in 1896, was first made by reducing tungstic oxide with carbon. About 1919, tools and die materials were made from the carbides. In the twenties tungsten carbide was bonded with cobalt at the Krupp Laboratory at Essen, Germany, and used for tools, wire drawing dies, etc. The product "widia" is used at present. Cobalt is almost invariably the bonding material used for cementing carbides for use as cutting tools and dies. The carbides of titanium and tantalum are often mixed to produce cemented tungsten carbide for use in cutting operations. These products of powder metallurgy involve the pressing of various metallic powders into desired shapes and sintering at high temperatures.

Tungsten carbide is also cast into desired shapes for other applications. It is being used as a substitute for diamonds in drills for drilling oil wells. For this application it is necessary that the drill be extremely abrasion resistant in order to maintain the gage of the drill hole.

The use of tungsten carbide products is rapidly expanding and new uses are constantly developing. There are wide applications in the field of mining, such as for rock drill bits and oil-well drilling tools; in metal cutting tools; in dies for wire drawing; and in metal forming such as for facing rolls for producing certain sheet metals. Tungsten carbide is also used for hard facing materials where it may be deposited by means of arc welding. During World War II, the Germans introduced armor-piercing projectiles made from tungsten carbide for use in tank warfare. This innovation has consequently placed

greater demands upon the ballistic performance of armorplate.

Tungsten pigments, lakes, and mordants are used in the manufacture of printing inks, paints, enamels, waxes, rubber, and paper. Tungsten finds other uses in corrosion-resistant alloys, targets in X-ray tubes, electrodes in atomic hydrogen or gas-shielded electric arc welding, electrodes for spark plugs, crosshairs for optical instruments, in glass-blowing equipment, and, in some instances, as electrodes for arc melting titanium metal. It is used in certain chemical applications such as discs and vessels. Tungstates are used in fluorescent lamps and optical glass, especially in aerial camera lenses to raise the refractive index.

The chief sources of tungsten are the ores, wolframite, ferberite, huebnerite, and scheelite. The first three form a continuous series of naturally occurring iron-manganese tungstates with ferberite on the iron end and huebnerite on the manganese end. (See table VIII-5 for limiting compositions.) Compositions in between are the wolframites. Scheelite is a calcium tungstate. At the present time wolframite is the greatest world source of tungsten but domestically scheelite predominates. Scheelite is used principally in the manufacture of ferrotungsten and directly in tungsten steels, while the wolframite group is mostly used in the production of tungsten powder. However, in certain cases they can be interchanged. The products made from tungsten ores can be grouped as: (1) Tungsten compounds, (2) tungsten metal powder, including tungsten carbide, (3) metallic tungsten, and (4) ferrotungsten.

The total world reserves are estimated at 175 million units of tungstic oxide, WO_3 (equivalent to nearly 3 billion pounds of tungsten). Asia has the largest deposits, principally in Burma, Malaya, China, Japan, and Korea. China has the largest and richest deposits in the world. Lesser or poorer grade deposits are found in North America, South America, Europe, and Australia. With the recent closing of the door to Chinese tungsten, United States needs for tungsten have greatly stimulated domestic and other sources of production. Domestic tungsten ore production in this emergency period accounted for about one-third of the total United States supply, 86 percent of which in 1952 came from California, Nevada, and North Carolina.

Numerous methods of dressing and concentrating tungsten ores are used, depending

upon the nature of the ores and the complexity of the associated minerals. Some are primitive while others use the most modern flotation, magnetic, or electrostatic separation techniques. Domestic scheelite, which is often fine grained, presents the problem of sliming as a result of too fine crushing. Chemical treatment is, therefore, often used in order to produce synthetic scheelite which is used in steel production or further processed into metal powder.

The military demands for tungsten in armor-piercing projectiles, its expanded use in tooling in war economy, and its use in jet aircraft classify it definitely as a "war element." Its price has strongly reflected war and preparedness programs since 1914. To conserve this strategic element during emergency, it has been necessary for the Government to institute controls over prices, distribution, and uses.

Guaranteed prices for Government purchases of domestic ore have been incorporated into the control program.

Almost the entire commercial development and growth of the tungsten industry has taken place since 1900. Variations in demand have made production and prices vary erratically, with conspicuous peaks in 1918, 1929, 1937, 1943, and 1953. Since World War I, China (except for World War II years 1943-45, when transportation routes were blocked) has maintained the lead as the world's greatest ore producer, followed by the United States and Burma. Bolivia and Portugal have contributed lesser amounts.

For convenience, development and growth of the industry can be grouped into four periods: Early development through World War I; post-World War I--the twenties and thirties; World War II; and the post-World War II period.

EARLY DEVELOPMENT THROUGH WORLD WAR I

Pre-World War I

Although tungsten ore deposits were known to exist in the United States as early as 1872 (1 ton was actually mined in Connecticut), no domestic production was reported until 1898. No real interest was shown in tungsten until after Taylor and White in 1900 discovered that tungsten steel, when heated to near its melting point prior to cooling, produced a tool the cutting speed and tool life of which would be increased beyond expectation.

Prior to 1900, tungsten ores and concentrates were imported; demand was only about 66,000 pounds of contained tungsten a year. Most of this went into production of Mushet-type tool steel (about 2% C, 2% Mn, and 8-10% W), while a small amount went into the manufacture of sodium tungstate for use in fluoroscopes, for mordants in dyeing cloth, and for flameproofing cottons. The Taylor and White steel was similar to the Mushet type except that it contained about 4 percent chromium (in 1903 the composition was changed to about 0.70% C, 4% Cr, and 14% W).

Continued growth and development in use of tungsten in armorplate, car springs, permanent magnets for telephones, filaments for electric lamps, and the like caused much activity among miners of tungsten ores. From a start of 46 tons of concentrates containing at least 60% WO_3 and a price of \$2.50 per short-ton unit in

1900, production climbed steadily to 1640 tons (1,733,592 pounds contained tungsten) in 1907. The yearly average was 602 tons (572,373 pounds of contained tungsten). In 1907 the United States became the leading world producer of tungsten ores, the greatest portion of which came from Colorado, California, and Idaho. In 1910, the peak production prior to World War I was reached--1820 tons. However, a slowdown in the steel industry with a consequent lack of demand for tungsten led to a drop in tungsten production which continued, with some fluctuation, until the outbreak of World War I in Europe.

World War I

With the outbreak of war in Europe in the latter part of 1914, a threatened depression was averted through orders for munitions from foreign countries whose supply was cut off from Germany. There was great demand for tungsten in high-speed steel, and, in turn, for ores and concentrates. Prices soared, stimulating production in 1915 to a new high of 2165 tons (2,061,000 pounds contained tungsten), which sold for as high as \$67.50 per unit as compared with \$5.80 at the beginning of the year.

Prior to the outbreak of war Primus Chemical Company was the only producer of tungsten and tungsten alloys in appreciable quantities. With the placing of war orders, several other companies, including Crucible Steel Company, Vanadium Alloys

Steel Company, York Metal and Alloys Company, Wile Electric Furnace Company and Goldschmidt Thermit Company, began competing for purchase of ores and concentrates necessary for shellmaking. New applications were discovered. Victor Talking Machine Company put out a tungsten needle; tungsten replaced platinum in dental pins; the tungsten enclosed arc lamp was developed; tungsten make-and-break contacts and X-ray targets came into use; and a new use as a catalyst for production of ammonia from nitrogen and hydrogen was developed.

Meanwhile, China had entered the tungsten industry. K.C. Li in 1913 discovered that a specimen he had obtained from an innkeeper's backyard while on a tin exploration trip in China in 1911 was wolframite, which was being used by the Germans in ammunition manufacture. The scramble for tungsten after expansion of the market in 1915 started China towards becoming the largest tungsten ore and concentrate producer in the world.

The wartime boom reached a climax in April 1916, when some domestic ores were sold for as much as \$93.50 a unit at the mill. At this price supply soon overran the demand, making a drop in price inevitable. The year closed with the price stabilized at \$15-\$17 a unit for ores carrying 60 percent or more of tungsten oxide. Disposition of surplus resulted in a slight rise in prices in 1917.

The closing year of the war, 1918, was one of uncertainty, despite relatively stable prices. After the Armistice was signed on November 11, business was almost at a complete standstill. Prices fell to as little as \$12 per unit, with no buyers. Producers and consumers were caught with accumulations of stock for which there was no outlet. This situation was due almost entirely to a large and unexpected influx of ores and concentrates, particularly from China (see table I-1). Production in 1918 of 10,577 metric tons (over 11 million pounds of tungsten), made China the leading world producer.

POST WORLD WAR I--THE TWENTIES AND THIRTIES

Readjustment, 1919-1924

The period 1919-22 was unfavorable for the tungsten industry. Price conditions discouraged domestic miners. In 1919 Chinese ores and concentrates poured in at \$6-\$7 per short-ton unit, which was less than the cost of domestic production. As a consequence many domestic mines closed and by 1920 tungsten mining became practically nonexistent. Cheap Chinese and some Bolivian ores flooded the markets to further delay opening of domestic mines. Prices plunged further, from \$6.50-\$10.00 per unit at the beginning of the year to \$4.00-\$4.50 per unit by the end. In 1921, except for some development work, no ore was mined domestically and not a single concentrator was in operation. The likelihood of a tariff kept foreign ores coming in but at prices that by the end of the year dropped to \$2.00 for Chinese ores and concentrates and \$2.50-\$3.00 for Bolivian. The dormancy of the domestic tungsten industry continued through 1922, although world production exceeded the pre-1912 level.

The agitation for a tariff which began in 1916 finally resulted in the passage of the Fordney-McCumber Tariff Act, effective September 22, 1922, which imposed a duty of \$7.14 per short-ton unit. Prices quoted

at \$1.80 for wolframite in the spring of the year (see table VIII-1) rose to \$8.00-\$8.50, but even with this added inducement domestic mining remained idle for practically the next 2 years.

Technological changes also delayed the return to normal conditions; a tool bit mounted on a tool holder was found to do about as much work as a larger tool made entirely from tungsten steel. However, the keener competition which forced toolmakers to carry large stocks on hand for immediate delivery counteracted somewhat the dropoff of tungsten consumption due to tool-size change. Because of large reserves and civil war in China in 1924, no imports entered this country. However, China still dictated prices in 1923-24. Chinese wolframite in New York sold for \$7.50-\$9.25 per unit, and good scheelite for \$8.50-\$10.00. In comparison, London prices for wolframite concentrates carrying 65% WO₃ dropped from 13s. 6d. per long-ton unit in the beginning of 1923 to 9s. 6d. by the end of 1924; or with the shilling at 23¢, an equivalent of \$2.83 to \$1.95 per short-ton unit.

Inflation, 1925-1929

The period 1925-1929 was generally prosperous for industry. Imports of tungsten

ores and concentrates for consumption increased from zero in 1924 to 854,000 pounds (tungsten content) in 1925 and to 5,974,000 pounds by 1929. (See table I-1.) However, shipments from domestic mines for the same period decreased from 1,133,000 pounds (tungsten content) to 790,000 pounds, undoubtedly because of the low prices which prevailed at the time.

By 1929 new sintered tungsten carbide tools, about which there was some interest in the early twenties, attracted wide attention. Among the several varieties which appeared on the market were carboloy (Carboloy Co.), widia (Krupp Co. in Germany), dimondite (Firth Sterling Co.), hastellite (Haynes Stellite Co.), and strauss metal (Ludlum Steel Co.).

Depression, 1930-1932

Despite the worldwide business depression which began in late 1929, the domestic tungsten industry remained fairly active until 1932. Domestic mines in 1931 doubled their 1930 output and exceeded the production of any of 10 previous years, due undoubtedly to the increase in tariff on imported ores and concentrates from \$7.41 to \$7.93 a short-ton unit of WO_3 , effective June 18, 1930. On the other hand, foreign ore imports, Chinese in particular, fell off. However, the continued depression brought about almost complete collapse in the steel industry, which consumed over 90 percent of the tungsten output, and resulted in a drop of concentrate shipments from domestic mines from over 1 million pounds of contained tungsten in 1931 to slightly under 400,000 in 1932.

Rearmament, 1933-1938

During the period 1933-1938, business and industry gradually recovered from the depression. Total supply (sum of shipments from mines plus imports for consumption) of tungsten ores and concentrates reflected the upswing. From the 1932 low of 469,000 pounds (tungsten content), tungsten supply jumped to 1 million pounds in 1933. The European armament race that began in 1935 pushed industrial production to 9 million pounds in 1937. However, the 1938 business recession caused total supply to drop to 3 million pounds.

Both imports and domestic mine shipments of tungsten reacted to these swings in industry. Imports of tungsten ores and concentrates, which had increased rapidly from 310,000 pounds (tungsten content) in 1933 to a high of 5.5 million pounds in 1937, dropped precipitously to 163,000 pounds in 1938. The largest portion of this decrease, or 69 percent, represented the loss of imports from China caused largely by the disruption of Chinese commerce due to the Japanese invasion in mid-1937. Domestic mine shipments of tungsten ores and concentrates increased from 852,000 pounds (tungsten content) in 1933 to 3.3 million pounds in 1937, then slumped to 2.9 million pounds in the business recession of 1938.

Tungsten prices began a slow recovery in 1933 from the low of 1932, and rose steadily through 1937 before leveling off in 1938. (See tables I-1 and VIII-1.) The average annual price of tungsten concentrates rose from \$9.20 in 1932 to a high of \$19.50 in 1937 and then dropped to \$17.31 in 1938.

WORLD WAR II

The low rate of steel production during the first 8 months of 1939 contributed to a lessened demand for tungsten. The abrupt increase in domestic industrial activity during the closing months of 1939 with the outbreak of war, however, brought about increasing demand for tungsten.

During the wartime period the United States was one of the world's principal producers of tungsten. Shipments from mines in 1939 reached a high of 4 million pounds (tungsten content), the highest recorded for any previous year since World War I. Mine production during the closing months of 1939 gave added impetus to the development and re-equipment of properties

in the Western States. Prospects of Government purchases for strategic stockpile purposes provided additional incentive.

The Strategic Materials Act, Public Law 117 (53 Stat. 811), 76th Congress, signed by the President on June 7, 1939, authorized the expenditure of \$100 million over a 4-year period for the purchase of strategic materials for the accumulation of a stockpile. Purchases were to be made by the Procurement Division of the Treasury (procurement was later transferred to Metals Reserve Company, a subsidiary of the Reconstruction Finance Company).

Purchases of tungsten ores and concentrates authorized by the Strategic Materials

Act of 1939 continued through 1940. In June 1940, the Reconstruction Finance Corporation agreed to purchase a large tonnage of Chinese tungsten ore at the ports of Haiphong and Saigon, Indochina, which the Chinese Government wished to move to the United States before shipment could be stopped. Later in the year, Metals Reserve Company arranged to accept \$30 million worth of tungsten ores and concentrates from China in payment for a loan by the Export-Import Bank. In January 1941, another Chinese loan was arranged to be repaid in tungsten, antimony, and pig tin.

Tungsten supplies and industry stocks in early 1941 were insufficient for the demands of the national defense program partially because of the closing of the Burma Road from July 18 to October 17, 1940. Therefore, in February 1941 the President ordered both the Procurement Division of the Treasury Department and the Metals Reserve Company to sell stockpile tungsten to industry. Tungsten output was increased in 1941 through the adoption of the ultraviolet lamp for scheelite prospecting and a chemical process for tungsten recovery in low-grade ores. Of metallurgical interest was the development in 1941 of a high density W-Ni-Cu alloy for radium therapy, electric contacts, and the like.

In February 1942, the Metals Reserve Company was given the task of stimulating domestic tungsten production to still greater efforts in order to meet wartime requirements and a program was laid down to accomplish that purpose. Special representatives were sent throughout the Western

States to promote greater production. Purchase depots were established in Arizona, California, Colorado, Nevada, New Mexico, and South Dakota where mines could quickly dispose of small lots of tungsten ores and concentrates and receive prompt payment according to the price schedule of the Metals Reserve Company's purchase commitments.

In April 1942 it was announced that until December 31, 1943, the Metals Reserve Company would pay \$24 per short-ton unit of 60% WO₃ to small producers operating at maximum capacity. The program was later extended to December 31, 1944, and the price increased to \$30 per unit. Ore as low as 1% WO₃ was accepted in 10-ton lots; ore containing in excess of 3% WO₃ was accepted in lots as small as 1 ton.

In May 1942, the Defense Plant Corporation began construction of a 100-ton chemical treatment plant at Salt Lake City, Utah, to treat low-grade concentrates not amenable to ordinary milling methods. This plant provided a market for low-grade material which previously had no outlet in this country, and was instrumental in the production of over 5 million pounds of usable tungsten. The United States Vanadium Corporation operated this plant as agent for Metals Reserve Company. The Metals Reserve Company on April 30, 1944, discontinued its premium-price payments for domestic tungsten and suspended operations at the Salt Lake City re-treating plant. This action, and the subsequent closing of a number of mines, contributed to the decrease in mine production which followed in 1945.

THE POSTWAR PERIOD

Readjustment

The period 1946-1949 was one of readjustment from a war economy to production of peacetime goods. Since tungsten enters mainly into the manufacture of tool steels and munitions, its consumption is very sensitive to changes in industrial activity caused by the demands of war.

In 1946, the first year after the end of World War II, general imports and consumption continued the downward trend for the third consecutive year, bringing about the reduction of operations at most large mines and treatment plants and suspension of many smaller mines and mills. In the fourth quarter, however, there was a sharp increase brought about by the return to the

"18-4-1" type of high-speed steel by manufacturers who had been using the "6-6" type (6% W, 6% Mo, or the molybdenum-type high-speed steel).

On July 23, 1946, Public Law 520 (60 Stat. 596), Strategic and Critical Material Stock Piling Act, 79th Congress, amended the Stock Piling Act, Public Law 117 (53 Stat. 811), of June 7, 1939, and provided for the "acquisition and retention of stocks." These Government-owned stocks were to prevent a dangerous and costly dependence upon foreign nations in time of national emergency.

In the first half of 1947, increased world demand and speculation brought about high tungsten prices. With European competition for South American tungsten concentrates

and increased domestic demand, the price of imported tungsten concentrates rose by mid-June to a peak of \$33 a short-ton unit of WO_3 , duty paid; and domestic scheelite reached \$32 a short-ton unit, delivered. The price on foreign concentrates dropped by the year's end to \$28 due to an improvement in supply and buyers' resistance. Despite high prices and great demand in 1947, domestic mine shipments of tungsten concentrates continued the downward trend that had begun in the year 1943, dropping to 3 million pounds (tungsten content) a decrease of about 40 percent from the 5 million pounds (contained tungsten) shipped in 1946. However, imports remained at about the 1946 level.

In 1948, the great industrial activity expanded the consumption of tungsten, and stimulated imports, domestic mine production, and shipments. Domestic mine shipments rose about 30 percent above 1947's record. Imports increased about 25 percent. Consumption rose to 9 million pounds (tungsten content), or only about 13 percent above the 1947 level.

A downward readjustment of industrial production in 1949 brought a substantial decline in the production of high-speed steels and tungsten powder and reduced the pressure on prices. The price was downward on imported tungsten concentrates, ranging from \$25 to \$18 a short-ton unit of WO_3 , duty paid. Domestic mine shipments declined 30 percent from the 3.8 million pounds (tungsten content) in 1948 to a post-war low of 2.6 million pounds.

Korean Hostilities, 1950-1953

Early in 1950, industry began to revive from the recession of 1949, and the consumption of raw materials such as tungsten began to increase. The outbreak of hostilities in Korea in 1950 resulted in the enactment of the Defense Production Act, Public Law 774, 81st Congress (64 Stat. 798) in 1950. The act placed this country on an emergency basis and preparations were made to increase the production of armaments and munitions for defense needs. Increased industrial production required large quantities of high-speed cutting steels and alloys, and the needs of munitions brought an intense demand for tungsten. To alleviate this condition somewhat, the Strategic Materials Division of the Economic Cooperation Administration, which was provided with funds for the sole purpose of developing strategic mineral properties

abroad, early in the year made substantial loans (around \$1 million) to Portuguese tungsten miners to be used to develop tungsten properties. The loans were to be repaid in tungsten concentrates.

In the third quarter of 1950, China, the chief source of tungsten imports for the United States, decreased exports to this country. General imports of tungsten ores and concentrates from China decreased from 4.9 million pounds (tungsten content) in 1949 to 394,000 pounds in 1950. China was no longer an important source of tungsten for the United States.

The continuation of hostilities in Korea, the growing demand for tungsten, and the loss of supply from both China and Korea led to a rapid increase in the price of tungsten during 1951. London prices ranged from the equivalent of \$50 to \$82 a short-ton unit, whereas the highest price on domestic concentrates was frozen at \$65 by the Office of Price Stabilization (OPS), effective April 6, 1951. With the foreign price of tungsten concentrates at about \$65 (duty extra) or \$72.93 a short-ton unit (duty paid), this action tended to decrease the quantity of imports at a time when they were sorely needed by industry.

On May 1, 1951, the OPS freed from price control tungsten concentrates of foreign origin sold to any agency of the United States Government. General Services Administration (GSA) and the Defense Minerals Administration (DMA) then established a system for resale to industry. The International Materials Conference, established early in the year to cope with international problems relating to scarce materials, took action to reduce the international competitive bidding for tungsten. The price in London as of December 13, 1951, however, was still the equivalent of \$67 a short-ton unit.

To encourage domestic tungsten production, GSA announced on May 10, 1951, a purchase program whereby the Government would buy standard-grade tungsten concentrates at \$65 per short-ton unit for 5 years, or until 1,468,750 units were purchased. On June 20, the program was amended to provide for termination whenever 3 million short-ton units had been delivered, or on July 1, 1956, whichever came first.

Consumptionwise, 1951 was a critical year, with demands exceeding combined production or shipments from mines, and imports. The net result was a drawdown of inventories. (See table VI-4.) To overcome this shortage, drastic restrictions on the use of tungsten were initiated by the Government

through the issuance of Orders MO-4 and MO-6 by the Defense Minerals Administration regarding the allocation of tungsten concentrates; and Orders M-30 (revoked August 15), M-80 (Schedule 3), and M-81 by the National Production Authority, which regulated the allocation and use of tungsten products.

In 1952, output of tungsten ores and concentrates both here and abroad were sufficiently high to meet all tungsten requirements. Plant expansion and opening of new mines were responsible for increased production. This substantial increase augmented world supply to such an extent that international allotments were discontinued after December 1, 1952. (The increased production abroad was in part attributable to the program of Defense Materials Procurement Agency's Foreign Expansion Division, which took over ECA's pre-1952 foreign tungsten projects and expanded purchasing through General Services Administration's Emergency Procurement Service, and in some cases to development programs in such countries as Argentina, Brazil, Bolivia, Korea, Mexico, Peru, Portugal, Spain, and Thailand.

In 1953 an increase in supply of concentrates of 2 million pounds (tungsten content) over the 7 million pounds in 1952 led to removal by the Government of all controls on distribution and use of tungsten. To maintain high production rates and encourage further expansion, Congress extended the termination date of the Domestic Tungsten Purchase Program to July 1, 1958, or until 3 million units were purchased, whichever occurred first.

Year of Plenty, 1954

Increased domestic production and decreased consumption highlighted the year 1954. Consumption fell to the lowest level since 1949, due primarily to decreased industrial demand and overexpanded inventories. Shipment from domestic mines of 13 million pounds (tungsten content) reached an all-time high, attributable to the favorable price of \$63 a short-ton unit on Government purchases, mainly through GSA.

In contrast, foreign production decreased, largely because of declining prices which ranged from 102.5 to 215 s. (\$10.40-\$30.19) per long-ton unit, but also because of termination of purchase contracts. The Republic of Korea, which ranked third in world production in 1953 and was the largest single source for imports for consumption, closed its mines after the expiration of purchase contracts with the United States Government.

TABLE 1-1.--SALIENT STATISTICS OF TUNGSTEN ORES AND CONCENTRATES IN THE UNITED STATES, 1914-1954
(In thousands of pounds of contained tungsten)

Year	Shipments from mines ¹	General Imports	Imports for consumption ²	Apparent consumption ³	Exports ⁴	Total industrial stocks ⁵	Average value per short-ton unit of W ₆₃
1914...	942	775	299	1,717	(²)	.....	\$7.32
1915...	2,219	1,848	1,534	4,067	(²)	.....	29.30
1916...	5,637	4,304	4,097	9,326	615	.....	33.98
1917...	5,847	5,054	4,291	8,412	2,489	.....	18.00
1918...	4,817	12,233	11,646	15,731	1,319	.....	19.24
1919...	311	10,388	9,408	10,658	41	.....	18.02
1920...	206	4,203	1,949	4,404	5	.....	7.86
1921...	.....	2,257	1,614	2,257	0	.....	.....
1922...	.....	2,908	1,651	2,907	1	.....	.....
1923...	229	79	0	304	4	.....	10.00
1924	538	142	0	677	3	.....	8.47
1925...	1,133	1,694	854	2,817	10	.....	16.57
1926...	1,315	2,884	2,535	4,175	24	.....	11.10
1927...	1,108	2,198	2,171	3,290	16	.....	10.37
1928...	1,150	2,969	2,856	4,106	13	.....	10.40
1929...	790	6,446	5,974	7,154	82	.....	13.13
1930...	668	3,998	3,695	4,642	24	.....	12.09
1931...	1,336	189	167	679	846	.....	11.02
1932...	377	106	92	370	113	.....	9.20
1933...	852	379	310	548	683	.....	9.58
1934...	1,950	954	847	2,341	563	.....	14.57
1935...	2,279	892	813	2,373	798	.....	13.37
1936...	2,486	3,767	3,586	6,149	(²)	.....	14.83
1937...	3,331	5,696	5,561	9,027	(²)	.....	19.50
1938...	2,897	162	163	3,059	(²)	.....	17.31
1939...	4,080	3,112	1,485	(²)	(²)	2,952	17.11
1940...	5,062	9,666	5,611	9,955	(²)	2,897	20.61
1941...	6,250	13,153	11,522	16,699	(²)	2,669	23.41
1942...	8,882	15,410	14,326	17,389	8	3,772	24.12
1943...	11,368	18,678	19,445	19,313	1	2,918	25.08
1944...	9,787	18,234	18,396	19,165	0	1,946	23.35
1945...	5,267	8,639	4,774	14,146	2	4,341	23.17
1946...	4,942	6,811	6,869	6,458	37	3,980	20.17
1947...	2,945	9,002	6,018	7,812	148	3,712	23.43
1948...	3,838	9,748	7,548	8,853	394	5,848	26.27
1949...	2,632	7,357	6,274	4,958	97	5,056	26.38
1950...	4,588	8,342	16,147	6,597	6	5,338	28.25
1951...	5,973	7,533	6,377	11,410	0	4,272	61.02
1952...	7,244	16,985	17,406	8,634	10	3,025	63.44
1953...	9,128	28,994	27,683	7,734	12	4,698	63.00
1954...	13,051	22,989	24,132	4,037	37	4,371	63.00
1955...	.....	.....	.....	.....	.....	.....	.....
1956...	.....	.....	.....	.....	.....	.....	.....

¹ Partly estimated.

² Consists of tungsten, metal, wire shapes, ferro tungsten, and alloys. No record of any tungsten ore, or concentrates exported in 1914-1938. Starting in 1942, figures are for ores and concentrates only.

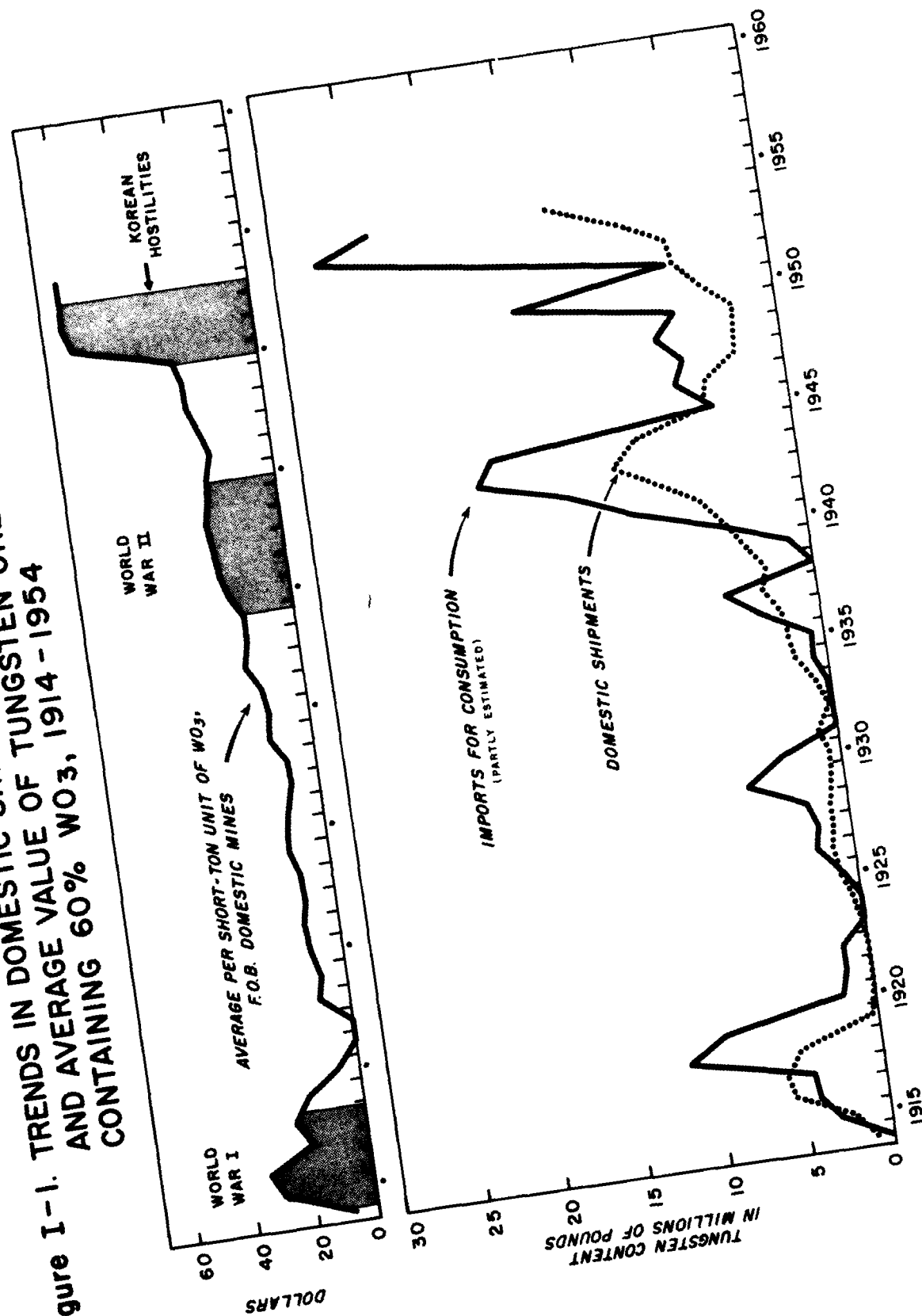
³ Complete data are not available.

⁴ Data for years 1914-38 not available; figures for years 1939-54 do not include Government stockpile.

⁵ After 1939 figures are for recorded consumption.

Source: Mineral Yearbook, Bureau of Mines (published annually).

Figure I-1. TRENDS IN DOMESTIC SHIPMENTS, IMPORTS FOR CONSUMPTION, AND AVERAGE VALUE OF TUNGSTEN ORES AND CONCENTRATES CONTAINING 60% WO₃, 1914 - 1954



CHAPTER II RESOURCES

CHAPTER II RESOURCES

The most important tungsten deposits of the world are largely in quartz veins that contain wolframite (including huebnerite and ferberite) with a little scheelite and, less commonly, scheelite alone. Contact metamorphic scheelite deposits are of secondary world importance. Of lesser significance are scheelite and wolframite placer deposits, tungsten minerals in pegmatite, tungsten-bearing iron and manganese oxides, and disseminated tungsten minerals in igneous rocks.

The United States currently produces about 3 times as much scheelite as wolframite. Inasmuch as the 2 types of ores are not completely interchangeable for specialized uses, the supply and demand must be balanced by imports of wolframite.

Quartz veins containing minerals of the wolframite group and scheelite are the most common occurrence of tungsten. The veins range from thin seams to massive veins many feet wide and are commonly found in granitic rocks or are closely associated with granitic rocks. Cassiterite (tin oxide) is in some places also present in the wolframite-bearing quartz veins. The tungsten minerals are irregularly distributed in the veins, but locally veins a foot or more in width are almost entirely composed of tungsten minerals. The pockety occurrence of the tungsten minerals makes grade prediction and reserve calculation difficult, especially in mines in the early stages of development. The WO_3 content in active mines ranges from 0.25 to more than 10 percent, usually averaging 0.5 to 1 percent.

Contact metamorphic deposits are not as important as quartz veins on a worldwide basis, but several large producers are of this type, including San Dong, Korea; King Island, Australia; and Pine Creek, Calif.

Scheelite is generally the only tungsten mineral in these deposits, and it is almost invariably found in tactite, a rock formed chiefly by the alteration of limestone or marble near intrusive granitic rocks. Tactite is a distinctive, dark colored, heavy metamorphic rock composed chiefly of one or more of the following minerals: Garnet, pyroxene, epidote, amphibole, and quartz. Tactite is not present at all intrusive contacts between marble and granitic rocks, and much tactite does not contain scheelite. Most scheelite is disseminated in tactite, but some is localized by bedding and fractures. The WO_3 content of contact deposits ranges from 0.2 to several percent, and the average grade of the deposits worked is probably about 0.5 percent WO_3 .

Detailed information on the geology of tungsten deposits can be obtained from the literature cited in the list of references for this chapter cited in the bibliography, Chapter XI.

World resources of tungsten in measured, indicated, and inferred ore are estimated at about 175 million short ton units¹ of WO_3 . The deposits of China account for 77 percent of this estimate and are about 15 times greater than those of the nearest competitor, the United States. These estimates of reserves are at best speculative, being based on information of variable reliability and on interpretations using different premises. Estimates of reserves in individual countries are given in table II-1 and locations of the principal deposits or regions are shown in figure II-1.

In past production the United States ranks second to China. The United States is the world's largest consumer of tungsten but is not self-sufficient, although production peaks have exceeded consumption lows.

UNITED STATES DEPOSITS

The principal reserves of tungsten ore in the United States are confined to a few properties: Pine Creek Mine, California; the Mill City, Osgood Range, Tern Piute and Rawhide districts, Nevada; the Ima

Mine, Idaho; the Hamme district, North Carolina; the Browns Lake deposit,

¹A short-ton unit is 20 pounds of WO_3 . Rock assaying 1 percent of WO_3 contains 1 unit per ton.

Montana; and the Climax Mine, Colorado. The balance of the significant reserves is distributed through 30 smaller properties. All told, more than 1,000 tungsten occurrences are known in the United States.

TABLE II-1. WORLD TUNGSTEN RESERVES IN 1954
(Estimated units of tungsten trioxide in measured, indicated, and inferred ore)

	Short-ton units WO ₃
Argentina.....	500,000
Australia.....	1,600,000
Bolivia.....	5,500,000
Brazil.....	2,500,000
Burma.....	4,800,000
Canada.....	1,000,000
China.....	134,500,000
England.....	400,000
France.....	150,000
Indochina.....	300,000
Japan.....	100,000
Korea.....	7,000,000
Malaya.....	1,400,000
Mexico.....	150,000
Nigeria.....	Small
Peru.....	550,000
Portugal.....	2,000,000
Southern Rhodesia.....	100,000
Spain.....	650,000
Sweden.....	Small
Tanganyika.....	Small
Thailand.....	500,000
United States.....	9,000,000
U.S.S.R.....	1,700,000

The estimated tonnage and grade of ore reserves in the United States are given in table II-2. No deduction has been made for mining or metallurgical losses, which are within the limits of error of the ore estimates.

Wolframite-type minerals (huebnerite, wolframite, and ferberite) are produced from the Hamme district, N. C.; Boulder County and Climax, Colo.; Black Pearl, Ariz.; and Ima, Idaho. Wolframite has also been produced from other deposits, including Boriama, Las Guijas, and Little Dragoon, Ariz.; Tungstania and Hub, Nev.; Germania, Wash.; Black Hills, S. D.; and Silverton, Colo. Only small future production is expected from these minor districts.

Of a total United States production of about 8.2 million units of WO₃ from 1900-1951, about 28 percent was wolframite-type and the remainder scheelite. Current United States production is about 25 percent wolframite. In the past, relative proportions of the two types of concentrates ranged widely, from predominant wolframite-type during 1900-1916 when Boulder County, Colo., was the principal producer, to greatly predominant scheelite in the period 1924-45 before large production started at Hamme and Climax.

The locations of the principal tungsten deposits of the United States are shown in figure II-2, with symbols indicating the approximate magnitude of reserves.

Boulder, Atolia, and Yellow Pine districts, which produced nearly half the total United States output prior to 1948, now have only small reserves and little promise of important future production. New discoveries must be made to replace output from these districts if United States production is to be maintained at the 1954 rate for very long. It is notable that although 2 of the 6 major tungsten districts of the United States (Yellow Pine and Hamme) were discovered and developed in the period 1940-1945, no major discoveries have resulted from the post-1950 expansion of tungsten production.

The lowest grade ore to be worked profitably in the United States contained about 0.25 percent of WO₃ and sold in 1954 at \$63 per short-ton unit of WO₃. To make such satisfactory recovery from such low-grade material, large tonnages must be available for treatment in expensive plants.

Submarginal ore containing 0.1 percent or less of WO₃ is present at Climax, Colo.; Henderson Gulch, Mont.; and Cunningham Hill, N. Mex. Substantial byproduct production has been made from the Climax molybdenum mine since 1948, and will doubtless continue in the future. The reserves at Climax are listed as inferred only because the content of WO₃ is not accurately known, even though the reserves of molybdenum ore are proved. At Cunningham Hill and Henderson Gulch, only limited exploration has been done and the technology of production has not been worked out; it appears that costs of profitable production would be several times the 1954 price of tungsten. For such low-grade material, only a relatively small part of the contained tungsten can be recovered in any foreseeable metallurgical process.

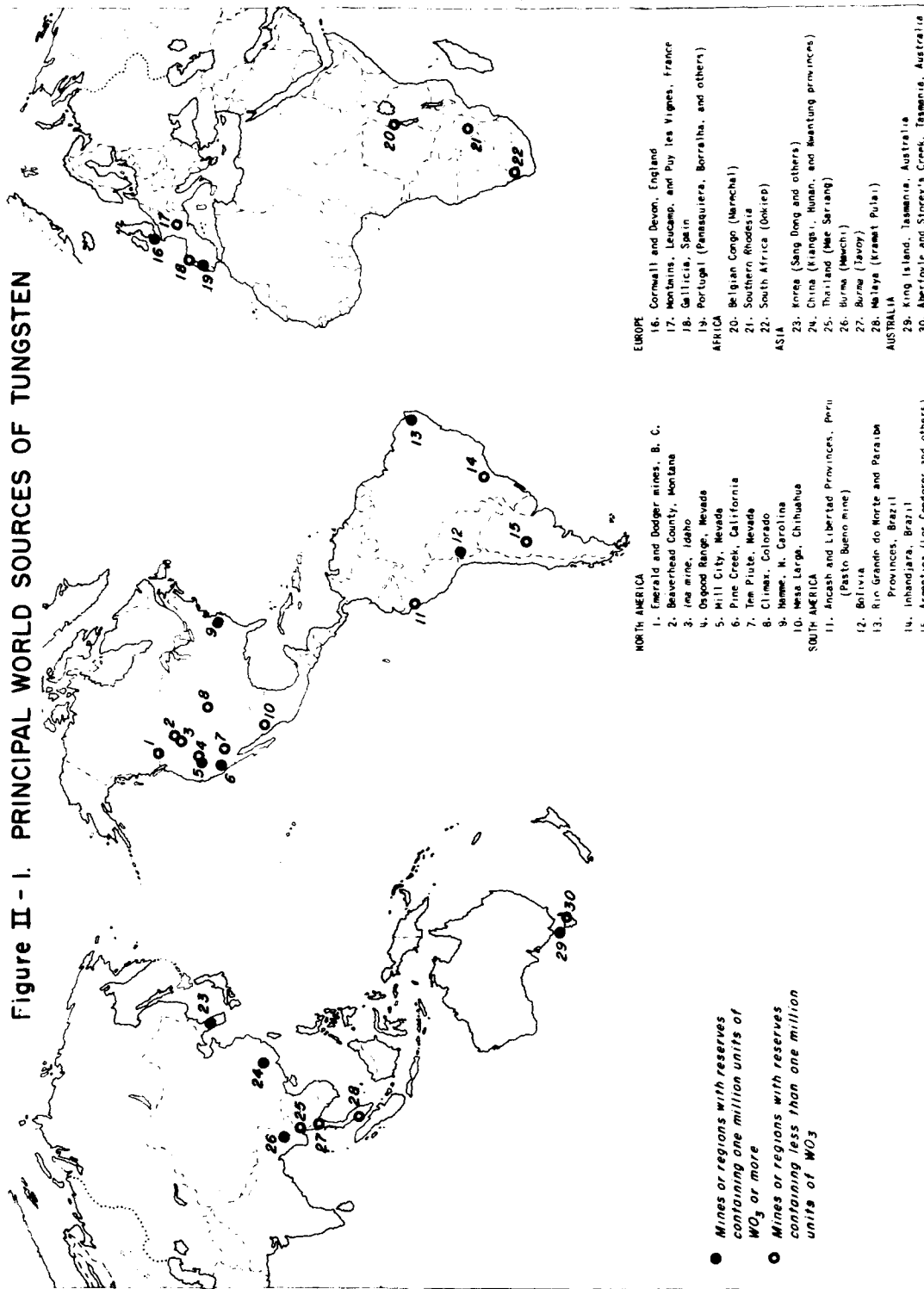
TABLE II-2. TUNGSTEN RESERVES OF THE UNITED STATES, BY GRADE OF ORE, 1954
(In short-ton units of WO₃)

Grade	Measured and indicated	Inferred
1.0% WO ₃ plus.....	130,000	140,000
0.5% WO ₃ to 1.0%.....	3,200,000	3,900,000
0.1% WO ₃ to 0.5%.....	900,000	850,000
Totals.....	4,230,000	5,190,000
Submarginal ore (from part of which production can be made as byproduct).....		
0.01% to 0.10%.....		1,500,000

Alaska

No important tungsten deposits have been developed in Alaska, although perhaps a dozen or more tungsten occurrences are known. Total shipments from 1900 through

Figure II - I. PRINCIPAL WORLD SOURCES OF TUNGSTEN



1949 were only 10,620 units of WO_3 , derived principally from the Riverside Mine near Hyder, southeastern Alaska, and from the Stepovich Mine at Gilmore Dome, northeast of Fairbanks.

The Gilmore Dome deposit is a contact-metamorphic replacement of a limestone bed in schist. The ore is lenticular, with perhaps 200 tons per lens, is thin, averaging about 1 foot, and has a WO_3 content of about 1.5 percent. The dip is 20° to 40° . The ore mineral is scheelite.

Wolframite occurs in minor quantities at the Lost River tin deposit on the Seward Peninsula. The tin concentrates contain about 2.5 percent WO_3 , but as the tonnage of such concentrates is small, the tungsten output and reserve is negligible.

At the Riverside Mine, scheelite and galena with some silver and gold are present in a quartz vein that has an average width of about 3 feet. Despite considerable exploration in a vertical range of 700 feet and a length of 1,500 feet, less than 2,000 units of WO_3 was produced.

Arizona

Although more than 80 occurrences of tungsten minerals are known in Arizona, important production has been made from only 5 districts. The Borianna Mine in Mohave County at the end of 1945 had yielded far more than the combined output from the rest of the State, and also had much larger inferred reserves. The Campo Bonito, Little Dragoon, Las Guijas, and Huachuca districts yielded 12,000 to 25,000 units apiece over a period of many years, largely from a single mine in each district. The reserves at these properties are not large, although the Campo Bonito area offers opportunities for developing ore. The multitude of small prospects in the State gives little promise of much production. Many of them have yielded a few units, and probably will make small outputs in the future.

The Borianna Mine, Mohave County, idle and under water since 1943, produced wolframite and scheelite from narrow quartz veins in schist. Reserves, largely inferred, are estimated at 56,000 tons containing 59,000 units along the downward rake of the ore shoot. The Black Pearl Mine in Yavapai County is little developed but has a chance of becoming a substantial producer. Reserves of quartz-huebnerite ore containing 0.7 percent of WO_3 are substantial to shallow depths and might be

increased several fold by deeper exploration.

The Morning Star and Pure Gold Mines in the Campo Bonito area of the Old Hat district, Pinal County, contain fine-grained scheelite in quartz which averages about 1.6 percent of WO_3 .

California

Tungsten mineralization is widespread in California, principally in connection with the Sierra Nevada batholith and other intrusive rocks of southeastern California. The principal productive areas are the Atolia and Bishop districts and the west slope of the Sierra Nevada in Madera, Fresno, and Tulare Counties.

Atolia district.--Cumulative past production from Atolia is more than 1 million units of WO_3 , greater than that of any other district in California and third largest in the Nation. Ore reserves are now small and the district is not likely to make a large future output.

The tungsten deposits consist of scheelite in quartz veins in quartz monzonite. Most of the ore shoots are shallow and were worked out within a few hundred feet of the surface. At the Union Mine, ore was produced to a depth of 1,000 feet. The ore was of high grade, averaging about 4 percent of WO_3 .

About 10 percent of past production came from placer deposits on the pediment slopes below the veins. Because the deposits are in a desert where water is scarce and expensive, only the richer parts of the placer were workable, and many million cubic yards containing up to a quarter of a pound of WO_3 per cubic yard remain unworked.

Bishop district.--The tungsten deposits of the Bishop district contain the largest known ore reserves in the United States, principally in the Pine Creek Mine of U. S. Vanadium Corporation. The deposits are of contact metamorphic origin and consist of scheelite in tectite. The content of WO_3 is in general 0.3 to 1 percent.

The Pine Creek Mine is opened to a depth of 2,250 feet beneath the outcrop, which is at an altitude of 11,500 feet. The tectite ore averages about 0.45 percent of WO_3 . In the upper third of the ore zone, molybdenite and powellite content was equivalent to about 1.0 percent of MoS_2 ; the ore also contained about 0.2 percent of Cu, and the copper concentrate contained silver. The molybdenum content

decreases with depth and is much less important in the lower workings. The quantity of ore below the deepest mine level is unknown.

The Black Rock Mine in Mono County, 50 miles north of Bishop, is now producing a substantial tonnage of ore containing about 0.6 percent WO_3 from scheelite-bearing tactite. Reserves are limited but considerable exploration and development is being done from underground, and additional ore may be located.

Other deposits in the Bishop region that contain some reserves of tungsten ore include the Adamson, Brownstone, Hanging Valley, Lakeview, and Hilton Creek. It is also probable that additional ore will be found in the Tungsten Hills near Bishop, especially in the Round Valley Mine.

Western slope Sierra Nevada.--The Strawberry Mine (Fresno Mining Company) in Madera County has small reserves of good-grade scheelite ore in tactite. The three small productive deposits, now opened with shallow workings only, have not been explored sufficiently at depth to show the ultimate reserves.

The Tungstore, Big Jim (Tulare County Tungsten Mines), Garnet Dike, and Consolidated tungsten mines are largely depleted. The Mud No. 7 deposit has a moderate reserve of scheelite-bearing tactite.

Many small deposits are known in Kern, Tulare, Fresno, Madera, Mariposa, Tuolumne, and El Dorado Counties. In general the content of WO_3 is too low to permit hauling to distant mills, and the tonnage available is too small to warrant mills at the prospects.

Other deposits.--Contact-metamorphic scheelite deposits at Darwin are largely depleted but contain small ore reserves. The Starbrite tactite deposit 25 miles north of Barstow is of good grade but is largely depleted. Small deposits with little ore reserves include those in the Panamint Range, New York and Providence Mountains, Old Woman Mountains, Cargo Muchacho district, and in San Diego and Riverside Counties. The Alpine Mine in Hope Valley, Alpine County, contains a small reserve that will soon be depleted, but indications are good that exploration will yield a moderate reserve at the nearby Valpine Mine. A small amount of scheelite occurs in parts of the gold-quartz veins of Grass Valley.

Colorado

The principal tungsten production in Colorado is from the Climax molybdenum mine, where huebnerite is recovered as a byproduct from molybdenum ore. The content of WO_3 in the ore is only a few hundredths of a percent and only a rather small part of this is recovered. The reserves of molybdenum ore are very large, and consequently the total amount of tungsten in reserves is large, although each ton of ore mined yields only a very small amount of tungsten.

The ferberite deposits of Boulder County were the largest source of tungsten in the United States from 1900 to 1919. The greatest annual output, 162,420 units of WO_3 , was made in 1917. From 1919 to 1952, some production was made each year except 1921-22 and 1932, and a maximum of 41,580 units was reached in 1940. Although the district has not been a major source of tungsten since 1918, the total output through 1945 was 1,457,000 units of WO_3 , the greatest of any district in the United States.

The ferberite occurs as small, high-grade shoots in narrow quartz veins. The content of WO_3 in ore has ranged from 1 to 20 percent and averaged about 8 percent. Most of the veins are 6 to 36 inches wide, but veins of solid ferberite as narrow as 1 inch have been mined, and a few stopes have been opened to widths of 16 feet where ore occurred in anastomosing veins.

More than 155 ore shoots were found in the Boulder district between 1900 and 1945. Most of the shoots were mined out within 100 feet of the surface and only the Conger ore shoot, the largest in the district, extended as deep as 575 feet. A number of blind ore shoots that did not extend to the surface were found by underground exploration in a few of the larger mines, and the probable presence of other blind shoots provides the principal chance for future production from the district.

Known ore reserves in the Boulder district are very small and the chance of making important discoveries is poor.

Small amounts of huebnerite ore are present in the Silverton and Telluride districts, San Juan and San Miguel Counties, and on the east side of the Mosquito Range, Park and Summit Counties.

Idaho

The Ima Mine, Lemhi County, and the Yellow Pine Mine, Valley County, are the only important tungsten deposits in Idaho, although many others are known.

The Ima Mine has large reserves of quartz-huebnerite ore with minor scheelite, and has good prospects for discovery of additional ore in geologically favorable ground extending out from present workings. The ore also contains tetrahedrite, galena, sphalerite, chalcopyrite, rhodochrosite, and fluorite, and the sulfide concentrate is valuable for silver, copper, lead, and zinc. The content of WO_3 is about 0.5 percent, and about 1 ton of sulfide concentrate is recovered for every 25 tons of ore treated. Sulfide concentrates shipped in 1940 contained 44.6 ounces Ag per ton, 3.5 percent Cu, 6.9 percent Pb, 4.8 percent Zn, and 0.01 ounce Au.

The Yellow Pine Mine was the largest domestic source of tungsten and antimony during World War II and yielded 825,970 units of WO_3 from time of discovery in 1941 to the end of 1945. The tungsten ore body was exhausted and the only tungsten reserves left are in the antimony ore which contains a little tungsten, and in the mill tailings. The tungsten ore mineral is scheelite. The tungsten ore body was a filling and replacement of brecciated quartz monzonite near the major fault zone. Ore reserves are small, but all possibilities of discovering additional tungsten ore in the area have not been exhausted.

Missouri

Wolframite accompanies silver-lead minerals in quartz veins near Silver Mine 9 miles west from Fredericktown, Madison County, Mo. Total output is only about 2,200 units, reserves are negligible, and chances for new discoveries are poor.

Montana

Prior to 1954, a little tungsten was produced in Montana from the Jardine Mine and the Henderson Gulch placer, at both of which scheelite was recovered as a by-product of gold mining. In 1954 the Browns Lake deposit, northwest of Dillon, in Beaverhead County, came into production. Minerals Engineering Company, the operator, reported that the ore body con-

tains 825,000 tons of tactite averaging 0.39 percent WO_3 , according to Mining World (January 1955).

At the Combination Mine northwest of Philipsburg, Granite County, a little huebnerite is present in a narrow, gently dipping quartz vein formerly worked for silver. The vein is 1 to 2 feet thick and contains about 13.9 ounces Ag, 0.015 ounces Au, 0.89 percent Pb and 0.86 percent Cu.

Nevada

Nevada was the leading tungsten-producing State from 1925 through 1939 and from 1945 through 1947. The most important deposits are the contact-metamorphic ore bodies in the Eugene Mountains (Nevada-Massachusetts Company), the Osgood Range (Getchell Mine, Inc. and U. S. Vanadium Corporation), the Rawhide district (Nevada Scheelite Company) and the Tem Piute district; the quartz-scheelite veins of the Minerva district; and the tungsten-manganese deposits at Golconda. Tungsten deposits are reported from 16 of the 17 counties of Nevada. Many possibilities exist for finding additional ore at known deposits and for finding new deposits in Nevada.

Eugene Mountains.--The deposits worked by the Nevada-Massachusetts Company in the Eugene Mountains, Pershing County, have yielded more than 1 million units of WO_3 and have good geologic possibilities of an equivalent future production from downward extensions of known ore bodies. The scheelite deposits occur in tactite replacing thin beds of limestone in a thick hornfels sequence. The content of WO_3 in ore mined ranges from 0.3 to 2 percent, and currently averages about 0.45 percent. The ore bodies are remarkably continuous laterally and vertically, and the bottom limit has not been reached. The deepest workings, those in the Humboldt Mine, are 1,700 feet on the dip or 1,420 feet vertically below the collar of the shaft. The thickness of ore mined ranges from 2 to 25 feet, and the lateral extent of ore shoots is up to 1,200 feet.

Osgood Range.--The tungsten deposits of the Osgood Range are distributed about the periphery of a granodiorite stock which has invaded argillite with interbedded limestone layers a few inches to several hundred feet thick. The ore bodies consist of scheelite-bearing tactite containing 0.2 to 0.8 percent of WO_3 . The lower limit of material mined is currently about 0.3 percent of WO .

The principal ore reserves are in the Riley mine of U. S. Vanadium Corporation and the Granite Creek Mine of Getchell Mine, Inc. Eight other deposits have been worked on a small scale.

Rawhide district.--The Nevada Scheelite Mine is opened to a depth of 400 feet through a vertical shaft. The ore body consists of scheelite in tactite at the contact between granite and limestone. The primary ore contains pyrite and a little chalcopyrite. In the oxidized zone, which extends to a depth of more than 200 feet, the sulfides are changed to a limonite gossan which apparently contains some of the tungsten in the mineral ferritungstite. The content of WO_3 ranges from 0.65 to 1.5 percent. The ore reserves are substantial.

Tem Piute district.--At the north end of the Tem Piute Range tactite is present for a length of 6,000 feet along the west side of a granitic stock in concordant contact with limestone. Scheelite is present in only part of this tactite, which forms a band 15 to 110 feet thick directly at the contact, and also exists as irregular masses extending as much as 450 feet away from the granite. In the Lincoln Mine, at the north end of the zone, ore containing as much as 1.0 percent of WO_3 was mined. Elsewhere, very large tonnages contain 0.2 to 0.4 percent WO_3 . It is known from mine workings and drill holes that the deposits extend to a depth of at least 600 feet. The geologic setting suggests that they may be thousands of feet deep.

Minerva district.--Quartz veins with scheelite, in limestone country rock, have been worked in the Minerva district, Snake Range, White Pine County. The deposits contain 0.5 to 1.5 percent of WO_3 and occur in ore shoots of small vertical extent but great lateral continuity. The veins are broken by many faults that complicate mine exploration and development. Geologic possibilities exist for discovery of additional ore.

Golconda.--At Golconda, Humboldt County, tungsten is present in notable quantities in ferruginous and manganiferous fanglomerate. The content of WO_3 in the high-grade portion was as much as 7 percent. The tungsten cannot be concentrated mechanically and must be recovered by chemical digestion. In 1940-45, Rare Metals Corporation, affiliate of the Nevada-Massachusetts Company, recovered about 100,000 units of WO_3 from material containing more than 0.8 percent of WO_3 . Material containing less than this quantity could not be

worked because of the high cost of chemical treatment. Large reserves of submarginal material containing about 0.5 percent of WO_3 remain in the deposits.

Other deposits.--At the Victory Mine of Gabbs Exploration Company, a scheelite ore body about 200 feet long and up to 50 feet wide replaces granite several hundred feet distant from a limestone contact. The ore averages about 0.75 percent of WO_3 and has been explored to depth of several hundred feet. The bottom limit is unknown.

Tactite deposits containing 0.3 to 0.5 percent of WO_3 , with appreciable reserves, exist in the Nightingale district, Oak Spring district, Pilot Mountains, and at the Black Horse mine in Esmeralda County.

At Tennessee Mountain, Elko County, scheelite-bearing tactite deposits have been explored only slightly, and have possibilities for considerable tonnage of low-grade ore.

In White Pine County, quartz-huebnerite veins at Tungstonia and scheelite-calcite pipes at Cherry Creek contain small reserves. Unexplored scheelite-bearing tactite at Monte Cristo, White Pine Range, has possibilities of substantial tonnage containing 0.3 to 0.5 percent of WO_3 .

New Mexico

None of the known tungsten occurrences in New Mexico contain workable tungsten ore bodies of importance.

At Cunningham Hill on the Ortiz Mine grant, Sante Fe County, scheelite is present in small quantities in clastic breccia that crops out over an area of 30 acres. The breccia appears to be a pipe-like, steep-sided body that extends to several hundred feet in depth and contains many tens of millions of tons of material. Preliminary investigation suggests that as much as 50 million tons might contain 0.05 to 0.08 percent of WO_3 .

North Carolina

The Hamme district, developed since 1943 by the Tungsten Mining Corporation, is now the largest producer of huebnerite in the United States, and in 1953 and 1954 the Hamme Mine was the leading producer of tungsten concentrate in the United States. From 1943 to 1951 inclusive, production amounted to more than 300,000 units of WO_3 from ore that averaged about 0.8 percent of WO_3 . In 1954, production at the Hamme mine was 153,000 units of WO_3 . About 90

percent of the concentrate is huebnerite and the remainder is scheelite.

In the Hamme Mine huebnerite and minor scheelite are present in lenticular quartz veins as much as 40 feet wide, in granite. The largest veins are parallel to a shear zone that extends for several miles. Development work in the lowest levels of the mine has shown that the ore is persistent.

The mines of the district were partially explored to a depth of 500 feet by 1951 without reaching any downward limit to mineralization. Two shafts have been sunk at the Hamme Mine to below 1500 feet to permit development on 4 more levels at 200 foot vertical intervals. The ore reserves are large and probably will be increased by future exploration. The district will rank in ultimate production as one of the major tungsten districts of the United States.

South Dakota

Past tungsten production in South Dakota came principally from replacement deposits of wolframite in Cambrian dolomite near Lead. These deposits were worked out by the Homestake Mining Company.

Utah

No important tungsten deposits have been discovered in Utah, and the total past pro-

duction of the State is not large. The Gold Hill district made the largest output, followed by the West Tintic, Grouse Creek, and San Francisco districts. Small shipments were also made from the House Range and the Mineral Range.

Washington

The only tungsten mine in Washington of past importance is the Germania, which produced about 75,000 units of WO_3 from a quartz vein containing wolframite and associated minerals. It appears that no ore reserves remain in this mine.

Tungsten minerals are recorded from at least 60 localities in the State, and small outputs have been made from 10 of these in addition to Germania. Total known ore reserves are insignificant.

Wyoming

Noncommercial occurrences of scheelite have been found in 5 districts in Wyoming. The best prospects are in the Copper Mountain district, Fremont County, where small lenses of scheelite-bearing quartz-zoisite rock contain 1 to 3 percent of WO_3 . It is not likely that the district contains more than a few thousand tons of this material, distributed in 15 prospects.

OTHER NORTH AMERICA

Canada

The largest known tungsten deposits in Canada are the Emerald and Dodger ore shoots of Canadian Exploration Ltd., at Salmo, British Columbia. The ore consists of scheelite in massive pyrrhotite with quartz, calcite, and biotite. The ore shoots are replacements of limestone in gently-tilted synclinal troughs near a granitic contact. The Dodger ore shoot appears to be about 7,000 feet long. Ore reserves in January 1954 were estimated at 515,000 tons averaging about 0.9 percent of WO_3 .

Veins containing wolframite are present 10 miles from Atlin, British Columbia, approximately 60 miles east from Skagway, Alaska. Reserves of indicated ore were estimated in 1951 by engineers for Transcontinental Resources, Ltd., to be 58,000 tons averaging 1.3 percent of WO_3 .

The Red Rose Mine of the Consolidated Mining and Smelting Company of Canada, Limited, in British Columbia, was leased

to Western Tungsten Copper Limited in 1951, and a 75-ton mill was placed in production at the end of the year. Scheelite and some ferberite are contained in a steep quartz vein. Reserves as of June 30, 1953, were estimated by the company to be 123,000 tons averaging 1.7 percent WO_3 .

The Burnt Hill tungsten mine in New Brunswick was equipped with a 150-ton mill in 1954. The ore is wolframite in a quartz vein.

The Hollinger Mine in the Porcupine district, Ontario, contains scheelite in parts of the gold-quartz veins. Reserves of ore from which tungsten production is planned were estimated at the end of 1951 to be 15,000 tons from which 0.325 percent of WO_3 (4,875 units) could be recovered. Small amounts of scheelite are present in many other gold mines of Ontario and Quebec, but apparently not in significant quantity.

Total Canadian reserves are estimated at 1 million units of WO_3 .

Cuba

Ferberite and a little scheelite are present in narrow quartz veins on the Isle of Pines, Cuba. The deposits appear to be small and of low grade, and give little promise of significant production. Despite considerable expenditures on the property, total production to 1952 was only a few thousand units of WO_3 .

Mexico

The small tungsten production of Mexico has come from Lower California, Sonora,

and Chihuahua. Ore reserves in Southern Sonora were estimated in 1945 to be 50,000 tons averaging 1.2 percent of WO_3 , largely in contact metamorphic deposits, partly in quartz veins. The known deposits in Lower California (El Fenomino Mine) were worked out by 1944. The Mesa Larga deposit in Chihuahua consists of scheelite and wolframite in placer and in quartz veins in grandiorite. The deposits were first worked in 1950, and production in 1951 was at the rate of 350 to 400 metric tons yearly of 65 percent WO_3 concentrates (23,000 to 26,000 short-ton units).

AFRICA

Angola

Wolframite is reported from the Ganda area of Benguela Province, Angola. No production has been made and the deposits are insufficiently developed to permit evaluation.

Belgian Congo

Tungsten production in the Belgian Congo started in 1940 and in 1947 reached a maximum of 44,000 units of WO_3 , which is approximately the current rate of output. The principal production is wolframite, in part associated with cassiterite, mainly from eluvial deposits but in part from veins in granite. The Marechal Mine in Ruanda-Urundi is the chief producer. Reserves are unknown, probably not large.

Egypt

A small quantity of wolframite has been produced in Egypt since 1937, the first year of production, when nearly 13,000 units were recovered. Wolframite, in some instances accompanied by cassiterite, is found in narrow quartz veins at Muelsh, Hafafit, Wadi el Dob, and Gekel Aku Marwa, all localities in southeastern Egypt northwest from Aswan. The deposits are not believed to be of importance.

Nigeria

Tungsten production in Nigeria has been small. The maximum annual output of 15,000 units of WO_3 was reached in 1939.

Wolframite occurs in narrow steep quartz veins in altered granite, accompanied in

part by cassiterite, columbite, and minor sulfides. The veins are up to 12 inches thick and 1,000 feet long. The content of WO_3 is low, possibly averaging about 0.5 percent.

The principal productive areas are the Tibchi and Yeli Hills in the plateau of the northern provinces. Deposits have also been worked at Pakuru and Tababindi in the northern part of the Tongolo Hills, and at Jemaa Amadu to the west of the Rishi Hills.

Southern Rhodesia

Some tungsten has been produced in Southern Rhodesia nearly every year since 1906. The total output to the end of 1950 was 4,815 long tons of concentrates, equivalent to 323,568 short ton units of WO_3 .

About a quarter of the total production was wolframite from quartz veins in the Tshontanda Mine, in the Wankie district at the west end of the Gwaai tin fields. The balance of the production was scheelite, in part from gold-bearing quartz veins, such as the Golden Valley Mine, near Gatooma, and the R.A.N. Mine, at Bindura, and in part from skarn or tactite deposits. Many scattered deposits of the tactite type are known, but most of them are small. The principal one is the Scheelite King, in the Mazoe district, which produced 1085 tons of concentrate from 1937 to 1950.

Southwest Africa

Small quantities of wolframite and scheelite have been produced since 1933 from Southwest Africa, a maximum output of 11,000 units being made in 1943.

Tanganyika

A few tons of wolframite were produced in 1935-1942 from placer deposits in the Ihunjere area, Bukoba district, 23 miles from Murongo, Tanganyika. The workable placer amounted to only about 22,000 cubic yards carrying 1 to 2 pounds of wolframite to the yard. The wolframite is derived from steep quartz veins which also contain small amounts of arsenopyrite and limonite.

Uganda

A small output of ferberite has been made in Uganda since 1937. The ore is mined from narrow quartz veins in the Kigezi district of southwest Uganda. Pro-

duction in 1950 was at the rate of about 9,000 units of WO_3 a year.

Union of South Africa

Production in South Africa reached a maximum of 43,000 units of WO_3 in 1944. The principal output came from 7 mines in the O'okiep copper district, Namaqualand. The largest tungsten mine in this district, the Nababeep Deep West, yielded about 52,000 units of WO_3 between 1941 and 1949 from 77,000 tons of ore averaging 0.92 percent of WO_3 . The ore consists of wolframite in quartz veins replacing bedded schist.

Wolframite is associated with cassiterite at Kurl's Rivers in Cape Province and at the Waterberg tin fields in the Transvaal.

ASIA

Burma

Known occurrences of tungsten and tin are located in a narrow belt extending for about 750 miles in a northerly direction from the southern tip of Burma at Victoria Point, through Mergui, Tavoy, Amherst, Thaton, Mawchi, the Yamethin and Kyaukse districts of Yengan, and the western part of Mong Pai State. The principal occurrences are quartz veins containing wolframite, cassiterite, and lesser amounts of scheelite. Placer deposits also account for some production.

The Mawchi Mines, in the Karenni State 160 miles northeast of Rangoon, are by far the largest in Burma and among the foremost of the world. Wolframite, cassiterite, scheelite, and minor sulfides occur in more than 60 quartz veins that range in thickness from thin stringers to 10 feet; most veins are less than 4 feet thick. The veins occur in a contact zone between granite and sedimentary rocks. The average content of WO_3 in the veins is about 1.3 percent, and the tin content is about 1.7 percent. A small amount of scheelite is present in metamorphosed limestone along the granitic contact. Some production also comes from alluvial deposits.

Burma reached a maximum production of nearly 550,000 units of WO_3 in 1941. Since then, war and disturbed political conditions have seriously retarded production. The Mawchi Mines produced about 200,000 units of WO_3 in 1939, about 38 percent of the total production of Burma. Ten other mines in the country each produced 8,000 units

or more and accounted for 30 percent of the total. The balance came from 245 minor deposits.

The Burma concentrates consist mostly of wolframite although small quantities of scheelite are produced from the Mawchi Mines. The largest part of the tungsten production comes from the ores that contain both cassiterite and wolframite, and concentrates from Taung area of the Yamethin district contain scheelite also. Mixed tin-tungsten concentrates are made from which wolframite is separated magnetically.

In 1938 the reserves of tungsten ore in Burma were estimated to be 4,800,000 units of WO_3 . It is believed that this figure was still valid in 1954 despite considerable production in the meanwhile, but no accurate confirmatory data are available.

China

The tungsten resources of China are undoubtedly the world's largest many times over. Several divergent estimates have been made of tonnage and grade. The veins have been traced and mapped at the surface in many instances, but have not been sufficiently developed at depth to delineate the ore vertically. The total reserve estimated by the Geological Survey for China probably contains a higher proportion of inferred ore than reserves estimated for many other countries. The published estimates are given in terms of metric tons of WO_3 , although the context suggests metric tons of concentrates containing 60 percent of

WO₃. Assuming that the latter is true, the estimated reserves contain about 134,500,000 units of WO₃ (Mineral Trade Notes, Vol. 26, No. 5, pp. 21-24, May 1948).

By far the greatest portion of China's tungsten resources is in southern Kiangsi, although important deposits are also present in Hunan, Kwangtung, and Kwangsi. The deposits are steep quartz veins in Mesozoic granite or in older phyllite, quartzite, or schist invaded by the granite. The veins are commonly 4 to 24 inches wide and some of them are as much as 6 to 10 feet. Some veins have been traced for more than 3,000 feet. Wolframite is the principal ore mineral, and is accompanied by a little scheelite, cassiterite, and sulfides. The content of WO₃ ranges widely, from less than 0.5 percent to 3.5 percent. The average is probably between 1 and 2 percent, possibly closer to 1 percent.

Five mines or districts in Kiangsi (Sihuashan, Yachishan, Pankushan, Kweimeishan, and Tachishan) and one in Kwangtung (Shuitung) each are credited with reserves containing more than 100,000 metric tons of 60 percent concentrate. These 6 districts contain 74 percent of the total reserves, and the balance is distributed in 17 other mines or districts.

The only important scheelite deposit known in China is in the Yulin district, northwestern Hunan, in an antimony mine. The scheelite was discovered in 1946, and by 1950 production was about 100 tons of scheelite monthly (7,500 units WO₃).

Indochina

Production of tungsten in Indochina has ranged from a maximum of 43,000 units of WO₃ in 1937 to nothing in 1946-48. The deposits are located in the mountains of Pia-Ouac, Tonkin, about 30 miles from Cao-Bang. Wolframite and cassiterite occur in quartz veins in granite and schist. In 1938, 49 tin-tungsten mines were known. No recent information is available about tungsten reserves of Indochina, which were estimated in 1938 to be 300,000 units of WO₃.

Japan

Tungsten production of Japan reached a maximum of 54,000 units of WO₃ in 1942 and has been insignificant since 1945. Reserves of proved and probable ore were estimated in 1946 to contain about 100,000 units of WO₃. The principal production

during World War II came from the Otani-Kamsoka Mine in Kyoto. Production has also been reported from the following mines: Kaneuchi, Kiwata, Takatori, Ebisu, Nitta, and Wachi. The principal deposits are quartz veins containing wolframite, cassiterite, and minor sulfides. The content of WO₃ is low, about 0.5 to 0.7 percent. The copper-tin ore of the Akenobe mine contains about 0.03 percent WO₃, half of which is recoverable.

Korea

Tungsten reserves in South Korea are estimated to contain about 7 million units of WO₃. About 90 percent of the reserves are in the San Dong Mine, which is estimated to contain 6,400,000 units of WO₃ in scheelite ore averaging about 1.7 percent of WO₃, plus a little bismuth and cobalt. The scheelite occurs in a biotite-quartz hornfels with fluorite, apatite, and sulfides. The deposit is several kilometers from known granitic rocks, but the mineralogy of associated calcsilicate hornfels suggests the deposit is of contact-metamorphic origin.

Other important deposits in South Korea are the quartz-wolframite veins of the Chungch'on Chongyang Mine, the scheelite-fluorite-bearing pegmatite of the Okpang Mine, and the stockwork breccias containing wolframite and scheelite at the Talsong, Ilgwang, and Namyang Mines.

Most of the other important tungsten deposits of Korea are quartz veins containing wolframite and molybdenite or wolframite and scheelite.

The principal tungsten-producing district in North Korea has been the Koksang-gun of northeastern Hwanghae-do and adjacent Togwan-gun in Hangyong-namdo. The Paeknyon Mine and the Kichu Mine were the most important. Each produced over 60,000 units of WO₃ per year during the peak production of the late 1930's and early 1940's. Data about the present status of these mines are lacking.

No reliable data are available on tungsten reserves of North Korea, which provided 53 percent of the total Korean production up to 1946.

Malaya

Tungsten reserves of Malaya were estimated in 1940 to be about 1,400,000 to 2,100,000 units of WO₃. The principal production in recent years was scheelite

from Kramat Pulai but output from there now is small. Some wolframite is produced from other deposits as a byproduct of tin mining. In 1951, production was 28 tons of wolframite and 18 tons of scheelite.

Thailand

The principal tungsten deposits of Thailand are along the Burmese border in extensions of the Burmese tungsten belt. Less important deposits are present in the South Thailand peninsula. All the deposits are remote from transportation.

The deposits are in veins, stockworks, and pegmatites in granite, schist, slate, phyllite, and marble, all deeply weathered. Wolframite, cassiterite, and a little scheelite are the ore minerals. Wolframite soon disappears under tropical weathering conditions so that alluvial deposits downstream contain only cassiterite.

The Mae Sariang district, about 60 miles southeast of the Mawchi Mines of Burma, has been the most important producer. Quartz veins containing pockets of wolframite are found in granite and phyllite. The veins range in width from 1 to 80 inches. The content of WO_3 is probably 1 to 1.5 percent, and the quantity of tin is negligible.

The Pilok tungsten-tin district in Kanchanaburi produces wolframite, cassiterite, and minor scheelite and sulfides from quartz veins and pegmatites in granitic rocks and associated meta-sedimentary rocks.

The South Thailand deposits are chiefly in veins and pegmatites similar to those in northwest Thailand, but some residual placer deposits of wolframite are also worked. Substantial production comes from mines in Nakon Sri Thamrat, Songkla, and Surat Thani provinces. The Chankit deposit in Changwal Surat Thani produces some scheelite and wolframite from contact metamorphic deposits.

Recently discovered deposits at Mae Sod, Province of Tak, are reported to be promising.

Production in Thailand reached a record total of about 106,000 units of WO_3 in 1943. The Mae Sariang district produced about 20,000 units annually. In 1953, the

Pilok district was the leading producer, and the Mae Sariang district was second.

Reserves, little known because of lack of underground development, are estimated to be about 500,000 units of WO_3 .

U. S. S. R.

Despite its great territory, Russia has apparently not developed sufficient tungsten resources to meet domestic demands, and consequently has long been an importer of tungsten.

Soviet tungsten deposits occur as quartz veins containing huebnerite and wolframite in granitic rocks with associated placers, and as contact-metamorphic tectite deposits containing scheelite.

Descriptions (in Russian) of various Russian tungsten deposits can be obtained from the references cited by Shimkin (1953).

Placers are apparently important in Russia. The Dzhiba deposit, a huebnerite placer, brought into production in 1935, was an important producer during World War II, but is now largely depleted. Other placer deposits of importance are Akchatau and Kok-kul in Kazakhstan, and some deposits in the Chita region, Eastern Siberia.

The Iul'tin deposit on the Amguema River on the remote Chukchi Peninsula is probably the most important discovery since World War II. Quartz veins and placers contain cassiterite and wolframite. Another discovery at Malo-Angatuyevskoye of wolframite in quartz veins is reputed to contain "considerable" reserves.

Scheelite-bearing contact metamorphic deposits have been developed at Tyrny-az in the northern Caucasus, at Gumbeik in the Urals, and at the Varzob group in Central Asia.

Minerals Yearbook (1951) estimates the 1951 Russian production at 495,000 units of WO_3 . Shimkin (1953) estimates the 1950 Russian production at 132,000 units of WO_3 .

Tungsten reserves for 1945 were estimated at 1,700,000 units of WO_3 by Shimkin (1953), who predicted that in the foreseeable future Russia will have to import three-fourths or more of its needs, presumably from China and North Korea.

AUSTRALIA

The largest tungsten deposit in Australia, and one of the largest of its type in the world, is the King Island, Tasmania, contact-metamorphic deposit. Scheelite is present in a tactite body estimated to contain 2 million tons averaging 0.7 percent WO_3 to a depth of 500 feet, as proved by drilling. The concentrates contain as much as 2 percent molybdenum.

At Storey's Creek, Tasmania, wolframite occurs in 2 quartz veins with cassiterite, bismuthinite, topaz, beryl, and fluorite. Ore reserves have been estimated (1945) at 100,000 tons containing 1.25 percent of WO_3 .

The Aberfoyle tin deposit, Tasmania, produces wolframite as a byproduct of tin mining, from quartz veins containing cassiterite, wolframite, pyrite, and a little sphalerite and fluorite. The grade of ore is about 1.5 percent of Sn, 0.2 percent of WO_3 . Reserves estimated by the company (1948) are 127,000 tons proved and 13,000 tons probable.

Before 1920, substantial production was obtained from deposits in Queensland, Northern Territory, and New South Wales. Production in these areas has been small in recent years and reserves are probably negligible.

EUROPE

England

Tungsten production from Cornwall, and to a minor extent from Devon, reached 25,000 units of WO_3 in 1909, 27,000 units in 1916, and 23,000 units in 1944.

Wolframite occurs in quartz veins in granite or slate, and is accompanied by cassiterite and other minerals characteristic of the tin lodes.

In 1948, the only producing mine was the Castle an Dinas, in Cornwall. During World War II, a low-grade lode deposit, the Bottle Hill Mine at Hemerdon near Plymouth, Devonshire, was opened and determined to contain at least 4 million tons of 0.1 percent or less WO_3 .

France

A small amount of tungsten has been produced annually in France since 1938, and a maximum output of 710 metric tons of 60 percent concentrate (46,860 short-ton units of WO_3) was reached in 1951. The producing mines are Montmins in Allier, Leucamp in Cantal, and Puy-les-Vignes in Haute Vienne. The ore consists of wolframite, a little scheelite, and some sulfides, in quartz.

At Puy-les-Vignes, 4 veins averaging 4 to 32 inches wide are worked. The content of WO_3 is 0.4 to 0.5 percent. The deposit has been opened to a depth of 220 meters (715 feet) on 13 levels.

Portugal

The tungsten deposits of Portugal, the largest in Europe, yielded a maximum production of nearly 500,000 units of WO_3 in 1943. Production in 1951 was about 300,000 units.

The principal mineral is wolframite, and scheelite makes up only about 1 percent of the output. Part of the tungsten production is in mixed wolframite-cassiterite concentrates.

The ore deposits are quartz veins in granite and metamorphic rocks. The veins are 1 to 60 inches thick and average about 12 inches. Cassiterite, pyrite, chalcopyrite, sphalerite, galena, and arsenopyrite, in places with muscovite, tourmaline, and fluorite, are associated with the wolframite.

The principal mines are the Panasqueira Mine of Beralt Tin and Wolfram Ltd. (British) and the Borralha Mine of Mines de Borralha S. A. (French). Many lesser deposits are known in Central and Northern Portugal, including the Riberia, Reventas, Roxo, Regoufe, Muro, and Cerva mines, each of which has reserves in excess of 50,000 units, according to company estimates.

The tungsten reserves of Portugal are estimated at about 2 million units of WO_3 in ores ranging from 0.4 to 1.2 percent of WO_3 , possibly averaging 1 percent.

Spain

In Spain, production of WO_3 reached a maximum of more than 250,000 units of WO_3 in 1943, but dropped to 18,000 units in 1945.

The deposits, similar to those of Portugal and in the same belt, consist of quartz veins carrying wolframite, cassiterite, and other minerals.

The tungsten deposits are largely in Galicia, northwest Spain; scheelite deposits are also found in Salamanca. The principal mines are Silleda and San Finx (Industrias Gallegas). Many small operations account for a large part of the total production.

Ore reserves are estimated to contain 650,000 units of WO_3 .

Sweden

Sweden has produced a small amount of tungsten annually since 1936, and reached a maximum of 32,000 units of WO_3 in 1946. The principal deposit is the Yxsjöberg mine in Central Sweden, which contains scheelite in skarn averaging 0.3 percent of WO_3 . Yxsjöberg is 200 km west-northwest of Stockholm. A less productive wolframite deposit is worked at Baggetorp, 16 km west of Finspang and 130 km west-southwest of Stockholm.

SOUTH AMERICA

Argentina

Tungsten mineralization in Argentina is confined to the Pampa Range, principally in the provinces of Cordoba and San Luis, and to a lesser extent in the provinces of Catamarca, San Juan, and Mendoza. The principal deposits are quartz veins carrying wolframite, scheelite, topaz, fluorite, and minor amounts of bismuthinite, pyrite, chalcopyrite, and occasional cassiterite and molybdenite. The country rocks are schist and gneiss. Contact metamorphic deposits are known but have not been important producers.

Production in Argentina reached a maximum of 2,390 metric tons of 60 percent WO_3 in 1943 (15,800 short-ton units), and declined to only a few tons per year after 1946.

The Sociedad Minera Argentina S. A. (Sominar), controlled by Thomas J. Williams, was the largest producer of tungsten in Argentina in the period 1937-45, and accounted for at least 40 percent of the country's output. Sominar controls the largest tungsten mine in Argentina (Los Condores) and at least 5 smaller properties (Avestruces, San Ignacio, La Bismutina, Auti, and San Virgilio). In Los Condores mines, 4 veins 1 to 7 feet thick have been developed along the strike for lengths up to 2,600 feet and to a maximum depth of 750 feet. The average content of WO_3 is about 0.5 percent, and the ratio of wolframite to scheelite is 3:2.

A total of 53 productive tungsten mines were known in Argentina in 1942. Of these, 44 had a rated capacity of less than 4 metric tons of concentrate per month each

(265 short ton units) and an average of 1.2 tons per month (80 short ton units).

The ore reserves of Argentina are not well known, but may approximate 500,000 units of WO_3 in ore containing 0.5 to 1 percent WO_3 .

Bolivia

Bolivia is the largest producer of tungsten in South America and one of the principal sources of United States imports. Nationalization of some of the principal mines in 1952 halted expansion programs planned by Patiño Mines and Enterprises Consolidated, Inc., by Mauricio Hochschild, and by Cia. Aramayo de Minas, but did not affect an export contract between the Mining Bank and the United States Government.

The tungsten deposits are scattered through the area known as the tin belt in the eastern Andes or Cordillera Real, but generally are not mixed with the tin ores. Of 43 known tungsten mines or districts, only 10 are reported to contain mixed tin-tungsten ores. The ore mineral is principally wolframite, although scheelite concentrates also are produced. The grade of ore ranges from about 1 to 4 percent of WO_3 and probably averages about 2 percent. The deposits occur in quartz veins of a high-temperature character, as indicated by the mineral association of wolframite, scheelite, tourmaline, muscovite, arsenopyrite, and pyrrhotite. The veins are in granodiorite or in nearby metamorphic rocks invaded by the granodiorite. The width of the veins is generally less than 5 feet.

Reserves of measured and indicated ore were estimated by F. Ahlfeld in 1941 to contain 25,000 metric tons of WO_3 (2,750,000 units), and the reserves in 1955 may still be near this figure. No detailed estimate was made of inferred ore, which may be equivalent to another 25,000 metric tons of WO_3 .

The principal mines are the Chojlla, Pacuni, Kami, Bolsa Negra, Juliana, Urania, Chicote Grande, Taminani, Caracoles, and Viloca.

Brazil

The principal tungsten production from Brazil is scheelite from the northeastern part of the country in the States of Rio Grande do Norte and Paraiba. More than 60 deposits are known in this area, discovered in 1942-43. The deposits are contact-metamorphic replacements of limestone lenses in schist near granite. The scheelite is contained in tactite composed of epidote, garnet, quartz, and scapolite. The average content of WO_3 is low, 0.5 percent or less. The deposits are deeply weathered with some concentration of scheelite at the surface. Large production was attained shortly after discovery because the surface outcrops could be worked by thousands of laborers without extensive mechanization.

The scheelite deposits are not explored in depth and little is known about ore re-

serves. Production to the end of 1951 was about 700,000 units of WO_3 , and reserves of inferred ore may contain another 2 million units.

At the Inhandjara mine in São Paulo, huebnerite occurs in a quartz vein with mica and topaz, in gneiss and quartz porphyry. The main vein is a little over 3 feet thick and about 1,240 feet long.

Peru

The principal tungsten deposits of Peru are in the northwestern part of the country, in the Departments of Ancash and Libertad, at altitudes of 10,000 to 16,500 feet. Wolframite accompanied by pyrite, sphalerite, tetrahedrite, enargite, and galena occurs in quartz veins that range in thickness from a few inches to more than 2 feet. The content of WO_3 in the veins worked is commonly more than 1 percent, and may average about 1.8 percent. As the mines are worked by lessees and are not extensively developed to prove ore in advance of mining, there is little measured or indicated ore. The inferred reserves are estimated to contain about 550,000 units of WO_3 . The Pasto Bueno mine, owned by Soc. Anonima Fermin Malaga de Santollalla e Hijos, is the most important deposit.

The maximum annual production in Peru was about 48,000 units of WO_3 , reached in 1943 and approximately equalled in 1953.

CHAPTER III
MINING AND METALLURGY

CHAPTER III MINING AND METALLURGY

MINING METHODS

Tungsten deposits are mined by numerous methods, since their manners of distribution and occurrence are varied. Mining techniques are influenced by mine locations, which largely determine whether hand methods or the more productive mechanical methods can be used. Chinese production, where total output is large, is dependent upon cheap and abundant labor. The United States, on the other hand, has no low-cost labor, and much less labor is available, so that mechanization is used to a greater extent.

In China, mining methods in all camps are still simple and crude. Hand drilling and black powder are generally used. Open cuts along the vein outcrops, short adits, and shallow shafts are adapted to suit local topography and the position of the veins. No electric power has been used. The crude ore is first hand sorted, then hand crushed, and jigged or panned.

"The inefficiency of hand labor and the large number of men engaged make the cost of production rather high. In 1937, some 28,000 men were engaged in active mining in the camp of Southern Kiangsi." This quotation from Ke-Chin Hsu in 1943 illustrates the crudeness of methods up to that time. Unsettled conditions have retarded progress in recent years.

In the United States, tungsten ore is mined by simple and comparatively inexpensive open-pit methods as well as by the more expensive underground methods. The choice of method depends on many factors, among which are: (1) The location and physical characteristics of the deposit, (2) the local topography; and (3) the cost of production balanced against overall yield expectancy. In the main, tungsten mining methods fall into two categories: Open-cut or open-pit, and underground.

Open-Pit Mining

This is the simplest and cheapest method of mining and is most feasible when the ores are lying near the surface and over a large area rather than in deep veins or

erratic occurrences. The technique consists of first removing the overburden, followed by drilling and blasting, and then excavating. Various types of drills are used. The most modern mines use electrical equipment. Ore is hauled from the pit by motor truck. Roadways are constantly being adjusted to proper incline for reaching the bottom as mining proceeds.

A good example of this type of operation is the Yellow Pine Mine in Idaho where tungsten was mined with antimony on a large scale during the war. Placer deposits are mined by open-cut methods.

An underground haulage system is sometimes employed to remove ore from an open pit. In such cases, ore is mined around and fed into a raise at the bottom of the pit, giving the pit a funnel shape referred to as a "gloryhole." Ore is loaded through chute gates onto cars on the level below. A skip and hoist is used to remove ore from the mine. The Round Valley Tungsten Mine, Bishop, California, uses this method.

Underground Mining

The mining of ores by underground methods is approached scientifically by the use of stopes either naturally or artificially supported. The word "stopping" is a broad term which relates to the underground excavation of ore from veins or other bodies by means of a series of horizontal, vertical, or inclined workings. It covers the breaking of ore, its removal from underground workings, and the use of supporting devices for preventing the collapse of surrounding rock. Figure III-1 is an excellent illustration of underground mining as done at the Lincoln Mine in the Tem Piute range of Nevada. As can be seen from the sketch, development includes a shaft with four main levels, several sub-levels, and stopes connected by raises and winzes. It may be noted that while the second and third levels were opened from the main shaft, the fourth was opened from No. 3 winze and then connected to the shaft.

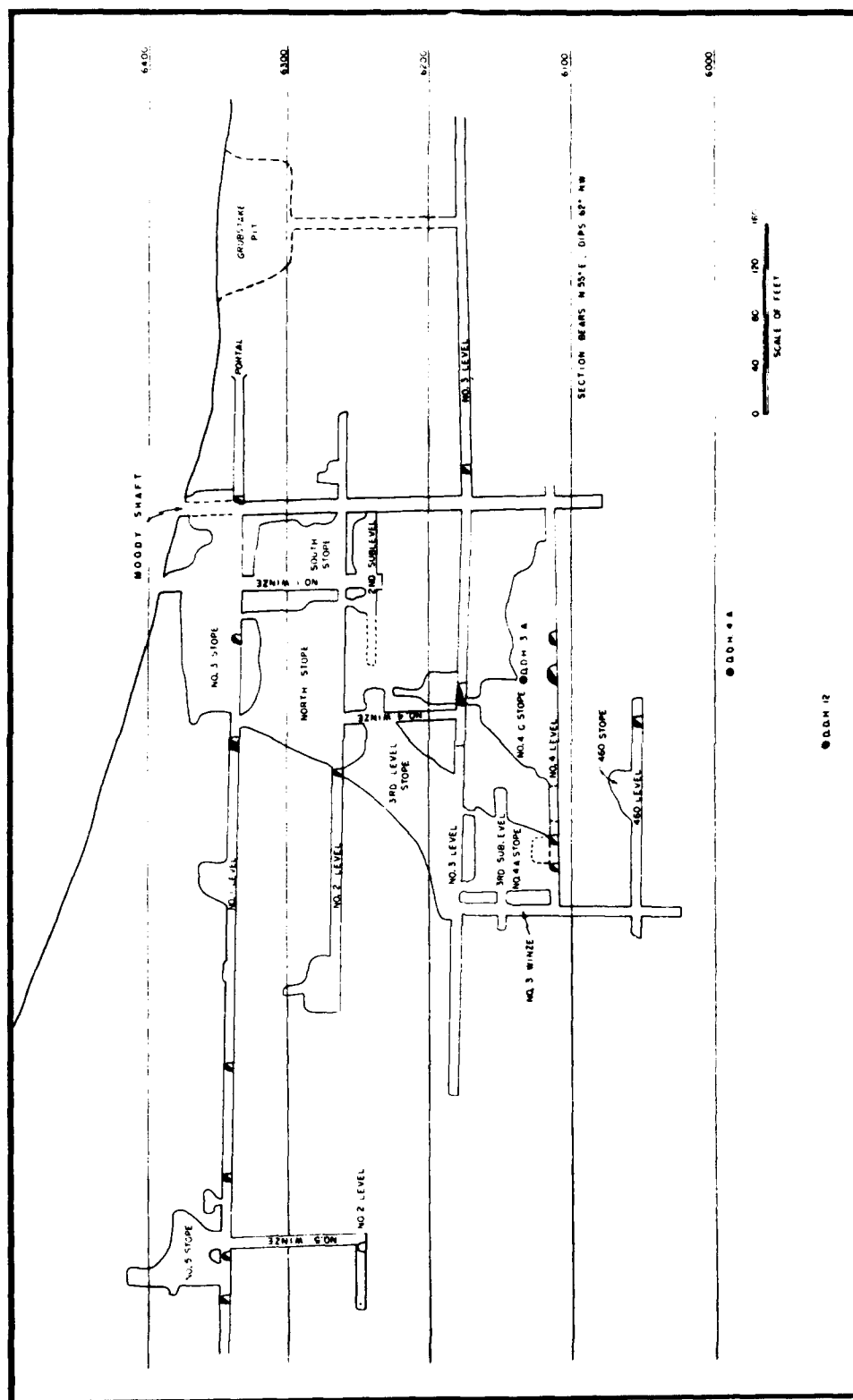


Figure III-1.—Longitudinal section and plane of vein, Moody ore zone, Lincoln mine.
(Reprinted from Bureau of Mines R. I. 4626.)

Various stoping methods are employed in underground tungsten ore mining and, depending on the means used to support the country rock, can be classified as (1) open stopes, (2) timbered stopes, (3) filled stopes, (4) shrinkage stopes, and (5) caving method.

Open stopes.--Applicable to ores that do not warrant high costs, this method is limited to tabular deposits having strong walls. Ore is mined in such a manner that columns of ore are left for support from floor to roof. The finished stope is an open cavity. Columns may or may not be removed at the completion of mining.

Timbered stopes.--In mining large irregular deposits, timbers are often used to provide temporary support for ore and walls and to provide a scaffolding to support men and equipment. A popular system of timbering, the square-set method, resembles scaffolding. Ore is mined from the highest set onto the frames below, or into ore passes. This method provides an opportunity for underground sorting and for following very irregular ore. If weak rock is encountered it is customary to fill the lower portion of the stope.

Filled stopes.--In this method, used principally in narrow veins, waste material is used to fill up the excavated areas. Timber, if any, is used only as temporary support. Overhead mining may be used, and as work progresses upward, chutes are made through the fill to deliver broken ore to the level below. This practice was used by Cold Springs Mine, Boulder County, Colorado.

Shrinkage stopes.--In this type of stope, which is restricted to narrow, strong ore

veins having strong walls, just enough ore is removed to provide room at the top for the miners to drill to higher levels. Partial removal of ore is necessary because of an approximate 40 percent increase in volume of the ore when broken. The remaining ore acts as support to men and walls. Once the stope is completely worked, it is left practically full of broken ore, which may be removed at will. Stopes are either left empty and permitted to cave or are filled. Nevada-Massachusetts Company Mine in Mill City, Nevada, uses this method.

Caving mining.--This is a method whereby a block of ore is completely undercut and weakened at the sides so that it collapses and is broken up under its own weight. The ore so broken descends into underlying chutes, extending from haulage levels, where it is drawn off.

In one method, known as sublevel caving, the ore block to be mined is approached horizontally by means of a series of drifts, beginning near the top of the ore body, which are used for approaching approximate positions for drilling. Figure III-2 illustrates the sublevel method of caving as done by the Pine Creek Mine in Inyo County, California, where both open and shrinkage stopes have been used. A scrapper-loading drift is located at the bottom of the stope for scraping the fallen and broken ore into the cars located on the haulage level. Once the ore has been stoped to a convenient and safe height, the whole process is repeated at the next lower level. This process of caving is suitable for massive deposits too weak to stand without support.

BENEFICIATION

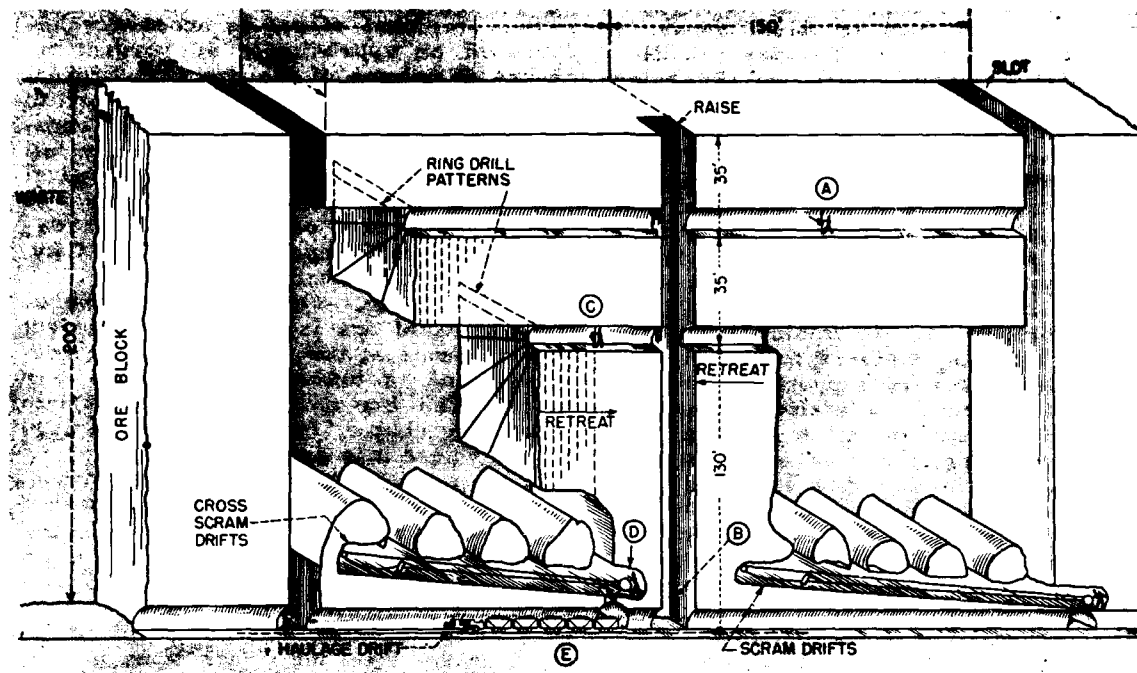
After leaving the mine or mines, most ores, because they contain impurities which must be removed if they are to be of value, must undergo a separation process referred to as ore dressing or as it may be called milling, mineral dressing, or beneficiation. Ore dressing involves, essentially, physical separation of value-bearing minerals in an ore from the undesired minerals or gangue. Its primary purpose in the case of tungsten is to effect an increase in tungsten trioxide content of the ore to at least 60 percent and a decrease in impurities to meet particular requirements.

It may be wise to point out that a mineral-bearing material is not considered ore

unless it can be worked at a profit. An ore body may thus be defined as a hard rock material containing a naturally occurring aggregate of minerals concentrated in such quantities as to make extraction of one or more mineral products contained in them commercially profitable.

Steps involved in ore dressing include: Crushing and grinding to liberate the mineral particles; screening, classification, thickening, etc., to put the pulp into a condition best suited for a particular concentration process; and separation of the minerals. All tungsten-concentrating methods, with the exception of some magnetic or hand-picking operations, act upon a

Figure III - 2. How a Block of Ore is Developed and Mined



ORE IS MINED by sub-level method. Long-hole diamond-drill (See below.) Letters indicate major operations shown in blast holes are drilled from sub-levels in half-ring pattern. photographs. Cars are loaded with slushers.

Steps in current mining of a block of ore are as follows:

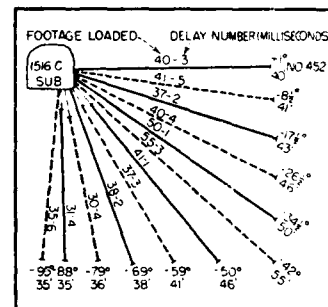
1. First a drift is driven in ore.
2. Crosscut is driven near (A) of the ore zone.
3. Development of a large block of ore for diamond-drill blasthole mining is started by advancing two scam drifts on the strike of the ore. (See idealized sketch of stope development).
4. Then four additional scam drifts normal to the strike of the ore are driven.
5. Three raises are driven on 150-ft. centers.

6. The two end raises are stripped of timber and prepared for conversion into slots.

7. Sub levels are established at 70-ft. and 35-ft. centers.

8. Ring drilling with diamond drills are started at two end raises converted into slots. Retreat is toward the central man and supply raise.

9. Blasted ore is removed from scam drifts with scrapers and loaded into mine cars on haulage level immediately below.



DOTTED LINES show half-ring drilled 2 1/2 ft. behind other half-ring (solid)

(Reprinted, with permission, from *Engineering and Mining Journal*, May 1951.)

mineral-water mixture. The resulting products are one or more mineral concentrates and a tailing or worthless fraction which is discarded. Middling, an intermediate product, if produced, requires further treatment before resolving into a concentrate and tailing.

Historically, one of the oldest methods of accomplishing separation (gravity concentration) is to mix crushed ore with water and then subject the mixture to a shaking, throwing, and flowing motion on appropriate machines. Mineral particles, being much heavier than the gangue, travel faster and farther, thereby effecting a separation. Gravity concentration is advantageous in that a high-grade concentrate is produced relatively free from impurities. However, a low-percentage recovery generally is obtained. Therefore, for improvement of separation and yields, other methods or combination of methods, such as flotation, magnetic, electrostatic, roasting, and leaching are relied upon.

In recent years flotation has been adapted as an adjunct to or replacement of other concentrating methods. In the treatment of low-grade, disseminated domestic tungsten ores, flotation is inadequate and must be supplemented usually by chemical treatment to upgrade the ore to a marketable product.

Flotation concentration accomplishes the same results as gravity concentration in that it renders a mixture of finely ground minerals susceptible to separation simply by causing selective attachment of air bubbles to specific mineral particles from the surface of the mixture or pulp as a mineral concentrate. Use is made of the fact that a mineral in order to float must have or be given a water-repellent surface; otherwise it sinks. Flotation then may be described as follows: If air is introduced into a mixture of finely divided ore and water to which the proper collecting agent has been added, small particles of so-called floatable water-repellent minerals will attach themselves to the film of the rising bubble and be carried to the surface, regardless of the fact that they may be heavier than water (an exact inversion of gravity concentration). The addition of small amounts of a frothing agent will stabilize the bubbles so that a more permanent froth forms; bubbles formed without any stabilizer will break as soon as they reach the surface. The mineralized froth is then removed mechanically. Minerals difficult to float will be wetted by

water and sink to the bottom. Thus there can be effected an easy separation of minerals, assuming, of course, that grinding was sufficient to unlock the particles of different composition. Either desired minerals or impurities can be carried off by foam.

To effect a clean separation of minerals, proper reagents must be added; these in accordance to their purpose are known as frothers, collectors, and modifiers.

Frothing agents are organic compounds that contain both polar (water-avid) and nonpolar (water-repellent or air-avid) groups in their molecules. The polar part contains the hydroxyl (OH) or carboxyl (COOH) group which is absorbed by water; the nonpolar or hydrocarbon group is absorbed by the bubble film, thereby promoting stable bubbles. The most commonly used frothing agents are the pine oils and cresol. A desirable property of frothers is that they have no collecting properties. This condition is favored by the presence of the hydroxyl radical; the carboxyl radical shows a tendency to react with mineral surfaces.

Collecting agents are organic compounds which alter the surface of mineral particles in such a manner as to promote bubble attachment and prevent their being wetted by water. They are similar to frothers in that they contain both polar and nonpolar groups. They differ in that the polar part of the molecule, being reactive, adheres to the surfaces of mineral particles so that the nonpolar hydrocarbon end pointing away from the mineral surface produces an oily water-repellent or air-avid coating, thereby inducing air bubble attachment and floatability. Alkaline xanthates and similar sulfur-containing compounds react chemically with sulfide minerals to produce highly insoluble and floatable compounds, but have no effect on oxides. Oxides and other minerals which do not possess a metallic luster can be collected successfully by oleic acid and its derivatives, the oleates or soaps, to form an oily water-repellent film.

Modifying agents are used to modify pulp so that the desired minerals will collect in the froth while the remainder remain in suspension or sink. These, generally inorganic compounds, can be further separated into groups according to functions, such as pH regulators, depressors, activators, dispersers, etc.

It has been experienced that collectors work best in a certain concentration (pH) of

pulp strictly in a definite range, usually from pH 7-pH 13. Lime, soda ash, and sulfuric acid are some regulators. Dispersing agents, such as soda ash or water glass (sodium silicate) prevent particles of gangue from coating floatable minerals.

Gravity Concentration

The high specific gravity of tungsten minerals as compared to that of their associated gangue minerals makes them amenable to gravity concentration. However, tungsten minerals are very friable and heavy and will form slimes unless precautions are taken to prevent over-grinding. Minerals should be recovered as soon as "free." For this reason, operations including crushing, screening, grinding, jigging, classifying, and tabling are common in plant flow sheets.

The main drawback with all gravity methods of concentration is the loss of tungsten in fine sizes. This has been greatly reduced by inserting a mineral jig in the grinding circuit between the ball or roll grinding mill and classifier. The jig is a very efficient mineral selector and is capable of producing a high-grade concentrate with recovery over 60 percent. Functioning best on unclassified feed, ball or rod mill discharges, screen under-size can be treated to recover both coarse and fine minerals without further preparation.

For the recovery of the very fine range of minerals, in the minus 150 to plus 1000 mesh range, the Denver-Buckman tilting concentrator was developed to replace conventional slime tables, increasing recovery of WO_3 over that of tables by at least 50 percent.

Flotation

Flotation for the treatment of slimes and complex ores, primarily those containing sulfides, has become increasingly important. Many tungsten ores contain pyrite, arsenopyrite, molybdenum, bismuth, copper, lead, and zinc minerals, all of which would contaminate gravity concentrates and must therefore be removed.

For the effective removal of sulfides, ores or concentrates must be ground (ball-mills are suitable) to flotation size and the sulfides floated or collected with pine oil, zanthate, or hydroxy-type reagents. Small amounts of sulfides can be effectively removed by roasting and magnetic

treatment, but flotation, either on a continuous or batch basis, is preferred. In the batch treatment of gravity concentrates, the pulp is continuously circulated within the cell; at the same time froth product, low in tungsten, is removed. The unfloated product or tailings are dewatered, dried, and bagged as high-grade concentrate. Nonfloatable impurities such as calcite and apatite are removed by dissolving in dilute hydrochloric acid under controlled conditions to prevent solution of tungstate.

Of the tungsten minerals, scheelite is the easiest to float. Fatty acids and soaps, such as oleic acid and sodium oleate, are the usual collecting reagents, and when used with an alkaline dispersing agent such as caustic soda, soda ash, or sodium silicate, a satisfactory separation of scheelite from quartz or mica can be obtained. The oleic compounds form a film of calcium oleate around the scheelite particles for easy flotation while sodium silicate depresses the quartz and mica. Water must be softened before flotation to prevent excess reagent consumption, which would be taken up by the calcium salts in hard water. At low temperature lime must be added to prevent flocculation of scheelite.

A satisfactory separation of scheelite from cassiterite was reported by Nedrogorov. The method, applicable to gravity concentrates containing scheelite, cassiterite, and heavy sulfides, was described as follows: Scheelite was floated from a bath containing, per ton of feed, 11 pounds of calcined soda, 2 pounds of sodium silicate to depress cassiterite, about 11 pounds of sodium sulfide to depress the sulfides, and 2 pounds of oleic acid as a frother. The pulp temperature was maintained at 100 F. Upon removal of the scheelite, sulfides appeared in the froth, indicating they acted as a barrier between the scheelite and cassiterite.

Ferberite, wolframite, and huebnerite may be recovered by flotation, but not as readily as is scheelite. Of the three, huebnerite is the easiest and ferberite the most difficult to float. The same general reagents are employed, with acidified dichromates being used to depress gangue minerals such as silicates, apatite, and fluorite. Sodium cyanide is sometimes used to depress unwanted sulfides. The use of manganese sulfate will reduce any tendency of tungstate minerals to be depressed in an acid circuit. Generally acid circuits are used if ores contain carbonates and

apatites, while alkaline circuits are preferred in their absence.

Magnetic Separation

Magnetic separation is accomplished essentially by running crushed ore on belts through a field of electromagnets which attract the more magnetic particles. When ores contain cassiterite, pyrite, garnet, and epidote, magnetic separation is a useful companion to table and flotation concentration, especially in the separation of wolframite from cassiterite, which is nonmagnetic. Garnet and epidote, the usual minerals present in contact metamorphic deposits, cannot be satisfactorily separated by gravity methods, but because they are highly magnetic they are easily removed from dried concentrates by high-intensity magnetic separation. Magnetite and ilmenite, if present, can be removed in this manner. Small amounts of pyrite can be eliminated magnetically from scheelite concentrates by a superficial roast which alters the surface of the pyrite, rendering it magnetic.

Electrostatic Separation

Electrostatic separation takes advantage of the differences in electrical conductivity between some minerals. It depends on the fact that two substances having like charges of electricity will repel each other, while those with unlike charges will attract each other. If a mixture of minerals containing good and poor conductors is dropped upon a highly charged conducting surface, the good conductors are immediately charged similarly to that of the surface and are repelled from it. Nonconductors already having a charge opposite that of the conductive surface are reluctant to receive the charge and are, therefore, forcibly attracted. Cassiterite when associated with scheelite can be removed in this manner. In brief, the ores or concentrates are electrically charged and passed over a grounded roll. Cassiterite, being a good conductor, loses its charge to the roll and falls off, while scheelite, being a poor conductor, adheres to the roll. Pyrite can be removed in this manner if it has not undergone a surface oxidation. Electrostatic separation is used principally on reasonably coarse material (around 80 to 120 mesh); chemical treatment is almost always used on finer sizes (under about 180 mesh).

Chemical Separation

In the final cleaning of scheelite, one of two chemical treatments may be used. The first consists of boiling in caustic soda or digesting with steam and sodium carbonate in an autoclave. The second involves the heating of scheelite mixed with sodium carbonate, sodium chloride, and coke at 600-700 C. (1112-1292 F.), regrinding the product, leaching, and precipitating the tungstate with calcium chloride or lime. Wolframite, especially when particle size is under 180 mesh, is usually converted to sodium tungstate to eliminate impurities.

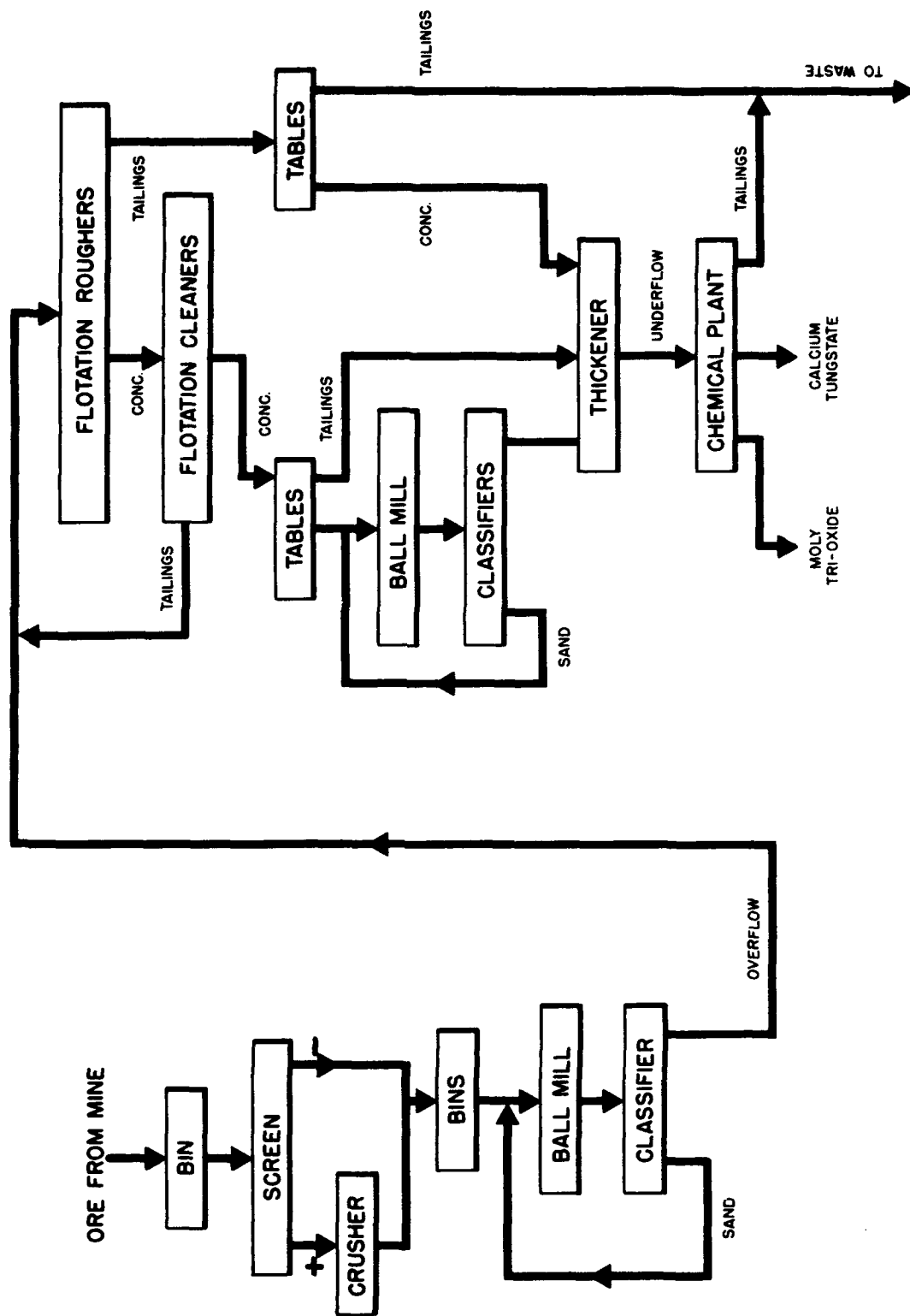
Flowsheets

To select a generally applicable flow sheet that would be practical for any one ore type would be difficult, because of wide variations in composition. Therefore, the flowsheets illustrated, with the exception of Wah Chang's (figure III-6), are practices employed on specific types of ores and concentrates.

The flowsheet shown in figure III-3 is for an ore averaging 0.53 percent WO_3 and containing scheelite as the main tungsten mineral, with small amounts of powellite. Molybdenite, chalcopyrite, covellite, and bornite containing gold and silver, are the other valuable minerals; garnet, apatite, calcite, fluorite, and quartz comprise the gangue minerals. The process illustrated by this flowsheet is unique in that flotation instead of conventional gravity methods is used to separate the bulk of the gangue. The final scheelite-powellite flotation concentrate is tabled to remove coarse scheelite, which is reground for further treatment or sold as concentrate carrying 60-73 percent WO_3 and 2.5-3 percent molybdenum for use where molybdenum is not objectionable. To produce a high-grade, marketable concentrate and recover both tungsten and molybdenum, chemical separation is used. Briefly, this involves: (1) The treatment of flotation concentrates with steam and sodium carbonate to produce soluble sodium tungstate and molybdate; (2) the precipitation and removal of molybdenum as sulfide, and (3) precipitation and removal of tungsten as calcium tungstate, or, as it is sometimes called, "synthetic" scheelite. Recovery of tungsten is 95 percent.

The flowsheet of the Nevada-Massachusetts Company, which utilizes tabling in preference to flotation to remove the major

FIGURE III-3-FLOW SHEET FOR SCHEELITE CONCENTRATION
ILLUSTRATING STRAIGHT FLOTATION
(U. S. VANADIUM CORP. PINE CREEK PLANT)



percentage of scheelite (65-70%) in low-grade ore, is shown in figure III-4. Tabling is used to reduce tonnage going to flotation cells in order to reduce reagent and operating cost. As is indicated from the number of crushing steps, scheelite is removed as soon as liberated from the gangue to reduce sliming during grinding.

Ore treated by this procedure consists of an aggregate of quartz, garnet, epidote, calcite, and scheelite. Tungsten content of the ore varies from 0.25 to 3.0 percent. By maintaining a pH of 10-10.1 in the concentrator, 12-13 percent of the calcite can be removed.

Upgrading the final concentrate to a minimum of 70 percent WO_3 is accomplished by roasting gravity concentrates and subjecting the product to magnetic separation to remove deleterious minerals, and by giving flotation concentrates an acid treatment.

Before any flowsheet is put into operation, it is wise to make laboratory tests to ascertain the amenability of ores to specific treatment, and the steps to follow for the greatest monetary return. Figure III-5 illustrates such a procedure. Laboratory tests indicated that a low-grade ore, containing about 0.5 percent ferberite plus intimately locked scheelite in the ratio of 10 to 1, can be concentrated to an acceptable grade of plus 60 percent WO_3 in two steps; First, using gravity concentration to raise the WO_3 content and reject the bulk of the gangue as tailings, and second, cleaning the rougher concentrates to remove undesirable minerals.

The ore was composed chiefly of feldspar and quartz with lesser amounts of pyrite, muscovite, ferberite, and scheelite. Traces of bismuthinite, magnetite, biotite, and chalcopyrite were present. Laboratory tests showed that by crushing the ore to minus 1/4 inch, 94 percent of the tungsten, assaying 27.4 percent WO_3 , could be recovered by the use of jigs and tables. Then by subjecting the rougher concentrates to flotation and magnetic separation, a final concentrate

containing 66 percent WO_3 at 91 percent recovery could be produced.

Sulphydric-type collectors were employed to remove sulfide minerals. For their effective separation, rougher and cleaner flotation operations were maintained at a pH of 5 and 7.8 respectively. Molybdenite flotation was effected at a pH of 5.9. Fatty-acid collectors were used to remove ferberite and scheelite.

The flowsheet in figure III-6 differs from the others in that the concentrates and not ores are treated. Its primary purpose is to remove impurities. All possible methods or combination of methods for treatment of concentrates can be employed. Mechanical treatment is used whenever possible since it is more economical than chemical methods.

Wolframite-type concentrates produced by gravity method usually carry some scheelite, cassiterite, and sulfides. From these, wolframite can be separated out magnetically. Cassiterite can then be thrown out electrostatically and the sulfides floated, leaving a high-grade scheelite. The last traces of impurities such as sulfur, arsenic, bismuth, phosphorus, and antimony can be removed by roasting and leaching.

Scheelite concentrates seldom contain sulfides in any large amounts, but they usually contain objectionable elements such as phosphorus, arsenic, antimony, and molybdenum. Phosphorus or bismuth, if present as an oxide, as well as calcite and dolomite, if present, are acid-soluble and therefore can be leached with hydrochloric acid. Caustic soda is used if sulfides of arsenic and antimony are present. Acid concentration and temperature must be closely controlled to prevent solution of scheelite or hydrolysis of bismuth.

The method or combination of methods for the treatment of simple and complex ores at the Wah Chang plant are summarized below:

<u>Material for treatment</u>	<u>Methods used</u>
1. Scheelite, simple ore	Gravity, flotation, electrostatic
2. Scheelite, apatite, calcite, stibnite	Gravity, flotation, leaching
3. Scheelite and cassiterite concentrate	Electrostatic, gravity
4. Wolframite and cassiterite ore	Gravity, magnetic, tables, roasting
5. Wolframite, simple ore	Gravity, magnetic, roasting
6. Wolframite, and scheelite concentrate	Magnetic, electrostatic, flotation
7. Wolframite, cassiterite and bismuth concentrate	Magnetic, electrostatic, leaching
8. Wolframite, scheelite and cassiterite ore	Gravity, flotation, magnetic, electrostatic
9. Wolframite and molybdenite ore	Gravity, magnetic, flotation
10. Wolframite, scheelite, pyrite, arsenopyrite and other sulfide ores	Roasting, magnetic
11. All mixed ores, slimes, dust	Leaching, and fusion

[illegible]

	A	B	C
1. 24 x 24-in. Allis-Chalmers jaw crusher.	Soda ash	Sodium silicate	
2. 3 x 8-ft. vibrating screen.	Cresylic acid	Fresh water	
3. 3-ft. Taylor gratory crusher.	Xanthite		
4. 4 x 8-ft. Syme vibratory screen.			
5. 4-ft. Syme short-head cone crusher.			
6. 3 x 10-ft. Tyrock vibrating screen.			
7. Drag classifier for removal of chips.			
8. Mercury 60 ball mill.			
9. Mercury 60 1/2 ball mill.			
10. 8 x 21-ft. Dorr classifier.			
11. Pocket sizer.			
12. Three No. 6 Wiffley tables.			
13. Three-cell frust flotation machine.			
14. 11 Conoco tables.			
15. Two Wiffley tables.			
16. Two 42-in. Dorr thickeners.			
17. Six Agitair 36-in. flotation cells.			
18. 6 x 25-ft. Dorr classifier.			
19. Eight Agitair 36-in. flotation cells.			
20. Four Denver cleaner cells.			
21. 4 x 20-ft. Dorr classifier.			

III-10

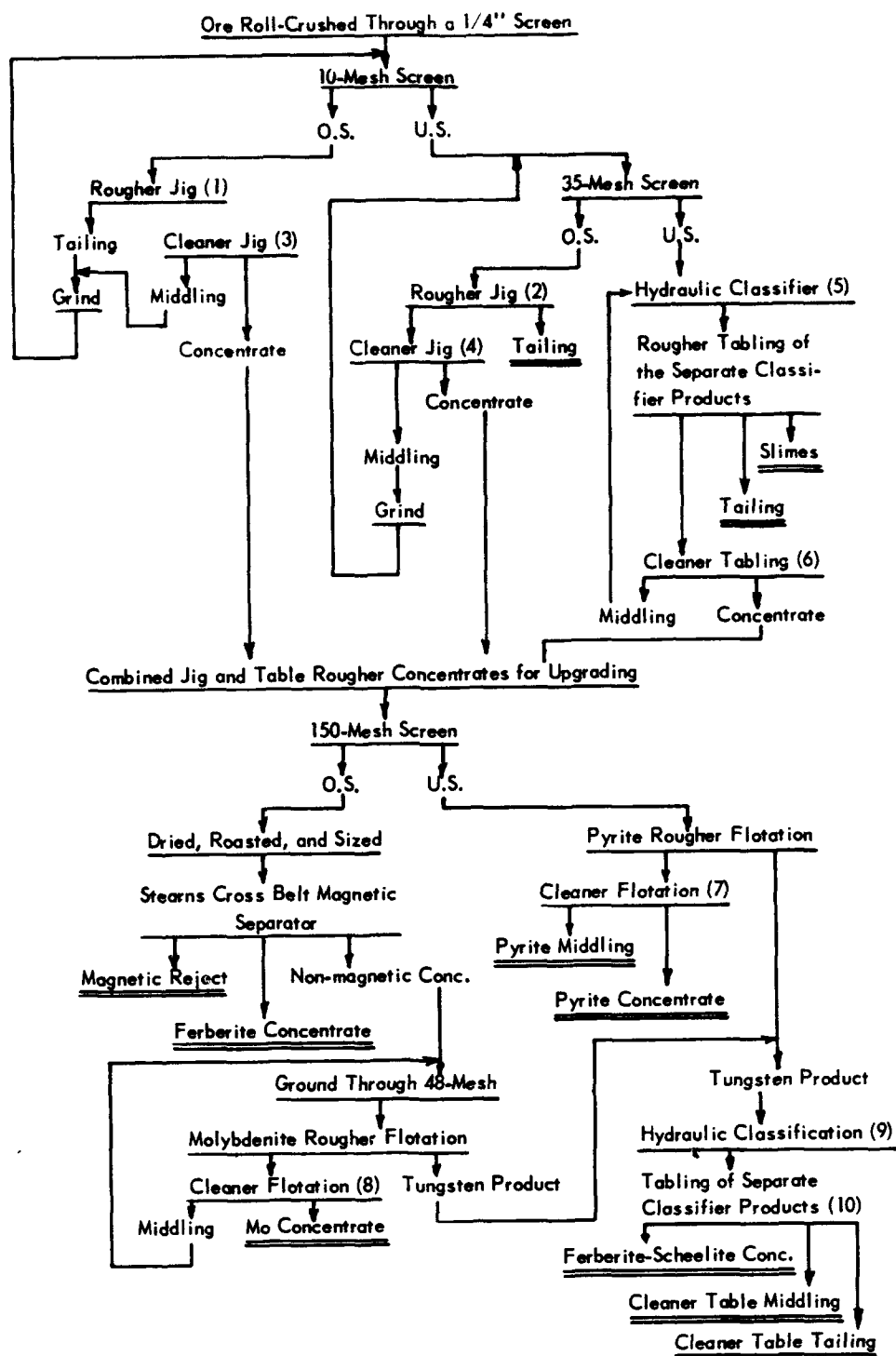


Figure III-5.—Test flowsheet of Germania Consolidated Mines, Inc., ferberite-scheelite ore.
(Reprinted from Bureau of Mines R. I. 5039.)

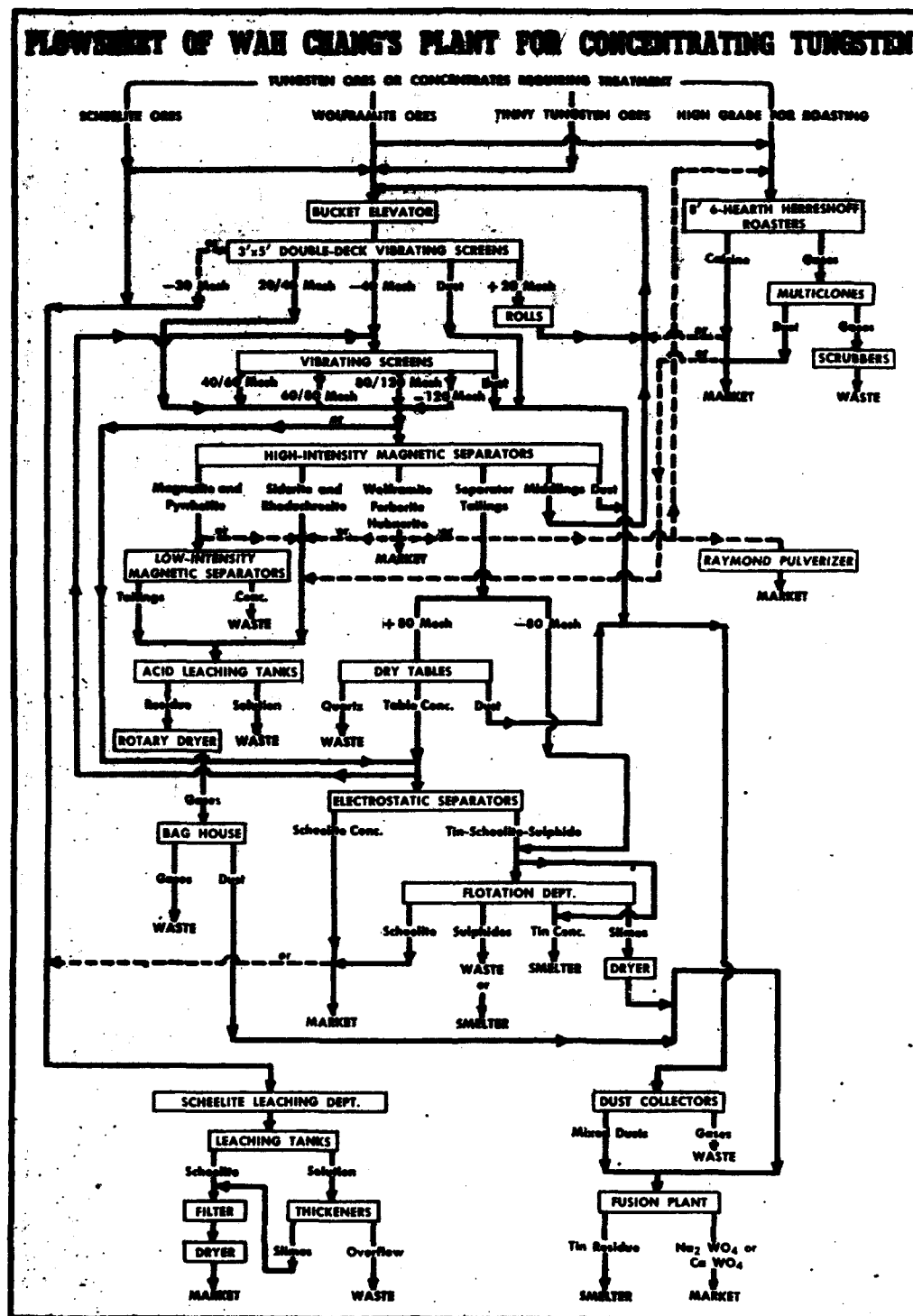


Figure III-6.

(Reprinted, with permission, from *Engineering and Mining Journal*, September 1944.)

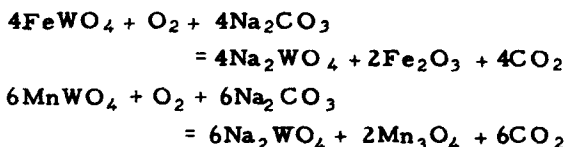
CHEMICAL TREATMENT OF ORES AND CONCENTRATES

The very high melting point of tungsten precludes handling it like most other metals. Even if refractories were available to withstand its high melting point, cast tungsten is extremely brittle and would be impossible to work mechanically. Hence treatment of tungsten ores and concentrates must of necessity entail production of intermediate products prior to the manufacture of metallic tungsten, tungsten carbide, chemicals, etc. Tungstic acid (H_2WO_4) is the usual intermediate product which is then treated to produce metallic tungsten in powder form. Figure III-7 is a schematic representation of the flow of tungsten from its ore to industrial uses. Steps involved in the production of metallic tungsten powder can be grouped as follows: (1) decomposition of ores, and (2) purification of tungstic oxide.

Decomposition of Tungsten Ores

Of the many methods available for the decomposition of tungsten-bearing ores and concentrates, those of commercial value fall into three groups: (1) Fusion with alkalis or alkali salts, (2) digestion with alkalis, and (3) digestion with acids (usually hydrochloric).

Fusion with sodium carbonate.--One of the processes most frequently used to decompose wolframite-type ores, particularly low-grade, is based upon a British patent by Robert Oxland obtained in 1847. After magnetic separation of wolframite from its gangue and possibly cassiterite, the separated ore is mixed with soda ash, along with some sodium chloride or fluoride to increase fluidity and lower reaction temperature, and roasted in a gas-fired reverberatory furnace or revolving kiln operating at temperatures between 800-1000 C. (1472-1832 F.) to convert the tungsten-bearing minerals to sodium tungstate. The reactions that occur may be represented by the following equations:



During roasting much of the arsenic and sulfur usually present is volatilized. Ample air is used to oxidize the manganese and iron completely. (Sodium nitrate may also

be used as a source of oxygen.) The fusion product is then cooled, ground, and leached with hot water. The water-soluble sodium tungstate is separated from the insoluble iron and manganese oxides by filtration. Excess sodium carbonate and impurities, such as sodium arsenate and sulfate, are crystallized out by cooling the solution down to freezing, and removed by centrifuging. The final sodium tungstate solution is evaporated in vacuum to produce sodium tungstate crystals. These crystals are redissolved in water and treated with a solution of magnesium or ammonium chloride to remove the last trace of arsenic, leaving a purified sodium tungstate solution ready for precipitation.

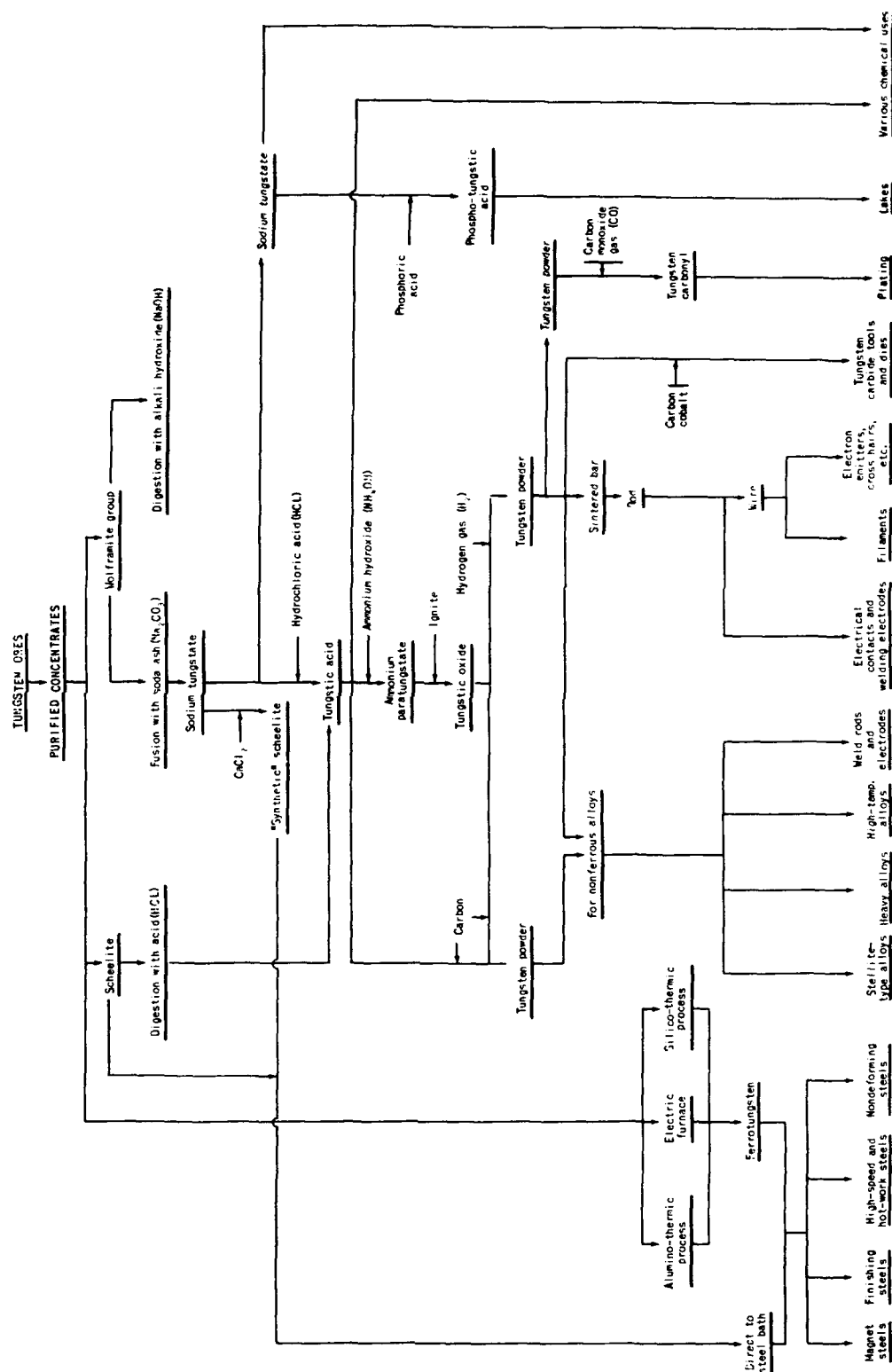
Digestion with alkali hydroxides.--An alternate method to the soda roast process is the decomposition of wolframite ore with alkali hydroxides--the method used in manufacture of tungsten filaments for electric lamps. In this process the separated wolframite is ground very fine and digested in a boiling, strong (40-50%) solution of sodium or potassium hydroxide. After decomposition of the ore, the residue is allowed to settle and the tungstate solution decanted off.

Decomposition with acid.--The decomposition of wolframite with acids yields a low-purity product, and is used only when it is desired to recover iron and manganese. However, it is the principal method used to decompose scheelite. Scheelite first dissolves in the acid, but immediately a precipitate of almost insoluble tungstic acid follows. Hydrochloric acid is generally used because of the high solubility of its calcium salt, which permits easy separation from the insoluble tungstic acid. The reaction which takes place is represented by the following equation:



The decomposition can be carried out in rubber-lined steel tanks; the procedure briefly is as follows: Ground scheelite (100-200 mesh) is slowly introduced into an acid-resistant vessel containing the necessary amount of acid. After proper charging, the reaction mixture is slowly brought to a boil by passing dry steam directly into the liquid. When the acid solution reaches 75-82 C. (167-180 F.) and a sufficient time has elapsed (about 2 hours), the steam is turned off and

Figure III-7. General Treatment of Tungsten Ores and Concentrates to Industrial Products



oxidizing agents such as nitric acid or manganese chloride are added to convert any oxidizable material to its highest possible state of oxidation. This insures the conversion of all tungsten to WO_3 . After the reaction quiets down, the charge is boiled an additional hour or so to drive off all gaseous products. Water is then added and the tungstic acid formed allowed to settle. The liquor is siphoned off to waste and the tungstic acid sludge filter-pressed and washed free of soluble impurities such as calcium chloride, ferric chloride, etc., with boiling water.

Purification of Tungstic Oxide

Crude tungstic acid prepared from any of the above decomposition methods may contain substantial amounts of impurities, depending upon the raw material and process used. Most common are undecomposed ore, cassiterite, iron, manganese, calcium, titanium, molybdenum, alumina, and silica.

In the manufacture of metal, especially for filaments, as much as 0.1 percent of iron causes tungsten sintered ingots to become brittle and unworkable. It is most fortunate that a great percentage of impurities can be removed during processing, usually reducing total impurities to about 0.1 percent. With the large number of operations necessary to obtain high-purity tungstic oxide from its ores, losses in tungsten content of about 10 percent can be expected.

Precipitation as tungstic acid.--Crude tungstic acid may be directly precipitated from sodium tungstate solution by hydrochloric acid. However, particle size and the degree to which tungstic acid can further be purified depends largely on the physical state of the precipitate, which in turn is directly influenced by the concentration of sodium tungstate and acid solutions before mixing, type of acid used, temperature of reaction, manner of bringing reactants together, etc.

Cold solutions favor a white colloidal precipitate and impurity pickup. A hydrochloric acid precipitate is fairly soluble in nitric acid; the reverse is true with a nitric acid precipitate. Rapid flow and rapid mixing favor the precipitation of coarse yellow oxide. The greater the concentration and the higher the reaction temperature, the coarser the precipitate. For best results, therefore, the tungstate solution should be run slowly, with constant stirring, into boiling concentrated

hydrochloric acid. The precipitate then is washed rapidly with dilute acid, and filtered to remove excess water.

Precipitation as calcium tungstate ("synthetic" scheelite).--The sodium tungstate obtained by either of the first two decomposition processes is sometimes purified by first treating with calcium chloride solution (specific gravity 1.16) to precipitate calcium tungstate, thus:
 $\text{Na}_2\text{WO}_4 + \text{CaCl}_2 = \text{NaCl} + \text{CaWO}_4$

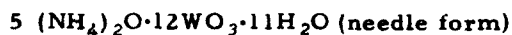
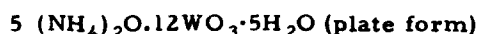
The white precipitate is thoroughly washed by repeated decantation with water to remove soluble salts such as sodium or calcium chloride, repulped to form a slurry, and then dissolved in concentrated boiling hydrochloric acid. On rapid mixing, coarse-grained tungstic acid precipitates. The yellow tungstic acid is washed by decantation, filtered, and dried in a steam-heated oven at 120-130 C. (248-266 F.).

Calcium tungstate or "synthetic" scheelite as it is often called is very frequently used without further purification as a starting material in tungsten metal or ferrotungsten production, or is added directly into a molten steel bath for the production of tungsten-bearing steels. In this latter application, high-grade natural scheelite of comparative purity is also used. When added directly to the steel bath, allowance must be made for about 5 percent tungsten loss.

Separation as ammonium paratungstate.--The crude tungstic acid obtained from the various decomposition processes absorbs and carries down with it some impurities. To reduce these impurities it is most practical to convert the tungstic acid into ammonium paratungstate. Tungstic acid, if not dehydrated at temperatures over about 170 C. (338 F.), dissolves very quickly in ammonia. (By drying at 170 C. tungstic acid will still contain 7-8 percent water which is, for all practical purposes, the theoretical composition, H_2WO_4 .) When all of the tungstic acid has dissolved, the liquor is diluted to a specific gravity of about 1.15 to prevent precipitation of ammonium paratungstate, then filtered off, leaving a sediment of gangue material and undecomposed ore which can later be reclaimed as ore.

By neutralizing the ammoniacal solution with nitric or hydrochloric acid, complete precipitation of ammonium paratungstate is effected. After filtering, the precipitation is dried in a hot-air oven at about 50 C. (122 F.). Crystallization of the salt can also be effected by evaporating the

ammoniacal solution to low bulk; however, this method is usually reserved for high-grade ore relatively free from molybdenum. The degree of hydration and crystalline form that results depends upon the temperature and time of crystallization. Two forms are common:

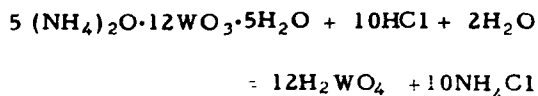


The needle form is found only if the temperature of precipitation or crystallization is below 50 C. (122 F.). Prolonged boiling in water will convert the crystals into plate form.

Impurities up to 0.05 percent may still be found in ammonium paratungstate, depending on the type of ore used. Those most frequently found are calcium, magnesium, iron, molybdenum, titanium, the alkali metals, and silicon. Molybdenum is difficult to remove because of its similarity in chemical behavior to tungsten. The most objectionable of these impurities can be removed before crystallization. Phosphorus and arsenic can be removed by precipitation of insoluble magnesium ammonium compounds which can then be removed by filtration. The heavy metals such as molybdenum are removed similarly with ammonium sulfide.

Crystals of ammonium paratungstate are only negligibly soluble in hot or cold water, and therefore further purification by recrystallization is fruitless. However, the crystals can be dissolved by acids and caustic soda, decomposed by heat, or reduced to metallic tungsten powder by hydrogen.

Dissolution of ammonium paratungstate in acid is generally adopted as the next step in obtaining pure tungstic acid. Crystals are added in small quantities to pure hydrochloric acid which is then brought to a boil by steam. The reaction involved can be represented by the equation:



After settling, the spent acid is decanted and the tungstic acid precipitate washed free of soluble salts. Further purification can be accomplished by resolution in ammonia and recrystallization as ammonium paratungstate, or by dissolution in caustic soda or potash and precipitation with hydrochloric acid. In any event, tungstic acid is washed, filtered, and dried to form a cake containing about 50 percent WO_3 .

Direct decomposition of ammonium paratungstate by heat at about 400 C. (752 F.) results in a high packing density (29-31 g/in.³) oxide with particle size ranging between 4 and 5 microns, while caustic soda or potash treatment prior to precipitation with hydrochloric acid and breakdown to tungstic oxide results in an oxide of low packing density (15-18 g/in.³) and particle size varying from 0.5 to 2 microns.

In the manufacture of ductile tungsten it is often desirable to add small amounts (up to about 2 percent) of nonvolatile oxides of thorium or alumina or volatile oxides of the alkali metals. Silica also fits the latter group. Alumina or thorium particles which are finely dispersed in the grain boundaries inhibit grain growth by acting as barriers between grains. On the other hand, tungsten metal to which volatile oxides are added tends to become large grained. Advantage is taken of these directly opposite effects in the manufacture of filaments. Thorium is added to prevent a phenomenon known as "offsetting" (failure by slip due to large grains) which occurs in straight-line filaments in the absence of nonvolatile oxides. Additions of volatile substances prevent sagging in coiled filaments used at high temperatures up to 2500 C. (4532 F.), since it has been determined that large, long grains reduce to a minimum intergranular weakness. Additives are almost always added to the oxide stage to obtain maximum homogeneity. This can conveniently be done by adding a standard aqueous solution of thorium nitrate or sodium potassium silicate to the part of the tungsten oxide to be doped and mixing thoroughly. The doped paste is then dried and ignited in silica dishes at 300-1000 C. (572-1832 F.), depending on particle size desired. Calcining temperatures of 650 C. (1202 F.) and above increase particle size and density.

PRODUCTION OF METAL POWDER

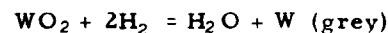
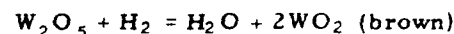
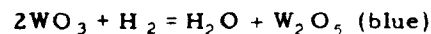
Tungsten metal in the form of powder is obtainable by various methods from tungstic acid or oxide or ammonium paratungstate. The method adopted depends on the purity desired and end use of the product. However, whatever method is used a tungsten loss of around 2 to 5 percent should be expected. For ductile tungsten and hard metal, freedom from impurities and controlled particle size are a prerequisite. For alloying, a greater latitude in impurities is permissible and particle size is not as important. In the former case, hydrogen reduction of the trioxide is universally adopted because the method lends itself to meeting the requirements of purity and close control. In the latter case, where economy and simplicity are the first considerations, carbon reduction is generally used, although other methods such as reduction with metals, electrolytic reduction, etc., have been developed.

Hydrogen Reduction

Reduction of tungstic acid or oxide is relatively simple, but the conditions of reduction markedly influence particle size, which may range from 1/2 to 500 microns in diameter. For fine powder such as is used in ductile tungsten and tungsten carbide where high hardness and abrasion resistance is desired, temperatures should be as low as possible. As temperatures increase from 700 C. (1292 F.), the low for complete reduction, particle size increases--0.5 microns at 800 C. (1472 F.) to 10.0 microns at 1200 C. (2192 F.). In practice, a temperature no lower than 800 C. (1472 F.) is used, since reduction is too slow at lower temperatures. However, particle size is also related to the texture of the oxide; a coarse oxide will never produce a fine powder, but coarse powder can be obtained from fine oxide. The amount of water vapor present in the furnace atmosphere also affects particle size; the higher the concentration the larger the size--particle size up to 500 microns is possible. Two or more stages are usually used for reduction, but for the largest size, batch reduction at 1200 C. (2192 F.) is used.

In order to produce fine metal powder, tungstic oxide is reduced by hydrogen in gas-fired or electrically heated tubular furnaces. The oxide is placed in thin layers into heat-resistant metal boats (nickel or high nickel-chrome alloy), and fed slowly through heat-resistant tubes against a stream of rapidly flowing dry hydrogen which enters the discharge end. Surplus hydrogen is either burned at the feed end or, as is more practical, a closed system may be used thereby permitting recirculation of unburned hydrogen.

For reasons of size control the reduction is frequently carried out in at least two stages. In the first, the brown oxide WO_2 is produced at a comparatively low temperature. This is then mixed with a definite amount of unreduced yellow oxide WO_3 , and the mixture is reduced to the metal at slightly higher temperatures. Initial reduction temperature is approximately 550 C. (1022 F.), and complete reduction is effected between 780-1100 C. (1436-2012 F.), depending on the size of powders desired (usually under 5 microns). The reactions taking place during the two-stage reduction can be represented by the following equations:



Coarse powders up to 500 microns, required primarily for the tougher grades of carbide, can be conveniently produced by direct reduction of ammonium paratungstate with hydrogen. Batch reduction in an electric furnace is employed. The furnace is maintained at temperature between 800-1200 C. (1472-2192 F.) and reduction is completed in one operation.

The wide variations in particle size obtainable has led to Government issuance of an accepted particle-size specification for hydrogen-reduced powder. This specification and the chemistry of the powder are as follows:

Physical Specification

(1) Type I (fine powder)

Micron size	Percent particle count	Percent particle volume
1/2 and 1	70 to 85	15 to 40
2 and 3	15 to 30	45 to 85
4, 5, and 6 (max. 6)	0 to 5	0 to 15

(2) Type II (coarse powder)

1/2 and 1	15 to 35	0.2 to 0.6
2, 3, and 4	50 to 80	25 to 65
5, 6, and 7	5 to 15	20 to 55
8 and over	1/2 to 3	6 to 30

Particle size distribution should be established by microscopic examination of the powder, preferably by projection at a magnification on the order of 3,000 diameters.

Chemical Specification

Element		Percent
Tungsten	(%)	99.7 minimum
Oxygen	(%)	0.6 maximum
Iron	(Fe)	0.1 maximum
Molybdenum	(%)	0.1 maximum
Nonvolatile residues		0.1 maximum

¹Uncombined oxygen is not considered when computing the percent by weight of other constituents.

Carbon Reduction

Tungstic acid or oxide may be reduced by carbon or hydrocarbon gases. In one practice, lamp black is mixed with the oxide in stoichiometric equivalent (15.5 percent by weight of WO_3 , with 12-15 percent preferred) for the reaction represented by the equation $WO_3 + 3C = W + 3CO$. There is a tendency for the mixture to separate

into its component parts. To avoid this condition, 5 to 20 percent of the carbon required should be in the form of colophony. The mixture is then packed in luted graphite crucibles and heated in a gas-fired kiln to a temperature of 1100 C. (2012 F.). Covers must be sealed firmly to prevent oxidation by air leaking in. After a sufficient time at temperature to insure reduction of the oxide, the charge is furnace cooled to room temperature and removed. The tungsten powder is then washed free from ash and undecomposed oxide, dried, screened, and stored in airtight containers for future use. Tungsten loses from such an operation are seldom over 3 percent.

In another practice, natural gas is employed as a reductant and the operation is carried out in apparatus similar to that used in the production of hydrogen-reduced powder.

Metal powder produced by either process is not used where high purity is desired because of contamination with carbide and mineral substances from the reductant. Most of it is employed in the manufacture of cast tungsten carbide and some grades of sintered carbide.

Usual trade specifications for carbon-reduced powder call for a minimum of 98.8 percent tungsten and maximum of 0.25 percent carbon. Products are usually 65 mesh and finer, though premium grades are produced which approach the fineness of hydrogen-reduced powder.

MANUFACTURE OF DUCTILE TUNGSTEN

Ductile tungsten is made by converting sintered powdered metallic bars into malleable forms by working at elevated temperatures. The process in brief is:

Tungsten powders of high purity and suitable particle sizes are thoroughly mixed, put into a split die mold and hydraulically compressed at about 10-40 tons per square inch into a bar approximately 24 inches long by 3/4 inch square. Camphor dissolved in ether, or paraffin wax dissolved in benzene, is sometimes added to improve "green" strength of the pressed bar.

After removal from the mold, the bar is distinctly brittle. Pre-sintering in dry hydrogen at temperatures between 1000-1200 C. (1832-2192 F.) strengthens it and thus permits easy handling. Densities obtained by pressing and pre-sintering vary in the neighborhood of 10-13 grams per

cubic centimeter. (The theoretical density is 19.3 g/cm³.) After a final sintering treatment consisting of resistance heating, by pressing a direct current through the bar at 3000 C. (5432 F.), the bar is swaged at 1400-1500 C. (2552-2732 F.) to about 0.10 inch in diameter and drawn to fine wire at gradually lower temperatures. The final sinter increases density and ductility, reduces voids, removes impurities, and makes for a crystalline and metallic bar with hardness values of Rockwell C 25 to 35. In the production of rod and filament wire, expected yields from powder to rod and from powder to wire of around 75 and 55 percent, respectively, are not out of order. The low yields are due primarily to high end cropping. The tungsten in the scrap is recoverable.

In the final treatment the pre-sintered bar is enclosed in a bell-type hydrogen

furnace and is suspended vertically between a fixed water-cooled copper contact clamp at its upper end and a loose slip clamp submerged in a water-cooled well of mercury at its lower end. The loose slip clamp permits free movement of the bar without breaking the current as the bar shrinks during heating. Current passing through the bar is adjusted to about 90-95 percent of that required to melt the ingot. During this treatment the rod shrinks lineally about 15-20 percent and has a density of about 17-18 g/cm³.

At room temperature such a bar is still very brittle but can be forged when heated to temperatures around 1100-1700 C. (2012-3092 F.). All working is, therefore, hot but below the recrystallization temperature, which ranges from about 1600-2000 C. (2912-3632 F.) down to about 1200 C. (2132 F.), depending on the severity of cold work. Above its recrystallization temperature, tungsten metal is quite brittle. Jefferies has pointed out that slight grain growth can be detected in unworked bars at about 1000 C. (1832 F.). However, the grain size does not increase appreciably until temperatures of around 2600-2800 C. (4712-5072 F.) are reached, where it is at its maximum. With increased deformation this grain-coarsening temperature is lowered somewhat. At the same time, the temperature limit at which a bar can be worked is lowered.

For hot working (or what may better be called "hot-cold" working, since all working is done below the temperature of recrystallization) swaging is ideal. Swaging

is done between two halves of a spinning die which periodically fly apart centrifugally to allow entry of the bar, and then are forced together on impact with a surrounding ring of rollers, thus effecting a reduction in bar size by the repeated hammer-like blows of the die halves. Re-heating in hydrogen is done as required to avoid fracture. Swaging increases the density of the rod to 18-19 g/cm³. As the work progresses, a tough fibrous-like structure develops which imparts sufficient toughness to the rod so that from about 0.080 inch diameter it can be drawn at intermediate temperatures through tungsten carbide dies to about 0.040 inch diameter, after which it is pliable enough to be coiled onto a reel. At about 0.010 inch in diameter and under, drawing is done through diamond dies. Dies are maintained at 300-400 C. (572-752 F.) throughout the drawing operation. The larger sizes are usually drawn at about 800 C. to 1000 C. (1472-1832 F.); the smaller sizes from 300 C. (572 F.) to around 400 C. (752 F.). To permit threading through the die, pointing may be done by chemical etching with molten sodium nitrate (NaNO₃). The very fine sizes, however, are usually etched electrically in dilute acid. Colloidal graphite is used as lubricant for drawing.

Tungsten sheets are also produced by "hot-cold" working. The bar is first forged and then rolled to the desired thickness. However, because tungsten oxidizes readily at rolling temperatures, the sheets are usually "pack" rolled or protected by a metal envelope during rolling.

MANUFACTURE OF CEMENTED TUNGSTEN CARBIDE

Tungsten carbides are produced by reactions involving metal or oxides and carbon or carbonaceous compounds in a protective atmosphere at high temperatures. Several methods for obtaining carbides have been devised, the more practical of which are: (1) Fusion of tungsten metal or its trioxide and carbon at temperatures approaching the melting point of tungsten (classical method); (2) direct carburization of tungsten metal powder, its acid, or its trioxide with carbon or carbonaceous gases; (3) the combined reduction of the ore and carburization of the metal; (4) chemical separation from molten metal menstruum; and (5) deposition from a gas phase.

Preparation

Carburization of tungsten metal powder or its trioxide with carbon or carbonaceous gases.--Of all possibilities of carbide formation, carburization of tungsten powder or tungsten trioxide is preferred by the cemented carbide manufacturers. Here advantage is taken of the fact that tungsten metal powder or its trioxide will react with carbon below its melting point thereby producing the monocarbide (WC) between 850 to 2200 C. (1562-3992 F.). Carburization is usually carried out on the low side of the temperature range to retard grain growth. However, temperatures below 850 C.

(1562 F.) are not used because the reaction is too slow. Starting materials are pure tungsten powder or its trioxide and lamp black. These are blended, placed in carbon boats, and heated in a nonoxidizing atmosphere for about 2 hours at 1450-1500 C. (2642-2732 F.) in either an open high-frequency induction or carbon-tube furnace, after which the tungsten carbide product is allowed to cool under hydrogen to room temperature. The carbide is then crushed dry to pass a 200-mesh screen. Very thorough mixing is required to produce a product containing the minimum of free carbon. The standard powder contains not over 0.1 percent uncombined carbon. The total carbon should be between 6.05 and 6.2 percent.

Combined reduction of the ore and carburization of the metal.--The preparation of the monocarbide by direct reduction of the ore with carbon (bituminous coal) at a temperature around 1450 C. (2642 F.) in the presence of iron and tin, suggested recently by Li and Dice (U.S. Pat. 2,535,217--1950), has promising possibilities. The end product, after cooling and crushing, is leached in an aqueous solution of hydrochloric acid to remove the acid-soluble portion. The carbide is recovered from the residue by gravity separation. It is claimed a tungsten yield of about 86 percent is possible.

Philip M. McKenna (U.S. Pat. 2,529,778--1950) developed a similar procedure for preparing carbide, except that reduction took place in the presence of silicon. It was stated the method was suitable for any type ore, but for best results should have an added metal component such as iron, manganese, nickel, or cobalt.

Another innovation is that under a British patent (635,972--1950) wherein it is cited that tungsten carbide (WC) is made by pressing a mixture of tungsten and carbon at 14,000-84,000 lbs./in.², and then heating the compact in graphite crucibles under hydrogen at 1600 C. (2912 F.) for about 30 minutes.

Deposition from a gas phase.--D. T. Hurd, (General Electric) obtained a patent in 1952 (U.S. 2,601,023) for preparing tungsten carbide (WC) of particle size 0.5-20 microns from tungsten carbonyl of particle size about 5 times that of the desired carbide. The process comprises the introduction of tungsten carbonyl into a hot zone of a furnace maintained at temperatures of 650-1100 C. (1202-2012 F.) and then subjecting

the resultant decomposition product to a 4-part CO-1-part CO₂ atmosphere at 1000 C. (1832 F.).

Chemical separation from molten metal menstruum.--Still another method of carbide formation only recently receiving prominence in commercial production is the chemical separation of carbide from its parent matrix. The process is based on the high stability of carbides relative to base metal against acid attack whereby separation can be effected. Basically, the process involves the formation of carbides at high temperatures in a suitable menstruum, and dissolution of the melt in an appropriate acid. The residue is the desired carbide. Starting materials may include tungstic oxide plus carbon and solvent metal or, as is more practical for complex carbides, pre-alloyed carbides plus a molten solvent metal.

Philip M. McKenna (U.S. Pat. 2,113,355--1938) employed this principle in making titanium-tungsten-carbide metal powder. Tungsten and titanium powders were intimately mixed with graphite, charged into a graphite crucible along with nickel, and heated to 2000-2100 C. (3632-3812 F.) to react the powders. The reaction product, a titanium-carbide-tungsten-carbide solid solution, after crystallization was recovered by dissolving the nickel in aqua regia.

Sintered tungsten carbide, or "hard metal" as it is sometimes called, used for machining steels, generally contains some titanium carbide. The addition tends to prevent the cracking observed when hard metal was made up of only tungsten carbide and cobalt. This is then added as a double carbide of tungsten and titanium.

The usual procedure for making double carbide is to pack a mixture of titanium dioxide (preferably titanium carbide), tungsten powder, and carbon into covered carbon crucibles and heat under hydrogen to about 2000 C. (3632 F.) in a high-frequency vacuum furnace or carbon-tube furnace. In the reactions that ensue, carbon reduces TiO₂ to form titanium carbide and at the same time carburizes the tungsten metal powder. The net result is a double carbide of tungsten and titanium. The mass is then pulverized to a maximum particle size of about 15 microns. For a double carbide containing equal proportions of tungsten carbide and titanium carbide, the total carbon should be about 13 percent with not over about 0.5 percent free carbon.

Fabrication

Most tungsten carbides are made into products which require cementing or bonding with another metal, because sintered carbides are hard and nonmalleable. The metal commonly used is cobalt, generally in the order of 5 to 30 percent of the carbide. Increasing cobalt increases toughness but decreases hardness. For machining cast irons, fine-grained carbide with cobalt addition of 4-10 percent is used, depending on the toughness necessary. For large drawing dies, mining tools, and the like where toughness becomes increasingly important, a coarser grained carbide with cobalt varying from 6 to 30 percent is used. For machining steel, titanium carbide up to about 15 percent may be added for prevention of cracking, as stated previously. The applications of cemented carbides are discussed more fully in chapter V.

In the manufacture of cemented carbides for various products such as tools and dies, it is important to control the particle size of both the metal powders and the carbides. The performance of the finished product depends largely on the grain size of the material, the density, hardness and the surface condition. The methods of production determine these properties. Production of cemented carbide from concentrate to carbide involves about a 15 percent loss in tungsten. The additional 5 percent over that in the preparation of tungstic acid or oxide is incurred in handling due to fineness of powder.

There are three important methods of manufacture of cemented carbides: (1) Cold press, (2) hot press, and (3) extrusion.

Cold-press method.--This method makes use of open molds or dies made of either hardened steel or lined cemented carbide into which prepared tungsten carbide powders are placed after having been mixed with cobalt in a ball mill until a thin layer of ductile cobalt smears completely every particle of carbide. Cobalt is usually used as bonding material although nickel, if over about 20 percent, has been found satisfactory.

Up to about 1 percent paraffin wax dissolved in carbon tetrachloride is added to lubricate the mixture in order to facilitate easy flow under pressure. Without the lubricant, the metal powder, due to its extreme fineness, tends to crack. Warming the mixture will drive off the carbon tetrachloride, leaving the particles of

powder coated with a thin film of wax. This waxed mixture is then pressed, under pressure of 10 to 30 tons per square inch, into shapes somewhat near their final form. The molded articles are then placed on graphite slabs and slowly pre-heated to 800-900 C. (1472-1652 F.) in a protective atmosphere to vaporize the wax and sinter the cobalt. The treatment tends to strengthen the articles so that they can be machined or ground to the required shapes. The shaped pieces are then packed in carbon black or alumina, and sintered in a hydrogen atmosphere, usually in the presence of carbon, or in a vacuum, at temperatures varying from about 1350 C. (2462 F.) for grades containing 25 percent cobalt to 1450 C. (2642 F.) for 6 percent cobalt, and to nearly 1600 C. (2912 F.) for titanium carbide grades. In general, the higher the percentage of cobalt, the lower the sintering temperature. During sintering the cobalt metal becomes molten and dissolves about 14 percent of the tungsten carbide which, except for 1 percent, reprecipitates upon cooling. On sintering, the pieces shrink lineally about 20 percent and attain their final hardness and density.

Articles sintered in alumina powder show a slightly higher density but have a tendency to distort more than pieces that are packed in carbon, probably due to an uneven heat distribution. Carbon-packed pieces also show a slightly harder surface layer which may be due to the migration of cobalt away from the surface. This makes for a greater resistance to abrasion.

Free tungsten may be added to the carbide powder to obtain increased abrasion resistance. Some of the free tungsten reacts with the cobalt bond; however, most will react with tungsten carbide to form the lower carbide W_2C , which, though more brittle, is harder and therefore more wear-resistant than the saturated carbide.

Hot-press method.--This method, utilized principally for making large pieces and intricate shapes, differs from cold pressing in that pressing and sintering are carried out at the same time. Graphite molds may be used but are not reusable since they are broken away from the shapes after cooling. Pressures from about 500 to 2500 p.s.i. are applied to the powders while they are being heated to sintering temperature by means of a high-frequency current. As the shapes shrink during sintering, pressures are maintained sufficiently high for compacting the material into final forms. One advantage of hot

pressing is that shrinkage occurs in only the direction of pressing so that close tolerances can be maintained in all other directions. Care is necessary to prevent squeezing out the binder and to eliminate the formation of large "lakes" of binder within the product.

Extrusion process.--Rods, tubes, angles, twist drills, etc., may be made by first

mixing the bonding materials with a suitable plasticizer such as sugar dissolved in alcohol or ether and then extruding the mass under high pressure into the desired shapes. This is followed by low-temperature volatilization of the organic binder and sintering treatments similar to those used in the cold-press method.

MANUFACTURE OF CAST TUNGSTEN CARBIDE

Tungsten subcarbide W_2C or a mixture containing about 70 percent W_2C and 30 percent WC is sometimes produced by melting and casting. The castings are more brittle than sintered material and, therefore, have a more restricted range of use. However, they have been found superior to sintered tools for machining hard rubber, for hot or cold drawing dies, and for deep-boring bits. As a cutting tool, the chief drawback seems to be in resharpening worn edges. Chemical spray nozzles, sandblast nozzles, and valves and valve seats for gas lines containing abrasive particles, can be made by casting. Aside from use as castings, fused carbides are extensively used as filling material in hollow steel welding rods which can then be used to produce hard-wear-resistant surfaces.

Starting material for cast carbide production consists of mixing technically pure (99.0-99.5% pure) tungsten powder, ranging in particle size from 50 to 500 microns, with between 30 to 60 percent tungsten metal and tungsten carbide scrap. Carbon need not be added since an adequate pickup will be obtained from the carbon melting

crucible. (Without a scrap charge about 3 percent carbon as graphite is usually added.) To improve castability and obtain a carbide free from graphite, 5 percent tantalum carbide is generally added. The addition of tantalum carbide prevents the formation of graphite--a tendency of pure tungsten carbide--by the formation of a eutectic of WC-TaC. The charge is then placed in a graphite crucible to which a mold is attached. The entire assembly is then heated in a specially designed horizontal carbon-tube tilting furnace or a high-frequency vertical furnace to about 3000-3250 C. (5432-5882 F.). When the carbide becomes molten the horizontal furnace is tilted to permit the molten carbide to flow into the mold. In the vertical furnace, a hole in the bottom of the crucible allows easy flow of metal into the mold. After cooling to about 2000 C. (392 F.), the mold and melting crucible are removed from the furnace. At a dark-red heat the mold is broken away from the casting, and the casting is then cleaned for use as such, or ground to desired particle size for use as filler for welding rods.

PRODUCTION OF FERROTUNGSTEN

Ferrotungsten is produced from all types of tungsten ore. It is used as a melting additive in the production of tungsten high-speed and other tungsten-bearing steels.

American Society of Testing Materials Specification A-144-50 and National Stockpile Specification P-57a-R (table VIII-6) call for:

Element	Unit	Requirement
Tungsten	(%)	99.00 minimum
Carbon	(%)	0.05 maximum
Manganese	(%)	0.05 maximum
Phosphorus	(%)	0.005 maximum
Sulfur	(%)	0.005 maximum
Aluminum	(%)	0.05 maximum
Silicon	(%)	0.05 maximum
Iron	(%)	0.05 maximum
Copper	(%)	0.05 maximum
Lead	(%)	0.05 maximum
Antimony	(%)	0.05 maximum
As	(%)	0.05 maximum
Sum of elements other than tungsten and carbon	(%)	0.20 maximum

While molybdenum is not included in the specification, the usual trade requirements are for a product containing not more than 0.80 percent molybdenum.

Several methods of making ferrotungsten by the reduction of tungsten ores are possible, namely: (1) Crucible, (2) alumino-thermic, (3) silico-thermic, (4) metallo-thermic, and (5) electric furnace. The electric furnace is the most popular in the United States while Europeans favor a thermic process. A product containing 70 to 80 percent tungsten is obtained by either method.

Crucible Method

This method, employed until the electric furnaces displaced it in 1900, used clay-lined crucibles which were filled with proper amounts of tungsten concentrates, coke, and high-tungsten steel scrap and heated by gas. Crucible life was short, depending upon the percentage of tungsten produced per heat.

Alumino-thermic Method

In this method powdered aluminum is used to reduce tungsten ores or concentrates in an electric furnace. The particle size of the ore and the amount and size of aluminum added control the speed of reaction and the efficiency of operation. Proper fluxing with lime, soda ash, and fluorspar along with the aluminum removes the gangue as slag. Since aluminum reduces all metallic oxides, only high-purity concentrates are utilized to alleviate contamination of the charge.

Silico-thermic Method

This process, similar to aluminum reduction, utilizes ferrosilicon to lower the cost. Concentrate, generally scheelite, is charged into a molten bath of ferrosilicon in an electric furnace employing ferrosilicon electrodes.

Metallo-thermic Method

In this method (a combination of the silico-thermic and alumino-thermic processes) instead of using the electric furnace

or any extraneous applications of heat, the reaction is started by chemical combination. A small amount of highly reactive ignition mixture made up of barium peroxide and ferrosilicon is placed in the center of the charge of ore, ferrosilicon, and aluminum. When the reaction temperature is reached, in about 5 minutes, reduction occurs, yielding ferrotungsten. The furnace for such an operation is a knockdown hearth-type. A "button" of solidified ferrotungsten is left in the hearth.

Electric Furnace Method

Ferrotungsten is produced from all types of ore in the electric furnace by carbon or silicon reduction. The details of the process are governed by the type of ores to be reduced: manganese ores are reduced under acid slags, scheelite and ferberite require lime slags. Older methods employing carbon as a reducing agent have been largely supplanted by those using ferrosilicon because of the higher recovery of tungsten achieved. Reported recovery is about 92 percent tungsten.

The ore, in admixture with ferrosilicon and basic fluxes, is fed into small arc furnaces of the knockdown type. Slag is tapped at intervals while the metal is permitted to collect as a solid block of alloy, or "button," as it is called, in the hearth. Inasmuch as the high melting point and high viscosity of ferrotungsten makes pouring impractical, when a "button" of 8,000 to 14,000 pounds has accumulated the furnace is knocked down (dismantled), and the solid "button" of metal is cleaned and crushed to about 1 inch or finer.

CHAPTER IV
CHEMISTRY

CHAPTER IV CHEMISTRY

PROPERTIES OF TUNGSTEN MINERALS

Tungsten does not occur as a native metal, and is present in relatively few minerals, of which only ferberite, wolframite, huebnerite, and scheelite are commercially important. Other occurrences of tungsten are of minor importance and, with the exception of tungsten-bearing manganese and iron oxides at Golconda, Nevada, are not exploited as ores of tungsten. The physical and chemical properties of the commercial tungsten minerals are summarized in table IV-1.

The wolframite minerals (iron and manganese tungstates) are dark-colored with a submetallic luster, and have a high specific gravity. The composition ranges from FeWO_4 to MnWO_4 in a completely isomorphous series. The end of the series con-

taining more than 80 percent FeWO_4 is called ferberite, the end containing more than 80 percent MnWO_4 is called huebnerite, and the intermediate compounds are called wolframite.

Scheelite (calcium tungstate) is light-colored, commonly white, yellow, or pale brown, with resinous luster and high specific gravity. Scheelite forms a more or less gradational series with the mineral powellite (calcium molybdate), and may contain varying amounts of molybdenum. Under ultraviolet light, scheelite fluoresces bluish white, grading to cream or yellow with increasing content of molybdenum. The molybdenum must be removed from the scheelite by chemical treatment if a molybdenum-free product is required.

PHYSICAL AND CHEMICAL PROPERTIES OF WROUGHT TUNGSTEN METAL

Physical Properties

The properties obtainable in tungsten metal are due in part to its inherent characteristics and in part to mechanical and thermal treatment. Properties of pure metal (table IV-2) differ considerably from the metal of commerce, which is almost invariably impure. Of all the metallic elements, tungsten has the highest melting point, the highest modulus of elasticity, the lowest vapor pressure, and the lowest compressibility. It is nonmagnetic. Its electrical conductivity, though about one-third that of annealed copper, is higher than that of nickel, platinum, or iron. As can be seen from the table, the electrical resistance of tungsten increases as the temperature rises. Tungsten metalwork hardens rapidly. Tensiles up to 300 tons per square inch are obtainable in fine wire. Coefficient of expansion and electrical resistivity are increased somewhat by cold working.

Chemical Properties

At ordinary temperatures tungsten metal in any but powdered form is unaffected by

oxygen. However, at red heat in air, it readily oxidizes to the yellow trioxide (WO_3). Oxide is also produced by heating in carbon dioxide at about 1200 C. (2192 F.), or in carbon monoxide at 1000 C. (1832 F.). Other gases, such as CS_2 , NO, and NO_2 , react with tungsten at high temperatures, as do the elements S, B, C, and Si.

At red heat sulfur dioxide produces some oxide, while hydrogen sulfide only darkens the surface. Below about 1200 C. (2192 F.), very little absorption of hydrogen occurs.

Hydrochloric and hydrofluoric acids and ammonium and aqueous or molten potassium or sodium hydroxide, in the absence of oxygen have no corrosive effect on tungsten. If tungsten is exposed to dilute hydrochloric acid for a number of hours at approximately 110 C. (230 F.), a thin oxide coating is formed. Mixtures of concentrated HCl and HF attack it rapidly. Sodium or potassium hydroxide in the molten state will oxidize metallic tungsten in the presence of oxygen or oxidizing agents.

Under normal temperature, dilute or concentrated nitric acid produces no immediate effect on tungsten but dulls the surface after exposure for several days. At 110 C.

TABLE IV-1.--PHYSICAL AND CHEMICAL PROPERTIES OF COMMERCIAL TUNGSTEN MINERAL

Property	Forsterite	Sulfurite	Wulfenite	Wulfenite
Composition	FeWO ₄ plus as much as 20% MnWO ₄	(Fe, Mn) WO ₄	MnWO ₄ plus as much as 10% FeWO ₄	As ₂ W ₈
Sp. Gr.	7.6-7.5	7.6-7.5	7.6-7.5	8.0-8.5
Mo. S.	0-3.6	3.6-14.5	14.5-18.1	14.5-18.1
Fe. S.	18.4-14.7	14.7-3.7	3.7-0	0
Crystal system	Monoclinic	Monoclinic	Monoclinic	Tetragonal
Cleavage	Perfect in one direction	Perfect in one direction	Perfect in one direction	Good in several directions
Specific gravity	7.6-7.5	7.3-7.5	7.12-7.3	8.1, decreases with amount of MnO ₂
Color	Black	Dark grayish or brownish black to black	Yellowish brown to reddish brown	Pale yellow, brown, or mainly white
Tenacity	Brittle	Brittle	Brittle	Brittle
Luster	Submetallic to metallic	Submetallic to metallic	Submetallic to metallic adamantine, resinous	Resinous to vitreous
Fracture	Uneven	Uneven	Uneven	Uneven to subconchoidal
Hardness	4.5	4-4.5	4	4.5-5
Streak	Chocolate brown to brownish black	Reddish brown, dark brown, and black	Brownish red to greenish yellow	White
Transparency	Opaque to weakly translucent	Translucent to opaque	Transparent to translucent	Transparent to translucent

(230 F.) concentrated nitric acid oxidizes tungsten slowly to the yellow trioxide WO₃. Tungsten is not attacked by hydrofluoric acid but mixtures of nitric and hydrofluoric acids will attack it.

Neither dilute nor concentrated sulfuric acid attacks tungsten at room temperature, but at about 110 C. (230 F.) some intermediate tungsten oxides form and the reaction is accelerated as the temperature is increased. Dilute acids produce the yellow oxide on the surface.

Aqua regia oxidizes the surface of metallic tungsten. However, the thin film formed prevents further attack even in boiling acid.

At room temperature fluorine reacts with tungsten, forming the hexa- or oxy-fluoride, the latter if air or moisture is present. At red heat bromine and iodine will attack tungsten. Molten or boiling sulfur reacts with metallic tungsten very slowly.

Tungsten when fused with alkaline carbonates such as sodium or potassium carbonate dissolves very slowly. When treated with molten nitrates, nitrites, and peroxides, violent reaction occurs. It also dissolves readily in basic solutions of K₃Fe(CN)₆ or saturated solutions of NaClO₃, as well as in aqueous solutions of CuCl₂ or FeCl₃. A solution of NaOH and K₃Fe(CN)₆ makes a good etching reagent.

TABLE IV-2.--PROPERTIES OF PURE TUNGSTEN

Atomic number	74					
Atomic weight	183.92					
Atomic volume	19.3					
Density at 20 C. (68 F.)	19.3 g/cm ³ (0.697 lb./in. ³)					
Compressibility at 20 C. (68 F.)	2.8 x 10 ⁻⁷ per kg per sq. cm. (This value is the smallest for any metal.)					
Melting point	3410 ± 20 C. (6170 ± 36 F.) (Bureau of Standards)					
Boiling point	5900 C. (10,632 F.)					
Coefficient of linear thermal expansion	4.3 x 10 ⁻⁶ /°C.					
Specific heat at 20 C. (68 F.)	0.028 cal/g.°C.					
Latent heat of fusion	44 cal/g.					
Thermal conductivity at 20 C. (68 F.)	1.99 watts cm ⁻¹ °C ⁻¹					
Vapor pressure						
Deg. kelvin	2,200	3,800	3,800	4,600	5,200	6,400 (b.p.)
Baryes	9.89x10 ⁻⁷	9.09x10 ⁻²	58	2.9x10 ³	2.2x10 ⁴	1.1x10 ⁶
Electrical resistivity at 20 C. (68 F.)	5.5 microhm cm					
Electrical resistivity versus temperature						
Deg. cent.	227	727	1227	1727	2227	3227
Microhm cm	10.5	24.3	39.5	55.7	90.4	198.5
Emissivity (spectral) at 4000 Å						
Deg. cent.	227	727	1227	1727	2227	3227
Emissivity	0.498	0.486	0.476	0.469	0.455	0.449
Crystal structure - Body-centered cubic (lattice parameter = 3.158 Å)						
Mechanical properties:						
Wickens hardness numbers:						
Unstressed bar	255					
Swaged to 1.5 mm	407					
Reheated to 2700 C.	392					
Swaged to 3.5 mm	474					
Swaged to 4.8 mm	488					
Tensile strength of drawn wire						
dia mm	0.5	0.1	0.05	0.02	0.015	0.015
Kg./mm ²	185	300	345	425	470	470
Modulus of elasticity	50,000,000 lb/in. ²					
Modulus of rigidity	19,600,000 lb/in. ²					

PREPARATION OF CHEMICAL COMPOUNDS

Many compounds of tungsten have been reported, but those involving oxygen are of prime importance.

The More Useful Compounds

Tungsten trioxide or tungstic oxide (WO_3), a bright yellow amorphous powder, is the most important of the oxygen-bearing compounds and is generally used for the production of metal powder. It can be formed by the oxidation of the metal or roasting of the lower oxides. It is insoluble in water and acid solutions, but dissolves in alkali hydroxides or carbonates to give tungstates. The extraction of tungsten trioxide from wolframite and scheelite ores is treated in chapter III.

Tungstic acid (H_2WO_4).--Hydrated tungsten trioxide ($\text{WO}_3 \cdot \text{H}_2\text{O}$) is a yellow amorphous powder, which as previously stated, is precipitated from soluble tungstate solutions with hot concentrated hydrochloric acid. It can also be obtained by decomposition of wolframite with hot aqua regia.

Sodium tungstate (Na_2WO_4) in anhydrous form may be prepared by fusing tungsten trioxide with sodium hydroxide or carbonate. Crystallization above 6 C. (43 F.) of an aqueous solution of previously fused wolframite and sodium carbonate yields the dihydrate $\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O}$.

Calcium tungstate (CaWO_4) occurs in nature as the mineral scheelite. It may be obtained by precipitation from an acidified solution of sodium tungstate with calcium chloride.

Magnesium tungstate (MgWO_4) may be obtained by fusing together sodium tungstate and magnesium chloride. The tungstate is soluble in water.

Ammonium paratungstate in the hydrated crystal form, $5(\text{NH}_4)_2\text{O} \cdot 12\text{WO}_3 \cdot 11\text{H}_2\text{O}$, is obtained by treating tungstic acid with ammonia. It is produced from either wolframite or scheelite and is used as an intermediate in the production of tungsten powder and other tungsten compounds.

Tungsten bronzes are used as pigments in the paint industry because of their brilliant colors and their chemical inactivity. These tungsten compounds apparently possess tungsten atoms of two different valences and are of the general type, $\text{M}_2\text{O} \cdot (\text{WO}_3)_x \cdot \text{WO}_2$. The cation is generally an alkali metal such as sodium or potassium. They are prepared by several methods, one of which is the reduction of acid tungstates with hydrogen or carbonaceous gas, at elevated temperatures. Bronzes so produced are insoluble in water and except for hydrofluoric are not attacked by acids.

Tungsten hexacarbonyl ($\text{W}(\text{CO})_6$), a volatile solid, may be obtained by the interaction of tungsten metal powder with carbon monoxide at 225-300 C. (437-572 F.) under high pressure (about 200 atm). It is not soluble in water and will decompose at about 150 C. (302 F.). Its chief use has been in the production of pure metals. However, recent investigations have shown that suitable tungsten coatings can be deposited on base metals by thermal decomposition of the carbonyl at temperatures between 300-600 C. (572-1112 F.) under vacuum (maximum total pressure under about 2 mm Hg). Hydrogen is used as a carrier for carbonyl vapor and to remove carbon, while reduced pressures aid in minimizing premature decomposition of carbonyl. Low temperatures favor deposition of carbon which results in a hard, brittle deposit. On the other hand, high decomposition temperature and a high hydrogen-to-carbon-monoxide ratio (100:1) will minimize carbon deposition. By adding a little water vapor to the gas, deposition of carbon can be eliminated entirely, producing a relatively soft tungsten metal coating. The process is rather simple. An object to be plated is heated in vacuum to 300-600 C. (572-1112 F.), and exposed to carbonyl vapor. As the gas comes in contact with the hot surface, tungsten metal plates out, forming a good adherent metal coating. A suitable plating apparatus is described by James Lander in United States Patent 2516058 issued in 1950.

CHAPTER V
APPLICATIONS AND SUBSTITUTIONS

CHAPTER V APPLICATIONS AND SUBSTITUTIONS

APPLICATIONS

Cemented Tungsten Carbide

Cemented tungsten carbide has assumed increasing commercial importance during the past 10 years and has replaced some tungsten alloys, especially in the tool and die industry, for the more exacting applications.

The extreme hardness of tungsten carbide and its great resistance to wear and deterioration at relatively high temperatures, make it an excellent cutting material. Powder metallurgy techniques are employed in the production of finished tungsten carbide products. Tungsten carbide powder is sintered with a low-melting-point metal binder, generally cobalt, in a nonoxidizing atmosphere. Tantalum, titanium, or columbium carbides, used in small amounts, singly or in combination, enhance the properties of cemented tungsten carbides and thereby enlarge the scope of applications for which they may be used. Such combinations of carbides have greater resistance to tempering (softening) at high temperatures, and prevent cratering under the edges of cutting tools. Because sintered carbides are mechanically weak and because of savings in cost, tungsten carbide tools usually are made with carbide faces or tips fastened to good load-supporting carbon or low-alloy steel shanks. In addition to their use for faced tools, cemented tungsten carbides are processed into dies for hot and cold drawing operations.

The performance of cemented tungsten carbide products is dependent upon the various properties inherent in the material, such as high indentation and abrasive hardness and high compressive strength, modulus of elasticity, and fatigue endurance. These in turn are dependent on composition and proportion of mixtures, and condition of sintering.

Cemented carbides are not generally used in corrosive media except where high indentation hardness and abrasive resistance are needed. The binder is subject to attack by acids, and the carbide by many alkalis.

Attack by oxidation at high temperatures is a further limitation.

The quality of sintered carbide may best be predicted by means of a fracture test. Homogeneity of structure, and other desirable appearances in the fracture, become evident to the expert on close examination of the fracture.

The effect of temperature on hardness of these materials reveals that over a temperature range of 40-760 C. (104-1400 F.) an average drop in hardness of about 10 to 15 (Rockwell A scale) occurs for cemented tungsten carbide, or for titanium and tantalum combinations.

A coarse grain or an increase in the amount of binder decreases hardness, as shown by the hardness values given below:

<u>Cemented Carbide</u>	<u>Hardness Rockwell A</u>	
	<u>100 F.</u>	<u>1,400 F.</u>
WC-TiC-7% Co	93	79
WC-TaC-TiC-11% Co	91	75
WC-TaC-13% Co	86	72
94% WC-6% Co (fine grain)	92	82
94% WC-6% Co (coarse grain).....	91	78

Knoop hardness measurements of tungsten carbide bonded with cobalt place it on the Moh's scale above topaz (8) and below sapphire (9). In the hardness scale above tungsten carbide are aluminum oxide, silicon carbide, and boron carbide, increasing in hardness in the order named. These materials along with diamonds are used for grinding tungsten carbide tool tips during the course of machining operations.

The chief applications of cemented tungsten carbide products are for cutting tools, dies, wear-resistant parts, and high velocity armor-piercing projectiles. Applications of intermittent loads should be avoided because of low impact strength. Following is a list of tools representing various processing operations:

Uses where cutting ability is important--

Broaches
Facing, boring, turning, and threading tools
Files
Glass cutters
Milling cutters
Reamers
Shear blades
Lathe tools
Special carbide saws

Uses where resistance to wear is imperative--

Ball mill plugs
Brinell balls
Burnishing tools
Centers for lathes and grinders
Dies for extruding, swaging, wire drawing, etc.
Gate contact points
Paper guides
Rest pads and rollers
Rock drills
Rolls for precision cold rolling
Sandblast nozzles
Spring coiling arbors, pitch tools, guides, etc.
Teeth and jaws for excavators
Thread and wire guide

Tool tips are usually cemented in the holder by means of brazing, though mechanical fastening is sometimes employed. For brazing the carbide tips onto the steel shanks, powdered silver-copper alloys mixed with the required flux may be used. After brazing, the tool is cooled slowly to avoid setting up undue strains at the interfaces.

Tool tips are usually ground with diamond-silicon carbide wheels. In many cases honing is employed, since this helps prevent chipping at the cutting edge due to the elimination of microscopically large peaks which tend to break behind the cutting edge during operations.

Cemented tungsten carbides are used in dies for hot and cold drawing of wire such as tungsten, molybdenum, copper, aluminum, and steel. A large percentage of rod, wire, and tubing, from very small size to approximately 3-1/2 inches in diameter, is fabricated today through the use of these dies. Because of their great wear resistance, dies from these materials hold their dimensions over long periods and permit the fabrication of products that require

close tolerances. Other applications are in cold heading of bolts and in drawing operations, notably the drawing of the noses of shell forgings.

Tungsten carbides are finding use in hard facing application to resist wear. Carbide particles of various sizes are encased in a steel tube which, when applied as a weld rod, melts to form a molten matrix. Upon solidification, the carbide particles which do not melt are evenly distributed throughout the weld deposit. Instead of using a weld rod as for oxy-acetylene or electric welding, the base metal can be melted under an inert gas shield to produce a pool, and cast or sintered tungsten carbide particles poured into the puddle from a hopper directly behind the arc. In this arrangement the molten metal freezes around the carbide particles, locking them in.

In the field of ballistics, tungsten carbide has reached great importance during the last 10 years or so. Its first use in this area is credited to the Germans who made it into bullet cores during World War II. High velocity armor-piercing projectiles made of this material proved very successful, especially in anti-tank warfare, and necessitated further improvements in armor plate.

Tungsten Steels and Alloys

Tungsten combines with iron and carbon and other carbide forming alloying elements to form complex carbides which are stable at high temperatures. It is also a mild ferrite strengthener and may impart some hardenability to steel. Addition of only 1 or 2 percent tungsten to tool steels produces a fine grain and silky fracture when hardened. (Fine grained steels are less likely to distort or crack on hardening.) In addition, this increases toughness. However, it is their stable, wear-resistant complex carbides that have made tungsten steels superior to all other steels for difficult machining and forming applications. Tungsten in the lower percentages, under about 6 percent, improves shock resistance; higher percentages of tungsten improve resistance to wear and softening at working temperatures. Where only hardenability and good strength are desired, as in low alloy steels, they may be obtained with less cost by the use of cheaper alloying elements, such as chromium, silicon, manganese, carbon, nickel, etc.

High-speed steels. The common type of high-speed steel frequently referred to as "18-4-1" type, nominally contains 18 per-

cent tungsten, 4 percent chromium, 1 percent vanadium, and 0.50-0.80 percent carbon. The chief property of tungsten in steel, when in the presence of chromium, is its ability to retain considerable hardness at elevated temperatures. This property is often called "hot hardness" or "red hardness." It insures a wide permissible hardening range, ease of heat treating, and the retention of a sharp cutting edge at high speeds and elevated temperatures. A high carbon content results in a higher obtainable hardness, better cutting ability, and increased wear resistance. A lower carbon content increases shock resistance. A carbon content between 0.67-0.73 percent gives the best combination of hardness, cutting ability, and wear and shock resistance. The high carbon types of high-speed steels find use in cutting tools such as drills, broaches, reamers, shaper tools, etc., while the low carbons are applicable to hot-work uses, cold punches, etc. Increases in vanadium improve wear resistance and red hardness. These beneficial effects are incorporated in the "18-4-2" steels for general purpose cutting where fine finishes are required. Lowering the tungsten content to 14 percent increases toughness but at a sacrifice of wear resistance; however, an addition of 2 percent vanadium will give properties comparable to those of the "18-4-1" steels.

"Super high-speed" steels are modifications of the basic composition of high-speed steel with cobalt added. Cobalt additions up to 12 percent are effective in increasing red hardness, thereby increasing cutting ability at high tool temperatures and high speeds. Although the action of cobalt in high-speed steel is not completely understood, it does raise the solidus temperature, thereby permitting quenching from higher temperatures, with the consequence that more carbides go into solution to increase high temperature properties. To retain hardness, the carbon content must be increased. The biggest drawback of the super high-speed steels, however, is brittleness which causes chipping or breaking.

The cobalt type steels perform well in roughing cuts or cutting hard, gritty or scaly materials at high speeds, but for finishing cuts where tool temperatures are low they are inferior to the "18-4-1" type high-speed steels. They, therefore, find extensive use in machining cast iron and nonferrous alloys where machining involves discontinuous chips.

Development of the molybdenum type high-speed steels represented a noteworthy

trend in the tool steel industry. The ability of molybdenum to impart "red hardness" to steels, as calculated on a weight basis, is approximately twice that of tungsten--that is to say, 1 part of molybdenum can replace about 2 parts of tungsten without materially affecting the general mechanical properties of high-speed steels. Therefore, many high-speed steels may contain partial to total substitution of tungsten by molybdenum (see table V-1).

TABLE V-1--CHEMICAL COMPOSITION (%) OF SOME TUNGSTEN-BEARING HIGH-SPEED STEELS

Type*	C	W	Cr	V	Mn	Si
1. 18-4-1	0.70-0.80	18.0	4.0	1.0	0.15	0.15
2. 18-4-2	0.80	18.0	4.0	2.0	0.15	0.15
3. 18-4-3	1.00	18.0	4.0	3.0	0.15	0.15
4. 14-4-2	0.80	14.0	4.0	2.0	0.15	0.15
5. 14-4-3	1.00	14.0	4.0	3.0	0.15	0.15
6. 14-4-1 + 5% Co	0.75	14.0	4.0	1.0	0.15	0.15
7. 18-4-2 + 8% Co	0.80	18.0	4.0	2.0	0.15	0.15
8. 14-4-2 + 5% Co	0.80	14.0	4.0	1.0	0.15	0.15
9. 20-4-2 + 12% Co	0.80	20.0	4.0	2.0	0.15	0.15
10. 6-4-1-5	0.80	6.00	4.0	1.0	0.15	0.15
11. 6-4-4	1.25	6.00	4.0	4.0	0.15	0.15
12. 6-4-1-5 + 5% Co	0.80	6.00	4.0	1.0	0.15	0.15
13. 6-4-1-5 + 8% Co	0.80	6.00	4.0	1.0	0.15	0.15
14. 14-4-1-9	0.80	1.50	4.0	1.0	0.15	0.15
15. 14-4-1-9 + 5% Co	0.80	1.50	4.0	1.0	0.15	0.15
16. 14-4-2-9 + 5% Co	0.80	1.75	4.0	2.0	0.15	0.15

*Types represent: 18-4-1, 18-4-2, 18-4-3, 14-4-2, 14-4-3, 14-4-1 + 5% Co, 18-4-2 + 8% Co, 14-4-2 + 5% Co, 20-4-2 + 12% Co, 6-4-1-5, 6-4-4, 6-4-1-5 + 5% Co, 6-4-1-5 + 8% Co, 14-4-1-9, 14-4-1-9 + 5% Co, 14-4-2-9 + 5% Co.

Note: Mn and Si, about 0.12%; P and S about 0.02% maximum.

Hot-work steels.--The use of tungsten in steels permits the hot forming of metals at relatively high temperatures without seriously impairing their tool-life qualities. Tungsten type steels satisfactory for hot-working up to about 1150 F. (620 C.) contain low percentages of carbon, ranging from 0.25-0.60 percent, and generally from 9-15 percent of tungsten with small additions of other elements. To augment the beneficial effects of tungsten, 2-4 percent chromium, 0.3-0.6 percent vanadium, and sometimes about 2 percent molybdenum are added. Since these additions, like tungsten, are ferrite promoting elements, 1-3 percent nickel may be added to counteract this tendency. This small amount of nickel raises the hot-working range to about 1300 F. (705 C.).

Many characteristics of high-speed steels are also common to the tungsten hot-working steels. All are air-hardening steels. In addition, these tungsten steels show superior toughness and shock resistance due to lower carbon content. They resist softening at temperatures to about 1150 F. (620 C.), steels with above 12 percent tungsten being superior. The lower tungsten steels are preferred where shock and sudden changes in temperature are encountered. Where relatively high red hardness or wear re-

sistance is desirable, an 18 percent tungsten, 0.50 percent carbon type steel is recommended. Its behavior is like regular high-speed steel in heat treatment except that hardness values are slightly lower due to the lower carbon content.

Tungsten-chromium type.--Hot-working steels containing approximately equal proportions of tungsten and chromium were developed to utilize the beneficial effects of both. All contain approximately 0.3-0.5 percent carbon, 6-8 percent tungsten, 6-8 percent chromium, and 0.8-2 percent silicon. They may also contain 0.2-0.6 percent vanadium to increase hardness and high temperature stability. Hardness values depend upon the combination of carbon, tungsten, and chromium. Chromium contents higher than those in the 9-15 percent tungsten group help to reduce scaling during heat treatment. The high silicon content, introduced to make a fragile scale that can easily be removed, also improves resistance to wear and erosion, and decreases scaling on air cooling. These steels, not generally recommended for use at temperatures over 700 F. (370 C.), possess medium wear resistance, good strength, and good shock resistance. The lower carbon grades (0.35 percent), due to their high toughness, are used for punching or piercing hot metal, while the higher carbon grades are used for dies, grippers and headers in hot-forming operations.

By lowering the tungsten and chromium content to about 5 percent each, steels of greater strength and shock resistance can be produced at no great sacrifice in working hardness. These steels are preferred to the 9-15 percent tungsten steels in operations involving watercooling. A steel of comparable hardness can also be obtained by decreasing the tungsten content to about 1-2 percent and adding 1-2 percent molybdenum; by this, however, wear resistance is decreased. Nitriding in some cases increases wear resistance, with the result that tool service life may be increased from 2 to 3 times.

All of these steels are deep-hardening and can be hardened in air or oil. Although they do not possess the heat resistant properties of the 9-15 percent tungsten type steels, they are stronger and can withstand a considerably greater amount of shock. General applications are for dies for casting aluminum and its alloys, and for forging dies, punches, piercers, mandrels, shear blades, and the like.

Finishing steels and die steels.--When

3-6 percent tungsten is added to plain high-carbon (1.15-1.40% C.) tool steels, shallow water hardening steels possessing extremely hard wear or abrasive resistant surfaces are obtainable. Because of their intensely hard surfaces they take a keen edge, hence are suitable for finishing much harder material than will the plain carbon steels; provided, of course, feeds are light and speeds are slow. Tools from such steels are used primarily for cutting nonferrous metals, sometimes for drawing dies, and for cold striking dies when wear resistance is more important than shock resistance. For better wearing properties the carbon and tungsten content should be kept on the high side, but this will result in lower shock resistance and greater warpage. For improved shock resistance, tungsten is usually kept at about 4 percent and carbon about 1 percent. Chromium and vanadium may be added to increase toughness.

These composition steels are erratic in their heat-treatment, tending toward decarburization and graphitization when subjected to prolonged heating prior to quenching. The addition of chromium helps to counteract these defects, as well as to decrease warpage. Chromium also changes tungsten-carbon steel from a shallow-hardening to a deep-hardening steel, and if chromium is high it produces a degree of red hardness not obtained by tungsten or chromium alone.

The addition of tungsten in no way increases hardenability over that obtainable in a plain carbon steel at the same carbon level; therefore, a case and core structure is produced on quenching. By adding chromium or molybdenum and varying the amount up to 0.50 percent, the case can be controlled to any depth desired. It may be pointed out, however, that the core in tungsten carbon steels is always harder than that in plain carbon steels, which may account for the superior physical properties of the former.

With the addition of about 0.5-1.5 percent chromium, the steel shifts from a water-hardening to an oil-hardening type which not only has greater toughness but avoids the shallow-hardening difficulties of the plain tungsten steels. These steels make good taps and reamers.

"Nondeforming" steels.--Tungsten may be used in steels which are relatively non-deforming. These steels are among the most important of all tool steels because of their ability to maintain dimensional stability during the hardening process; this characteristic is attributable to residual austenite

present in the structure. This means that they may be machined in the soft or annealed condition and then hardened without appreciable changes in size. The presence of tungsten increases wear resistance and retards grain growth, thereby increasing resistance of intricate shapes to cracking on hardening. These steels are preferred for the finest cutting tools where a keen edge is necessary, hence they are used extensively for roll-turning tools, and for paper and wood-working knives. One of the tungsten oil-hardening steels contains 1.30-1.80 percent tungsten, 1.00 percent carbon and 0.75 percent chromium.

Shock resisting steels.--These steels contain 1.0-3.0 percent tungsten, up to 2 percent chromium, 0.25-1.50 percent silicon, and about 0.50 percent carbon; additions of about 0.20 percent vanadium increase fatigue resistance. They are oil-hardening, very tough, and shock resistant. Silicon increases wear resistance but reduces impact values proportionately, but not to a dangerous level. Reducing silicon content to about 0.25 percent improves impact values to such an extent that even at maximum hardness these steels will bend before breaking. Hence they are most frequently used for heading dies, punches, chisels, and shear blades. Also, because of their toughness they can be used for hot-working purposes. In these latter applications the chromium and tungsten content is kept high.

High temperature alloys.--Since World War II there has been an increasing demand for alloys possessing high strength and non-oxidizing properties at high operating temperatures. This demand has resulted from the ever increasing need for alloys that will

withstand the temperatures encountered in the combustion chambers of modern aircraft. Temperatures in aircraft engines vary, depending upon the type of engine and the part in question. In the case of jet engines, temperatures are such as to defy the use of any highly alloyed steel. Actually, as temperature requirements increase, the alloy compositions change from ferrous to nonferrous bases. Thus, medium temperature applications may employ stainless types with many modifications, whereas the high-temperature alloys are predominantly cobalt or nickel base alloys in combination with about 20 percent chromium. Other alloy elements such as tungsten, columbium, molybdenum, titanium and aluminum may be used for specific effects. Tungsten, molybdenum and columbium, added singly or in combination, increase strength at elevated temperatures. Titanium and aluminum increase strength by producing precipitation phases; this contributes to both higher hardness and increased resistance to creep.

The metallurgical behavior of the high-temperature steels and alloys is not too well understood, and this accounts partly for the complexity of the alloys used. Final choice can be made only on the basis of trial and error. Constant research is being done in this interesting and promising field.

Table V-2 includes some of the popular high-temperature steels and alloys which contain tungsten. There are many others. The reader is referred to *Metals Handbook*, 1948 edition, for a more complete listing and discussion of the mechanical properties of these steels.

Performance of high-temperature steels and alloys is measured in the laboratory by the stress rupture test, at various tempera-

TABLE V-2.--CHEMICAL COMPOSITION (%) OF TUNGSTEN-BEARING HIGH-TEMPERATURE ALLOYS

Alloy type	C	Cr	Ni	Co	Mo	W	Cb	Fe	Other
Chromium-Nickel alloys									
Stainless 418.....	0.12	13.0	2.0	--	0.5	3.0	--	Bal.	.5Min. .5Si
C S A.....	0.40	18.0	5.0	--	1.4	1.4	0.6	"	4 Min. .5Si
19-9 D L.....	0.30	19.0	9.0	--	1.2	1.2	0.4	"	1 Min. .5Si, .3Ti
19-9 W-Mo.....	0.10	19.0	9.0	--	0.4	1.2	0.4	"	1 Min. .5Si, .4Ti
E M E.....	0.10	19.0	12.0	--	--	3.0	1.0	"	.5Min. .5Si, .15N
17 W.....	0.40	13.0	19.0	--	0.5	2.0	--	"	.6Min. .6Si
S 495.....	0.40	15.0	20.0	--	4.0	4.0	4.0	"	1 Min. 1 Si
Chromium-Nickel-Cobalt alloys									
G-18-B.....	0.40	13.0	13.0	10.0	2.0	2.5	3.0	Bal.	.8Min. .8Si
N 153 H.C.....	0.40	16.0	15.0	13.0	3.0	2.0	1.0	"	1 Min. .5Si, .15N
N 154.....	0.30	16.0	24.0	21.0	3.0	2.0	1.0	"	1 Min. .5Si, .15N
N 155.....	0.15	21.0	20.0	20.0	3.0	2.5	1.0	"	1 Min. .5Si, .15N
S 990.....	0.40	20.0	20.0	20.0	4.0	4.0	4.0	"	1 Min. .6Si
S 816.....	0.40	20.0	20.0	20.0	4.0	4.0	4.0	"	1 Min. .6Si
Refractory 70.....	0.05	20.0	20.0	30.0	8.0	4.0	--	4 max.	1 Min. .6Si
" 80 (cast).....	0.10	20.0	20.0	30.0	10.0	5.0	--	Bal.	2 Min. .3Si
H S 23.....	0.40	25.0	2.0	Bal.	--	5.0	--	1.6 max.	.6Min. .7Si
H S 31(X-45).....	0.40	25.0	10.0	"	--	8.0	--	2 max.	.5Min. .5Si
								2 max.	.5Min. .5Si

H S = Haynes Stellite

tures ranging between 1200 F. (650 C.) and 1800 F. (980 C.). Creep, fatigue, and coefficient of thermal expansion values at these temperatures are also determined. Some alloys are used in the wrought condition, but in many cases castings made by precision methods are employed because of the difficulty of machining wrought alloys and cause cast materials have better endurance properties than others at high temperatures.

Magnet steels.--During the period 1880-90 tungsten was added to steel for producing permanent magnets. About 5.5 percent tungsten with 0.70 percent carbon was widely used. Tungsten was used also with cobalt in quantities of 3-9 percent. At present, tungsten magnet steel has been largely supplanted by the Fe-Ni-Co-Al type alloys which are sold under various trade names; the most widely known is Alnico.

Cobalt-chromium-tungsten alloys.--The first alloy of this type was discovered by Elwood Haynes and placed on the market in 1913 under the name "stellite" for use as a cast cutting tool. These alloys are practically devoid of iron, and maintain hardness and strength at temperatures above 1100 F. (590 C.) better than the best high-speed steels. The cobalt content may vary from 38 to 60 percent while tungsten may vary from 5 to 20 percent (see table V-3). Chromium is held to about 30 percent. The carbon may range from 1 to 2.45 percent. The cobalt content can be lowered appreciably by addition of about 4-5 percent molybdenum without impairing hot hardness. Sometimes about 0.20 percent boron is added to enhance performance. Such alloys are extremely hard and nearly as resistant to abrasion as the cemented tungsten carbides. In addition, they have low coefficients of friction with reference to steel and are very resistant to oxidization and corrosion. Because of this low coefficient of friction, such cobalt base alloys, with tungsten, are very useful for machining abrasive materials, and are usually furnished as cast tips which may be brazed to tool shanks for this purpose. Stellite type alloys may be machined with tungsten carbide or may be ground.

Some applications for cobalt base types of alloys are bushings, lathe centers, burrishing rollers, wear strips, knives, valve parts, dies, rods, pistons and plungers, guide rollers, machine gun barrels, etc.

One very important application of these hard alloys is their use for hard-faced articles which are subjected to extreme abrasion. Typical of such items are hard-faced plates, rolls, crushers, exhaust valve

TABLE V-3. CHEMICAL COMPOSITION OF COBALT-BASE TUNGSTEN-HEAVY ALLOYS

Alloy	Co	Cr	W	C	Ni	Fe	M
90-10 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—
80-20 M 2	38	30	10	1.0	—	—	—

Tungsten Stellite type
Alloys

seats, and pump parts subjected to erosion and corrosion. These alloys also have a high reflecting power, hence find use in tarnish and scratch resistant mirrors. The metal is usually deposited by means of either oxyacetylene or electric arc-welding by hand, or where uniformity is important, by mechanically controlled devices. Where smooth surfaces are desired, a finish grind is given with silicon carbide or alumina wheels.

Nickel base alloys.--The addition of small amounts of tungsten in combination with other alloying elements to nickel increases its resistance to corrosive attack by specific, particularly organic, acids. More important, tungsten increases certain physical properties which enhance the value of the material where it is subject to erosion and corrosion, or where strength is required at high operating temperature. Certain commercial nickel-base alloys make use of the beneficial effects of tungsten. Hastalloy C which contains 57 percent nickel, 17 percent molybdenum, 15 percent chromium, 5 percent tungsten, and 5 percent iron, is resistant to chloride solutions --most especially to hypochlorites and moist chlorine. Inconel (56% Ni, 22% Cr, 6% Cu, 6% Mo, and 1% W) was originally used for repelling the attack of sulphuric and nitric acids over a wide temperature range. It also resists the corrosive effects of salt water and alkalis. Such alloys are of particular use in the chemical and oil refining industries for handling hot or cold acids and caustic solutions.

Silver-tungsten alloys.--Alloys of silver and tungsten are made by powder metallurgy methods since the two elements are not miscible when heated together under ordinary metallurgical practices. Tungsten carbide may be used in place of the metal powder when indicated because of its extreme hardness. These alloys are useful as electrical contacts in circuit breakers and motor starters where currents are heavy and arcing is severe. The material should be relatively free from porosity. Tungsten

provides hardness and resistance to arcing and abrasion when the current is open; silver provides the electrical conductivity when the current is closed.

Tungsten-nickel-copper alloys.--High density alloys composed of approximately 90 percent tungsten, balance 6 percent nickel and 4 percent copper for machineability qualities, are invaluable as radioactive metal shields or containers for radioactive materials. For shielding against X-rays or gamma rays wherein radiation absorption is generally proportional to the density of the material used, these alloys with densities around 17 g./cm.³ are approximately one and one-half times as effective as lead (density 11.34 g./cm.³) against penetration of radioactivity. The increased use of radioactive isotopes for tracers, etc. makes this additional shielding important where size of containers must be limited.

Aside from being excellent shielding material, the alloys referred to as "heavy alloys" find use as circuit-breaker contacts; gyroscope rotors for positioning navigational instruments; balancing weights used in self-winding wrist watches; counterweights in aircraft for balancing purposes, or stabilizing aerial cameras; dampers in boring tools to reduce vibrations; floats in flowmeters; and many other engineering applications where high density materials are desirable.

Chemicals and Compounds

Luminescent powders (phosphors).--Phosphors are light-emitting substances which, when stimulated by short wave rays such as ultraviolet light, are more efficient than other light sources. Natural scheelite (calcium tungstate) exhibits this phenomenon of luminescence, but is not used as a light source because it is deficient in other desirable properties. On the other hand, tungsten compounds of exceedingly high purity are recognized for their luminescence. Traces of almost any foreign metal, with the exception of lead, impair their characteristic fluorescence. Lead, when added up to about 1 percent, intensifies the fluorescence of CaWO₄, however, the emission band is displaced toward the longer wave lengths, changing the luminescent color from the characteristic blue of CaWO₄ to a greenish hue. The addition of bismuth or uranium to a mixture of calcium oxide and calcium tungstate, on heating, forms compounds which on proper excitation emit

luminescent light which is yellow in color when bismuth is added, and green when uranium is the additive. These additives are referred to as activators and the final substances obtained after suitable heat treatment, such as sintering, are called phosphors. A wide range of luminescent colors can be obtained by such additions. These phosphors are utilized in the manufacture of luminescent pigments.

Some tungstates and their phosphor derivatives can be excited by short-wave ultraviolet rays, X-rays, and cathode rays, to give off visible light to provide an effective light source for many important commercial devices. The alkaline earth tungstates have long been employed in fluoroscopic and intensifying screens in X-ray work. They are also used to coat television tubes and electron microscope screens. When mixed with a suitable base they are simply painted on the screens.

The tungstates of calcium and magnesium have played a large part in the changeover from the older types of filament lighting to the fluorescent type now in prominent use. Fluorescent lighting was introduced in 1939 and has become so popular that it is estimated, on a dollar volume basis, it has already replaced filament lighting by more than 50 percent. In the fluorescent tube, tungsten filaments at each end are covered with barium or strontium oxides which, when heated, emit electrons. These electrons bombard the atoms of mercury vapor enclosed in the tube, causing them to give off short wave ultraviolet (invisible) light. This ultraviolet energy is then absorbed and converted into visible light by the phosphor deposit or coating on the inside surface of the tube. Various colors may be obtained by varying the procedure or type of activator in phosphor manufacture; however, combinations producing "natural" daylight are most often used. Though the daylight tones are most desirable for home and office use, their efficiency is less than the normal blue emanating from a pure calcium tungstate coating. It is estimated, however, that the daylight tube has an efficiency about two and one-half times that of the old filament type.

Miscellaneous applications.--By far the most important of all tungsten compounds is sodium tungstate. A complex derivative such as phosphotungstic acid, made by reacting the tungstate with phosphoric acid, is used as a mordant in the production of pigments, and along with silicotungstic acid is used in organic chemistry for the

determination of alkaloids. When added to a basic dyestuff, phosphotungstic acid precipitates the basic dye from solution. These dyes, insoluble in water and linseed oil, are very brilliant and have a greater resistance to light than do pigments precipitated by organic compounds. Because of their high brilliance and permanency, appreciable quantities are used in textile dyes, printing ink, oil and water paints, enamels, rubber, plastics, paper, and waxes. Combustible materials when treated with sodium tungstate solutions become fireproof. Rayon can be deglossed with solutions of sodium tungstate. Graphite crucibles can be given a hard acid-resistant lining by igniting a paste mixture of sodium tungstate powder plus binder under reducing conditions at a temperature high enough to decompose the tungstate; the surface is then burnished to give it a firm compact finish. Acid and abrasion resistant surfaces can also be obtained by pyrolysis of tungsten carbonyl. Plates can be produced of almost any desired hardness on any material that will withstand temperatures around 300 C. (572 F.). As a consequence, there exists a wide range of applications, especially in electronic devices and chemical processing equipment. The harder coatings provide excellent wearing surfaces such as are needed for bearings, dies, rolls, gauges, etc.

Although not yet produced entirely on a commercial basis, electrodeposition of a binary tungsten alloy having high hardness and good wear resistance at high temperatures is possible from an aqueous solution of sodium tungstate in the presence of nickel or cobalt salts. A tungsten nickel alloy containing up to 50 percent tungsten can be plated out from an acidified bath of nickel sulfate, nickel chloride and sodium tungstate. Nickel anodes are used.

Tungstates of lead are used as substitutes for white lead. The bright yellow tungsten trioxide finds use as a pigment in oil and water colors. One of the tungsten salts is reportedly used in optical glass to raise its refractive index. Apart from this use, tungsten components in glass manufacture at present are limited to that of opacifiers. A good acid resistant coating is obtained by painting metal with tungsten carbonyl. Tungsten compounds are being employed as catalysts in the hydrogenation of carbonaceous materials, and in the cracking of oil. Tungsten bronzes, because of their vivid colors, are substitutes for bronze powders employed in paints.

Pure Tungsten

Industrially pure tungsten has numerous applications in the electrical field. Its high melting point and low vapor pressure make it ideal for filaments in incandescent lamps and cathodes in electronic tubes. Emitters in high-power valves are now made of carburized thoriated tungsten wire, since this is less sensitive to traces of gas. The primary requirement of such filaments is freedom from sagging at operating temperatures. This has been successfully accomplished by doping the oxide, prior to reduction to the powder, with such materials as soda, silica, silicates, thoria and the like, to cause grain growth in a definite direction when the filament is heated to operating temperatures. Increased "know how" of tungsten manufacturers has made tungsten available to other industries such as electronics, welding, automotive ignition, etc.

In almost pure rod or wire form, tungsten finds applications for uses such as in thermocouples for temperature measurements up to 3000 C. (5432 F.) (a W-MO couple is being used for temperature measurements in vacuum furnaces); for electrodes in arc lamps; for electrodes in gas shielded or atomic hydrogen welding; for electrodes in electrochemical processes such as melting titanium metal; and for rods to make holes in molten glass prior to glass blowing. The high melting point and low vapor pressure of tungsten make it an ideal material for electrodes; a percentage of thoria is added to stabilize the arc. Consumption of the electrode takes place slowly, and contamination by vapor is negligible.

The high modulus of elasticity of tungsten wire make it well suited for use as cross hairs in telescopes and galvanometers, as surgical stitching material, and as springs for various instruments. Tungsten springs will withstand temperatures up to 1200 F. (650 C.) with little permanent set. When used in radio valves, tungsten springs reduce the tendency for microphonics by keeping the filament taut. Because tungsten has a thermal coefficient of expansion close to hard glass such as pyrex, it is used as lead-in wires in thermionic valves and other vacuum devices. In experimental furnaces, temperatures around 5400 F. (2980 C.) have been obtained by heating with tungsten elements surrounded by a hydrogen atmosphere.

Contact discs for the make-and-break type of electrical circuits such as those

employed in start-and-stop type devices, are made from tungsten rod or sheet. These are brazed onto a steel or copper backing to form the finished contacts. X-ray ma-

chines for therapeutic and radiographic work use tungsten discs as targets because of the high penetrability of X-rays.

SUBSTITUTIONS FOR TUNGSTEN

The importance of tungsten to our economy both in peace and in war, together with the uncertainty as to its supply in event of global warfare and its price fluctuation, has long been recognized. These considerations stimulated metallurgical research toward satisfactory substitutions, especially in the field of tool steels.

Tungsten Steel and Alloys

High-speed steels.--In the past, the high-speed tool steel industry was the largest single consumer of tungsten (as ferrotungsten and ore concentrates). During World War II, 50 to 76 percent of the United States consumption of 16 to 19 million pounds of tungsten per year, was used chiefly for high-speed steel of the 18%W-4%Cr-1%V type. In 1952 this usage dropped to 24 percent, increased in 1953 to 37 percent, only to decrease again to 31 percent in 1954. Actual tungsten consumption, most for high-speed steel, dropped to about one-fifth of the amount previously used.

Basic causes for the current downward trend in tungsten consumption in high-speed steel were several--substitutions, conservation in its use by NPA regulations, and price fluctuations. The rise in 1953 can be attributed to removal of all controls, the better supply situation, and the preference for higher tungsten high-speed steels.

High-speed tool steel production has shifted from the preponderance of the "18-4-1" type to three molybdenum bearing types (see table V-4). In these, two molybdenum bearing steels contain tungsten, the third, no tungsten. All have good cutting qualities. In addition to lower basic costs, they have one other important advantage--they can be fully hardened from lower austenitizing temperatures than can the regular tungsten high-speed steels; hence they are less susceptible to distortion and cracking. The chief disadvantage lies in their greater tendency to decarburize, necessitating some means of surface protection during heat treatment. The compositions of the standard "high speed steel, T-1," and the three molybdenum steels, are shown in table V-5.

TABLE V-4.--HIGH-SPEED TOOL STEEL SHIPMENTS
(In short tons)

Year	Class A molybdenum type	Percent of total	Class B tungsten type	Percent of total	Total
1942.....	--	--	--	--	72,000
1943.....	--	--	--	--	50,000
1944.....	--	--	--	--	30,000
1945.....	20,000	40	15,000	60	35,000
1946.....	7,000	44	9,000	56	16,000
1947.....	5,000	31	11,000	69	16,000
1948.....	8,000	47	9,000	53	17,000
1949.....	3,000	38	5,000	62	8,000
1950.....	9,000	53	8,000	47	17,000
1951.....	30,500	85	7,500	20	38,000
1952.....	19,800	88	2,600	12	22,400
1953.....	21,100	91	3,400	14	24,500
1954.....	12,800	84	2,500	16	15,300
1955.....	--	--	--	--	--
1956.....	--	--	--	--	--

All companies (19) reported in 1951-54; partial figures were given for all previous years.

Source: American Iron and Steel Institute Statistics.

TABLE V-5.--"18-4-1" HIGH-SPEED TOOL STEEL SUBSTITUTES

Element	Tungsten type	Molybdenum type substitutes			
	T-1	M-1	M-2	M-3	
Tungsten.....	18.0% Min.	6.75% Max.	2.4% Max.	--	
Molybdenum.....	--	5.5% Max.	9.25% Max.	7.25% Max.	
Chromium.....	4.0% Max.	4.5% Max.	4.5% Max.	4.5% Max.	
Vanadium.....	1.0% Max.	2.0% Max.	1.2% Max.	1.2% Max.	
Carbon.....	0.75% Min.	0.65% Min.	0.65% Min.	0.65% Min.	

Source: National Production Authority Classifications.

Partial or total replacement of tungsten with molybdenum or molybdenum plus 5-8 percent cobalt has had outstanding results. Molybdenum, a metal having chemical and physical properties similar to tungsten, is capable of holding the red hardness needed in high-speed steels, while cobalt, because it increases red hardness above that imparted by tungsten or molybdenum, increases cutting efficiency.

Just as the basic high tungsten high-speed steel "18-4-1" type has undergone modifications designed to improve its service in specific applications, so have the molybdenum types of high-speed tool steels undergone minor modifications to meet better specific use requirements. Modifications of "18-4-1" with suggested substitution of molybdenum types from industry recommendations are shown in table V-6. Which grade is preferred grade for each tool steel application, however, is often controversial.

Substitution of molybdenum types of high-speed steel for the tungsten "18-4-1" type steel obviously is directed toward conserva-

TABLE V-6.--COMPARABLE TUNGSTEN AND MOLYBDENUM TYPE OF HIGH-SPEED STEELS

Element	Tungsten type	Molybdenum type	Tungsten type	Molybdenum type
	T-1	M-1	T-2	M-7
Tungsten.....	18%	6.75% Max.	18%	6%
Molybdenum.....	--	5.50% Max.	--	1%
Chromium.....	4%	4.50% Max.	4%	4%
Vanadium.....	1%	2.0% Max.	2%	2%
Element	Tungsten type	Molybdenum type	Tungsten type	Molybdenum type
	TC-1 or TC-3	M-11	TC-2	M-12
Tungsten.....	18% 14%	2%	18%	2.0%
Molybdenum.....	--	3%	--	3.5%
Chromium.....	4% 4%	4%	4%	4.5%
Vanadium.....	1% 2%	1%	2%	2.0%
Substit.....	5%	5%	5%	8.0%

Source: Tool Steel Industry Recommendations.

tion of tungsten. This program can be extended in two or three directions worthy of mention. First, the use of molybdenum types of high-speed steel permits utilization of greater quantities of less pure scheelite. Molybdenum bearing scheelite could be used for 58-60 percent of the tungsten requirements for high-speed steel, thus freeing greater amounts of the limited supply of low molybdenum scheelite for uses which demand low impurity ores.

Hot-work steels.--Several types of steel, with or without tungsten, are used for hot work applications. The temperatures at which hot-forming operations are to be made, regulate the percentage of tungsten used in these steels. Up to 18 percent tungsten is used, in which range these steels are classified as high-speed types.

The tungsten bearing types of hot-work steels have the advantage over chromium and chrome-molybdenum types in that they maintain hardness during long high temperature operations. For this reason, substitutes for tungsten in such applications have

been few. Molybdenum was tried during the emergency conditions of World War II, but for the most part its use has been discontinued.

To supplement the effect of tungsten, vanadium is used in hot-work steels to increase resistance of the dies to soldering and washing, and chromium and molybdenum are used to improve toughness and resistance to thermal shock. Chrome-molybdenum-vanadium steels have good dimensional stability, and when nitrided provide hard working faces with enhanced spalling resistance.

While tungsten steels are less susceptible than tungsten-free steels to heat checking, they are not as resistant to rupture cracking under shock. Therefore, for high temperature service, tungsten is added to steel to reduce heat checking, and elements such as chromium and molybdenum are added to overcome the rupture cracking tendencies associated with tungsten. For lower temperature work, tungsten contents usually are lowered to 1.00 percent or omitted entirely; this improves rupture properties at little or no sacrifice in heat checking characteristics.

In table V-7 are shown various types of hot-work steels. Compositions given are nominal, and manufacturers often modify chromium and tungsten contents to meet individual problems. From these steels are produced tools for hot-working applications such as forging dies, dummy blocks, extrusion mandrels, hot punches, etc. Modifications are made for specific applications. For example: Type B steel is modified to a composition for die casting of aluminum and magnesium as follows:

C	Si	Cr	Mo	V	W
0.40%	1.05%	5.00%	1.35%	1.10%	None

TABLE V-7.--CHEMICAL COMPOSITION (%) OF HOT-WORK STEELS

Type of steel	C	Mn	Si	Cr	V	W	Mo	Ni
A. Chromium								
1. 0.65 carbon.....	0.65	0.30	0.30	4.00	0.75	--	0.50	
2. 0.90 carbon.....	0.90	0.30	0.30	4.00	0.75*	--	0.50	
B. (T9) Chromium-Molybdenum.....	0.35	0.30	1.00	5.00	0.40*	1.25*	1.50	--
C. (T8) 5 Chromium 5 Tungsten.....	0.40	0.30	1.00	5.00	0.40*	5.00	--	--
D. 7.5 Chromium 7.5 Tungsten.....	0.45	0.60	1.50	7.50	0.40*	7.5%	--	--
E. Molybdenum								
1. Low.....	0.40	0.25	0.50	3.75	0.75	1.3%	5.75	--
2. High.....	0.60	0.25	0.75	3.75	1.10	1.5%	8.50	--
F. Tungsten								
1. (T10) 9 percent.....	0.30	0.25	0.25	3.50	0.50*	9.00	--	--
2. 12 percent.....	0.40	0.25	0.25	2.50	0.50	12.00	--*	--*
3. 15 percent.....	0.40	0.25	0.25	3.00	0.50	15.00	3.00	2.00
4. 18 percent.....	0.50	0.25	0.25	4.00	1.00	18.00	--	--

*Optional element.

Die casting die steels.--Extensively used compositions for die casting applications have molybdenum substituted for tungsten. The modified Type B steel is an important one; another type is as follows:

C	Mn	Si	Cr	V	W	Mo
0.30%	0.75%	0.50%	0.80%	-	-	0.25%

These steels are ideally suited for applications involving low casting temperatures which do not require the high resistance to heat checking imparted by tungsten.

Plastic molding steels.--In these die steels the requirements in lower temperature service differ from those previously described, and further, their preparation presents problems in machining, hubbing, etc. Low carbon steels generally are preferred since they permit easy finishing by machining to desired patterns. They then are carburized or nitrided to produce hard surfaces which insure resistance to washing in service. Hence, tungsten finds little to no consistent usage. A widely used grade of plastic molding steel is a dead soft low carbon steel containing 0.05% and 0.15% Mn.

Whenever alloys are used in plastic molding steels, nickel, molybdenum, and chromium are the alloying elements. Typical compositions are:

C	Mn	Cr	Mo	Ni
0.70% max.	-	1.35%	0.20%	0.55%
0.07% max.	-	5.00%	0.50%	-
0.30% max.	0.75%	0.80%	0.25%	-
0.10% max.	0.50%	1.60%	-	3.50%

Tungsten-chromium die steels for hot-working.--In table V-8 are listed a few tungsten bearing die steels, and possible molybdenum substitutes containing little or no tungsten, used primarily in the hot-working of metals. Actual use of substitutes, however, should be approached cau-

tiously, and adopted only after a satisfactory trial period.

Nonferrous tungsten alloys.--Chief among these alloys are the cobalt base and high nickel-chromium stainless types of compositions. These have been discussed previously under high-temperature stainless jet alloys and stellites. Tungsten and molybdenum are both used in these alloys, though no positive claims can be made for one as a substitute for another. Since not too much is known at the present about the fundamental metallurgical reactions responsible for the properties of these alloys, no definite conclusions may be reached concerning alloy function.

Sintered Tungsten Carbide

Substantial savings of tungsten can be effected by the use of sintered tungsten carbide-tipped tools in place of tungsten-bearing alloy steel tools. However, machine tools on which they are to operate must have sufficient power and rigidity to withstand optimum cutting speeds withstandable by the carbide tool materials. Many existing machines are unsatisfactory for use with carbide tools, and changeover to carbides would actually result in wastage of tungsten. The uses of sintered tungsten carbide have been described earlier in the chapter, cutting tools and dies being the foremost products. For cutting operations, tungsten carbide tips are brazed or fastened to good load-supporting carbon or low alloy steel shanks. By this means, the weight of tungsten in the carbide tip is less than that in homogeneous types of high-speed steel tools. Added conservation is achieved by this practice because a tremendous increase in cutting efficiency results from the use of carbide-tipped tools. The same principle applies to dies and core drills.

The American Society of Mechanical Engineers, in a report issued about 1947, indicated the average production increase by the use of carbide tools as opposed to high-speed types, as follows: Cast iron, 60 percent; steel, 35 percent; aluminum, brass, bronze, other alloys and nonferrous materials, between 15 and 500 percent. Estimates of average savings in cost of production were given as follows: Cast iron, 28 percent; steel, 22 percent; other materials, between 20 and 40 percent. The above figures serve to illustrate that tungsten carbide has replaced alloy tool steels to a great extent, with savings in actual amounts of tungsten consumed.

TABLE V-9.--CHEMICAL COMPOSITION (%) OF TUNGSTEN-CHROMIUM DIE STEEL SUBSTITUTES (After Jeffries)

Elements	Tungsten die steels			Possible molybdenum substitutes		
	T-8	T-9	T-10	M-25 (For T-8)	M-26 (For T-9)	M-27 (For T-10)
C.....	0.30	0.30	0.30	0.35	0.35	0.50
W.....	5.00	1.25	0.00	--	1.00	--
Cr.....	0.00	5.00	3.25	5.00	3.50	3.50
V.....	--	--	0.25	--	.75	1.75
Si.....	--	--	--	.90	--	--
Mo.....	--	1.25	--	1.25	6.00	8.5

CHAPTER VI
SUPPLY AND DISTRIBUTION IN THE UNITED STATES

CHAPTER VI SUPPLY AND DISTRIBUTION IN THE UNITED STATES

The United States, as the leading industrial nation in the world, has always used greater quantities of tungsten than domestic mines could produce. Up until 1953 it has been necessary at times to import from 50 to 80 percent of the annual industrial requirements for tungsten. In 1953-54 domestic production exceeded consumption for the first time since the depression of the thirties. A protective tariff placed on imported ores stimulated the development of domestic tungsten mining. Also, the recent loss of China as a source of tungsten has made the United States more dependent upon domestic mines.

One of the greatest uses of tungsten has been in high-speed tool steels. Before World War II about 85 percent of tungsten consumption was in the form of ferrotungsten, and 10 percent of this was introduced directly into the steel bath as high-purity scheelite. All told, about 95 percent went into tool steels, primarily high-speed of the 18%W-4%Cr-1%V type, and 5 percent went into tungsten powder, chemicals, and miscellaneous products. Later, substitutes

such as molybdenum tool steels, together with increasing use of cemented tungsten carbide, displaced some of the tungsten high-speed steels.

By the end of 1951, the use pattern for ores and concentrates shifted; 30 percent was used for tool steels, 19 percent coming from ferrotungsten and 11 percent from high-purity scheelite introduced directly into the steel bath. On the other hand, 70 percent of total consumption was primarily in the form of tungsten powder, the majority of which was used to produce carbides. This increased to 76 percent in 1952, decreased in 1953 to 63 percent, but again increased in 1954 to 69 percent. The change in the consumption pattern represented a shift from tungsten tool steels to substitutes like molybdenum tool steels, and to an increasing use of cemented tungsten carbide for cutting-tools and projectiles. The drop in 1953 was due to cutbacks in production of armor-piercing projectiles, and the rise in 1954 to increased use of tungsten powder for carbide tools, and for new applications.

SUPPLY

Imports for consumption, and shipments from domestic mines, make up the sources of tungsten supply for the United States (see table I-1 and curves, figure I-1). This country is the world's leading producer of iron and steel as well as the largest consumer of tungsten. When domestic mine production is inadequate for its industrial needs, the United States finds it necessary to import a large portion of its tungsten supply. The United States and Russia are the only large steel-producing countries that supply an appreciable percentage of their own tungsten requirements. Thus, for the period 1914-1954, the total U. S. supply of ores and concentrates was 407 million pounds of contained tungsten, of which 260 million pounds (64 percent) was imported, and 147 million pounds (36 percent) was from domestic mines. Usually this country imports over half of its tungsten supply.

Imports

Imports of tungsten ores and concentrates fall into two classifications: (1) general imports, and (2) imports for consumption. General imports comprise ores and concentrates received in the United States, irrespective of final disposition, some of which are channeled directly into consumption while the remainder enter bonded warehouses. Imports for consumption comprise ores and concentrates imported directly for consumption on which duties were paid, and those withdrawn from bonded warehouses irrespective of time of importation. Import duties are paid on tungsten ores and concentrates from bonded warehouses at the time of withdrawal. Imports for the United States Government are entered duty free. Tungsten imports, as a part of total supply in this

survey, are regarded as imports for consumption. Imports of tungsten concentrates are usually stated in pounds of tungsten content which may easily be converted to tons of 60 percent tungsten trioxide (WO₃).

(A short ton of 60% WO₃ contains 951.72 lbs. of tungsten.) Imports for consumption are shown by countries beginning with the year 1934 in table VI-1 and figure VI-1.

TABLE VI-1--TUNGSTEN ORES AND CONCENTRATES IMPORTED FOR CONSUMPTION INTO THE UNITED STATES BY EMPLOYING COUNTRIES, 1925-1933¹
In pounds of contained tungsten

	North America		South America				Europe					
	Canada and Cuba	Mexico	Argentina	Bolivia	Brazil	Others ²	France	Spain	United Kingdom	Portugal	Others ²	
1925-1933 ² Av./yr.	--	--	--	--	--	19,638	--	--	--	--	--	1925-1933
1934.....	--	34,980	49,801	--	--	--	--	--	--	--	--	1934.....
1935.....	--	34,470	12,086	--	--	--	--	--	--	--	--	1935.....
1936.....	40,996	45,815	11,597	47,011	--	27,686	1,815	--	--	--	--	1936.....
1937.....	--	48,734	138,225	74,878	--	8,677	--	--	--	--	--	1937.....
1938.....	--	1,360	--	705	--	--	--	--	--	--	--	1938.....
1939.....	--	146,637	76,524	4,154	--	69,951	--	--	--	--	--	1939.....
1940.....	2,781	113,867	762,012	1,408,595	--	179,362	--	--	--	322,681	--	1940.....
1941.....	--	79,801	515,729	2,895,568	384	326,333	--	--	--	374,653	--	1941.....
1942.....	15,975	76,300	2,478,622	6,778,891	26,612	264,649	--	--	--	34,237	--	1942.....
1943.....	72,678	323,129	2,335,096	5,097,315	1,135,625	559,104	--	--	--	31,771	--	1943.....
1944.....	170,900	409,789	2,266,856	7,850,382	2,345,499	1,757,963	--	--	--	44,791	--	1944.....
1945.....	--	91,137	764,391	2,450,771	1,316,584	98,014	--	--	--	--	--	1945.....
1946.....	8,544	31,976	145,178	2,525,312	1,816,486	307,158	37	113,526	79,071	--	21,326	1946.....
1947.....	150,942	48,700	304,098	829,062	905,704	141,997	--	114,472	14,333	17,114	--	1947.....
1948.....	363,391	153,432	8,261	664,987	847,557	40,912	--	181,611	--	12,106	--	1948.....
1949.....	--	21,358	--	210,743	120,640	32,615	--	1,347,793	--	15	3,457	1949.....
1950.....	10,012	218,112	15,973	1,784,092	810,149	554,377	--	100,418	--	140,985	7,589	1950.....
1951.....	--	152,017	295,423	692,588	618,899	346,437	--	448,653	--	997,575	--	1951.....
1952.....	631,380	585,826	141,640	2,940,931	1,424,182	378,032	--	2,074,354	--	2,774,342	17,996	1952.....
1953.....	1,775,435	813,542	513,504	3,773,147	2,746,913	784,640	590,540	4,977,557	34,323	2,112,600	14,547	1953.....
1954.....	1,260,300	794,482	--	4,936,641	1,366,767	891,858	310,793	3,322,112	--	2,112,199	37,696	1954.....
1955.....	--	--	--	--	--	--	--	--	--	--	--	1955.....
1956.....	--	--	--	--	--	--	--	--	--	--	--	1956.....

	Africa				Asia				Oceania		Total		
	Belgian Congo	South Rhodesia	Union of South Africa	Others ²	Purma	China	Malaya	Korea	Thailand Siam	Others ²			Australia	New Zealand
1925-1933 ² Av./yr.	--	--	--	--	--	--	--	--	--	--	--	--	1925-1933
1934.....	--	--	--	--	--	709,055	33,385	--	--	--	--	--	1934.....
1935.....	--	--	--	--	--	669,143	90,020	--	--	1,909	--	--	1935.....
1936.....	--	--	13,786	--	--	2,553,254	436,871	--	--	71,344	131,190	--	1936.....
1937.....	--	--	54,041	27,740	--	3,794,440	975,786	--	--	77,031	306,770	--	1937.....
1938.....	--	--	23,233	--	--	69,986	67,460	--	--	--	--	--	1938.....
1939.....	--	--	--	--	12,878	899,806	123,622	--	--	3,876	56,639	--	1939.....
1940.....	--	--	53,511	73	93,549	1,899,526	162,783	--	196,180	44,417	573,038	--	1940.....
1941.....	41,826	--	124,343	37,579	--	6,575,020	31,619	--	410,245	14,237	97,874	--	1941.....
1942.....	147,829	47,458	154,569	218,903	--	3,819,599	--	--	--	42,757	20,173	--	1942.....
1943.....	--	--	17,974	--	--	44,223	9,140,852	--	--	104,188	295,165	6,997	1943.....
1944.....	25,543	--	31,243	--	--	78,890	3,626,221	--	--	--	90,720	--	1944.....
1945.....	27,858	--	--	--	--	--	25,073	--	--	--	33	--	1945.....
1946.....	426,908	883,599	33,356	--	--	82,514	--	--	92,217	123,075	13,775	104,366	1946.....
1947.....	534,343	203,354	109,869	19,907	--	1,650,354	4,850	--	533,827	110,018	224,994	6,497	1947.....
1948.....	116,417	12,728	--	11,337	--	3,699,850	--	980,765	379,833	71,595	5,149	--	1948.....
1949.....	94,684	1,542	--	--	5,862	4,548,046	--	497,441	383,612	152,557	77,893	--	1949.....
1950.....	236,501	--	34,148	--	120,925	7,439,167	--	2,481,707	1,043,973	541,672	467,787	22,718	1950.....
1951.....	30,746	--	650	19,096	289,296	18,175	--	705,131	739,519	155,692	846,631	--	1951.....
1952.....	37,330	--	--	12,098	305,168	42,318	367	3,923,314	1,158,183	155,209	905,429	--	1952.....
1953.....	277,810	178,571	51,903	40,555	1,607,723	--	59,602	5,901,998	1,704,271	111,209	1,308,072	36,396	1953.....
1954.....	1,038,664	158,865	365,042	--	1,010,787	--	142,721	4,289,331	663,896	109,443	1,417,314	37,453	1954.....
1955.....	--	--	--	--	--	--	--	--	--	--	--	--	1955.....
1956.....	--	--	--	--	--	--	--	--	--	--	--	--	1956.....

¹ Comprises ores and concentrates withdrawn from bonded warehouses during year (irrespective of time of importation) and receipts during year for consumption.

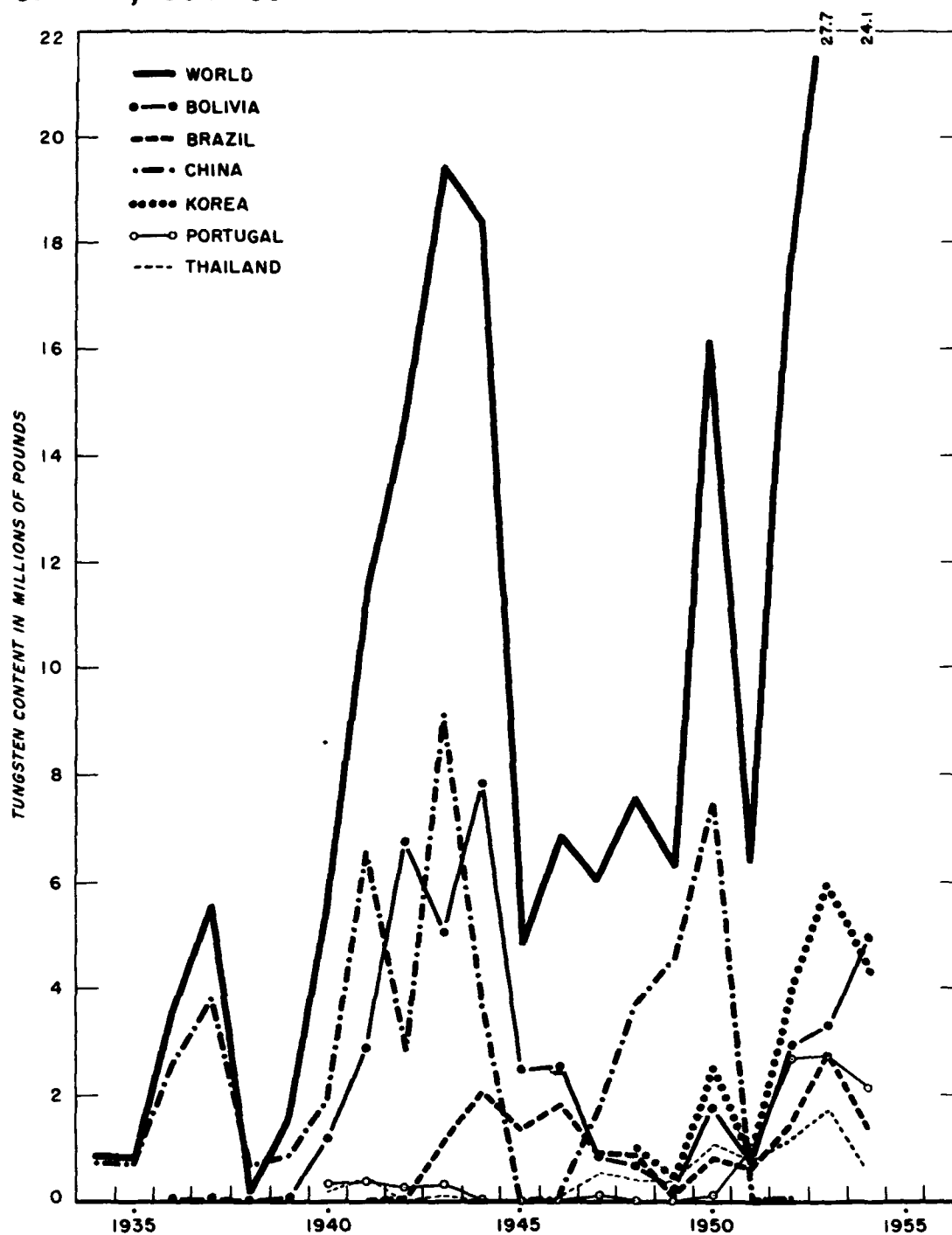
² Imports by countries not available 1925-1933.

³ Others in S. America include Chile, Ecuador and Peru; in Europe include Belgium, Finland, France, Netherlands, Sweden, W. Germany, and Yugoslavia; in Africa include British East Africa, other British South Africa, and Egypt; and in Asia include French Indo-China, India and Dependencies, Indonesia, Japan, Hong Kong, and Netherlands Indies.

⁴ Republic of Korea.

Sources: Minerals Yearbook, U. S. Bur. of Mines.

Fig. VI-1.- Imports for Consumption of Tungsten Ores and Concentrates into the United States by Major Exporting Countries, 1934-1954



The most important sources of tungsten imports (205 million pounds contained tungsten) for the period 1934-54 were China and Bolivia, which supplied 25 and 21 percent respectively. China has been the world's leading producer of tungsten since 1918 and usually has been the chief source of tungsten imports for the United States. With the Japanese invasion of China in 1937, tungsten imports from that source became uncertain, and by 1944 had declined to 20 percent of total tungsten imports; they virtually disappeared by 1945 when less than 1 percent of tungsten imports came from China.

With the end of World War II in 1945, however, importation of tungsten from China was gradually resumed, and by 1949 had climbed to 72 percent of total imports. The opening of hostilities in Korea in June 1950 again brought decreased imports of tungsten from China and by the third quarter imports practically ceased.

Bolivia has been the second largest supplier of tungsten imports to the United States, especially during World War II, making up to some extent the loss of supply from China. Imports of tungsten ores and concentrates from Bolivia began in 1936 with 47,000 pounds (tungsten content) and reached quantity movement during 1940 when 1.2 million pounds were imported. Bolivian imports reached a peak of 7 million pounds in 1944, decreased to a low of 211,000 pounds in 1949, only to increase again by 1954 to almost 5 million pounds.

Other major Latin American countries that supplied tungsten imports were Argentina and Brazil, accounting for 5 and 7 percent respectively of total imports for the period 1934-1954. The bulk of these tungsten imports came from South America during World War II and were made possible by technical and financial assistance from this country. When aid to foreign countries ceased, imports of tungsten from South America declined substantially. With the stoppage of imports from China, Latin American countries, encouraged by the United States, are again becoming an important source of tungsten.

In 1954 the largest supplies of tungsten concentrates, figured in millions of pounds of contained tungsten, came from Bolivia (4.9), Republic of Korea (4.3), Spain (3.2), and Portugal (2.1). Other countries supplying over 1 million pounds were Australia, Belgian Congo, Brazil, Burma, and Canada.

Tariff. -- Before World War I, imports of tungsten ores and concentrates were subject to a duty of 10 percent ad valorem under the Payne-Aldrich Act of 1909. The Underwood Act of 1913 abolished this duty, and tungsten concentrates were admitted free of duty until 1922. In that year, Chinese concentrates were selling for \$1.75 to \$3.50 a short ton unit in New York. It was impossible for domestic mines to produce and deliver tungsten concentrates at such low prices. In order to protect the domestic industry, the Fordney-McCumber Tariff Act went into effect on September 22, 1922. The act imposed a duty of 45 cents a pound of contained tungsten in tungsten ores and concentrates (\$7.14 per short ton unit of WO_3). This rate of duty remained in effect until it was increased, in the Smoot-Hawley Tariff Act of 1930, to 50 cents a pound of contained tungsten (\$7.93 per short ton unit). The United States tariff policy since 1930 has been to keep domestic mines in production despite low prices of foreign tungsten concentrates.

Effective May 22, 1948, under the International Trade Agreement signed at Geneva on October 30, 1947, the duty on tungsten ore and concentrates was lowered to 38 cents a pound of contained tungsten (\$6.03 per short ton unit of WO_3 , a reduction of \$1.90 a unit from the previous duty).

On December 11, 1950, China withdrew from the General Agreement on Tariff and Trade with the United States. As a result, import duty on tungsten concentrates was returned to the previous rate of 50 cents a pound of contained tungsten.

Domestic Mine Shipments

For the period 1914-1954, shipments of tungsten concentrates from domestic mines fluctuated between zero in 1922 and a peak of 13 million pounds (contained tungsten) reached in 1954 (see table VI-2).

TABLE VI-2.--TUNGSTEN ORES AND CONCENTRATES SHIPPED FROM MINES IN THE UNITED STATES, BY STATES, 1914-1954
(In pounds of contained tungsten)

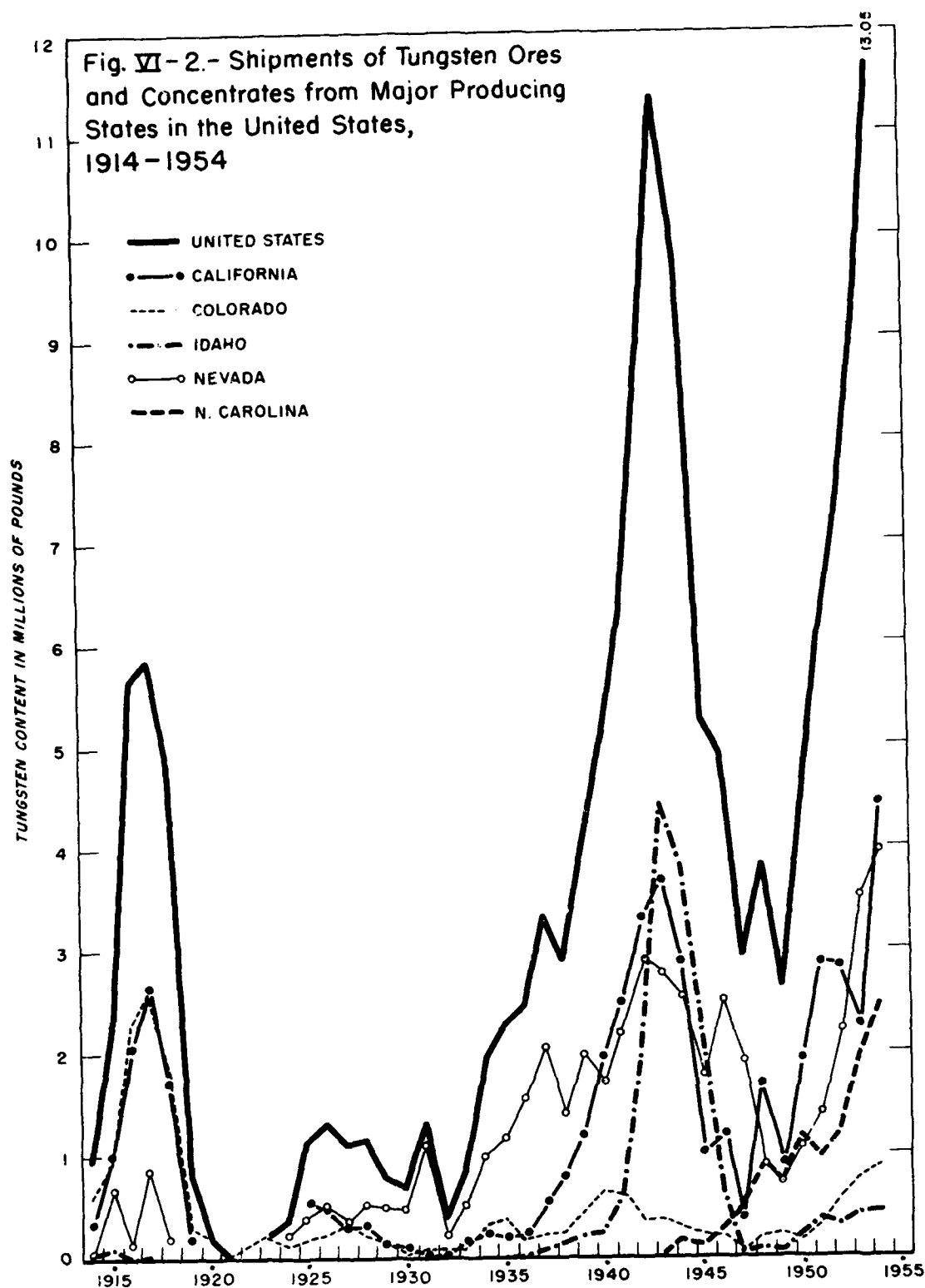
Year	Arizona	California	Colorado	Idaho	Nevada	North Carolina	South Dakota	Washington	Other States ¹	Total	Year
1914.....	--	342,720	599,760	--	--	--	--	--	--	942,480	1914.....
1915.....	120,304	499,600	916,776	23,800	52,360	--	133,280	1,464	67,552	1,733,720	1915.....
1916.....	207,536	2,066,792	2,285,752	96,152	655,928	--	227,528	7,156	41,392	3,247,344	1916.....
1917.....	142,800	2,347,512	2,577,064	1,304	136,136	--	251,360	2,800	84,728	5,085,724	1917.....
1918.....	203,776	1,705,032	1,818,320	11,424	854,496	--	191,320	1,800	30,368	4,814,224	1918.....
1919.....	(28,566)	(190,400)	(285,600)	--	(190,400)	--	(45,200)	--	(14,200)	(669,400)	1919.....
1920.....	--	--	205,632	--	--	--	--	--	--	205,632	1920.....
1921.....	--	--	6,664	--	--	--	--	--	--	6,664	1921.....
1922.....	--	--	--	--	--	--	--	--	--	--	1922.....
1923.....	--	--	229,432	--	--	--	--	--	--	229,432	1923.....
1924.....	--	--	114,760	--	(242,240)	--	--	--	--	(127,480)	1924.....
1925.....	8,565	546,287	191,296	--	87,190	--	--	--	--	733,338	1925.....
1926.....	43,733	406,362	220,799	--	518,628	--	80,655	--	--	1,269,817	1926.....
1927.....	1,363	292,178	315,972	--	356,360	--	134,132	--	5,517	1,110,942	1927.....
1928.....	--	318,920	218,008	--	524,552	--	81,472	--	6,640	1,143,052	1928.....
1929.....	19,034	142,768	144,661	--	474,776	--	4,758	--	--	641,937	1929.....
1930.....	952	111,351	44,731	--	474,891	--	--	--	--	627,101	1930.....
1931.....	92,268	33,310	93,268	--	1,110,658	--	--	1,464	29,522	1,339,222	1931.....
1932.....	59,008	36,455	--	--	1,029,364	--	--	14,571	22,251	1,131,249	1932.....
1933.....	39,972	165,599	81,847	--	523,444	--	--	40,424	--	711,287	1933.....
1934.....	245,563	227,461	325,488	952	993,545	--	--	150,283	75	1,715,267	1934.....
1935.....	374,973	190,345	371,170	--	1,166,147	--	--	18,100	--	2,110,635	1935.....
1936.....	465,392	240,785	171,309	10,469	1,552,255	--	--	45,623	--	2,485,033	1936.....
1937.....	332,150	549,142	208,426	94,220	2,049,053	--	--	55,910	7,114	3,096,015	1937.....
1938.....	35,213	798,442	228,413	146,345	1,395,463	--	--	89,471	1,214	2,654,261	1938.....
1939.....	95,172	1,202,022	455,874	216,992	1,990,560	--	--	7,112	40,346	4,069,056	1939.....
1940.....	332,150	1,970,560	659,542	247,447	1,709,239	(2)	--	7,405	71,346	4,356,739	1940.....
1941.....	263,626	2,477,327	600,535	624,328	2,178,487	--	--	64,117	64,363	6,212,653	1941.....
1942.....	208,426	3,314,840	357,743	2,306,225	2,906,649	--	--	40,904	49,500	7,835,347	1942.....
1943.....	59,366	3,684,108	399,750	4,423,506	2,709,505	38,070	--	3,807	14,362,200	12,888,001	1943.....
1944.....	27,400	2,980,856	281,709	3,811,639	2,536,334	177,600	1,664	4,758	94,300	11,749,057	1944.....
1945.....	94,317	1,021,145	222,402	2,027,163	1,767,344	125,648	3,407	1,407	4,459	5,649,435	1945.....
1946.....	19,034	1,031,070	202,716	610,250	2,440,652	292,179	152	15	124,771	4,480,469	1946.....
1947.....	12,372	374,978	64,718	58,655	1,901,369	511,005	--	--	1,113	2,908,072	1947.....
1948.....	21,389	1,681,689	197,458	81,848	90,132	918,411	--	--	52,211	3,853,098	1948.....
1949.....	(4)	906,037	211,282	62,414	704,274	732,824	--	--	--	2,616,871	1949.....
1950.....	384	1,927,400	186,592	211,346	1,049,096	1,080,480	--	--	11,194	4,275,312	1950.....
1951.....	10,472	2,862,664	319,872	358,904	1,410,806	791,034	--	--	12,117	5,435,709	1951.....
1952.....	67,706	2,835,445	595,000	317,016	2,217,058	1,143,084	(2)	--	14,182	6,935,395	1952.....
1953.....	128,000	2,209,000	777,000	420,000	3,514,000	1,974,000	1,000	--	5,000	10,027,000	1953.....
1954.....	5,700	4,437,300	876,300	431,000	3,951,000	2,456,200	--	--	4,000	13,681,500	1954.....
1955.....	--	--	--	--	--	--	--	--	--	--	1955.....
1956.....	--	--	--	--	--	--	--	--	--	--	1956.....

¹ Alaska, Connecticut, Montana, Missouri, New Mexico, Oregon, Texas, and Utah. In 1954 Montana shipped 601,000 pounds, and Utah 187,000 pounds.
² Less than half a ton; included under other States.
 () Estimates. Figures for years 1914-24 represent production.

Source: Minerals Yearbook, U. S. Bureau of Mines; Mineral Resources of the United States, Part II: Metals, U. S. Bureau of Mines.

Prior to 1925, production rather than shipments was recorded. In view of this fact the present discussion will deal with the period 1925-54. For these years tungsten shipments from domestic mines in terms of contained tungsten was 127 million pounds, or 38 percent of the total supply of 332 million pounds for the same period. Shipments were obtained from many widely scattered operations in 15 States and Alaska. Of these, 5 States--California, Colorado, Idaho, Nevada, and North Carolina--accounted for 121 million pounds, or 95 percent of the total. (The production position of each of the five States can easily be ascertained by looking at the curves in figure VI-2.)

California and Nevada together have consistently shipped over 50 percent of the total for each year (1925-54). Nevada ranked first as a supplier of tungsten, having shipped 46 million pounds (tungsten content) or 36 percent of total shipments. California ranked second with shipments of 38 million pounds or 30 percent of the total. Nevada reached a peak in 1942 with shipments of 3 million pounds, while California reached its record in 1954 with 4.5 million pounds. For a few years Idaho ranked as the largest producer of tungsten, due to the discovery of tungsten ore at the Yellow Pine Antimony Mine near Stibnite, Valley County, in the spring of 1941. This one mine produced more tungsten than any other mine in the



United States when it was mining tungsten ore, and its shipments placed the State of Idaho in first position as producer for the years 1943 through

1945. By 1945 the rich tungsten ore body in the Yellow Pine mine was exhausted, and Idaho lost its lead position.

DISTRIBUTION

Distribution in this survey consists of exports of tungsten ores and concentrates (60% WO_3 , minimum), and domestic consumption of ore and concentrates. However, prior to 1937 there is no record of any such exports, and a separate record was not kept until late 1941. Therefore, as a part of distribution, exports for years through 1938 include tungsten metal, wire, shapes, ferrotungsten and other tungsten alloys. In the years 1936-41, ferrotungsten data were not available. As can be seen from table I-1, exports of tungsten ores and concentrates have always been relatively insignificant, being under 5 percent of total distribution. At times there were no exports of ores and concentrates.

Exports

The small quantities of tungsten concentrates exported were to industrial countries which did not produce sufficient tungsten ores and concentrates for their own consumption, or to those which needed the particular kind of tungsten concentrates produced here. Among the chief importers of tungsten concentrates from the United States were Canada, Germany, France, Italy, India, Sweden and the United Kingdom.

Consumption

Tungsten concentrates are consumed in the United States in several forms. One of the most important applications of tungsten is for tool steels. Therefore, some of the tungsten concentrates are converted to ferrotungsten, the form in which it is introduced into the steel bath in the production of steel. Another practice has been to introduce high-purity scheelite concentrates directly into the steel bath. Lately, increasing quantities of tungsten concentrates have been consumed in the production of metal powder for producing tungsten rod, wire, sheet, alloy, and carbide. Minor quantities of concentrates are used for chemicals.

Beginning with the year 1941, which presumably represented the consumption

pattern of previous years, 95 percent of total tungsten concentrates consumed went into steel production, and 5 percent was in the form of metal powder, chemical compounds and other related products. During the ensuing period from 1941 through 1954, the proportion of tungsten concentrates consumed in tool steels declined from 95 percent of the total in 1941 to 31 percent in 1954. The greatest change, however, occurred in the consumption of concentrates for tungsten metal powder and other products, which increased from a mere 5 percent of the total in 1941 to a peak of 76 percent in 1952. Metal powder production decreased somewhat in the two succeeding years (see table VI-3 and figure VI-3). In 1952 about 75 percent of the powder produced went into the manufacture of tungsten carbide or "hard" metal. The shift in the relative quantities of tungsten concentrates consumed, from ferrous alloys to tungsten metal powder, may be explained partially by (1) the increased use of cemented carbide for cutting-tools and cores of armor-piercing anti-tank projectiles, and (2) the shift which started in 1950 from the use of tungsten-bearing to molybdenum-bearing tool steels. The revo-

TABLE VI-3.—CONSUMPTION OF TUNGSTEN ORES AND CONCENTRATES IN THE UNITED STATES, 1941-1954

(In pounds of contained tungsten)

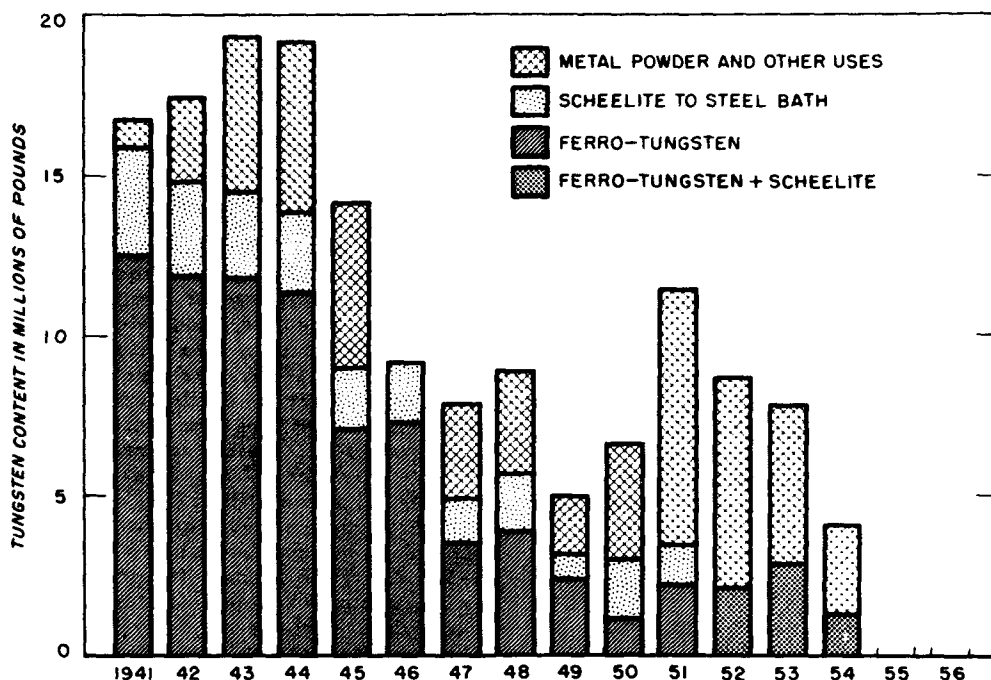
Year	Ferro-tungsten		Direct to steel		Metal powder and other uses		Total	
	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1941.....	14,120,200	76	3,311,800	21	1,334,000	7	18,766,000	100
1942.....	11,324,520	68	2,101,100	12	1,414,000	8	14,839,620	100
1943.....	11,780,930	71	2,103,420	12	1,428,200	8	15,312,550	100
1944.....	11,307,500	70	2,101,400	12	1,414,000	8	14,822,900	100
1945.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1946.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1947.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1948.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1949.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1950.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1951.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1952.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1953.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100
1954.....	11,201,000	70	1,819,000	11	1,434,000	8	14,454,000	100

¹ Includes scheelite used directly in steel bath; separate figures are not available.

Note:—In 1952, 1953, and 1954 hydrogen reduced metal powder manufacturers consumed 42, 40, and 44 percent respectively of the concentrates used during the year.

Source:—*Minerals Yearbook*, U.S. Bureau of Mines.

Fig. VI-3.- Consumption of Tungsten Ores and Concentrates Containing 60% WO₃, in the United States, 1941-1954



cation of end-use control on tungsten in the summer of 1953 resulted in a slightly increased use of tungsten in the manufacture of steel ingots.

The probable distribution of the uses of tungsten ores and concentrates in the United States in recent years is shown in percentages in the following table:

Use	1941	1949	1950	1951	1952	1953	1954
Feermolloys.....	45	63	45	30	24	37	17
Carbides.....	17	17	18	22	57	34	31
Hard facing alloys.....	1	1	1	1	1	2	2
Co-Cr-W-Mo Alloys.....	5	4	6	6	9	9	10
Electrical.....							
Equipment.....		6	8	6	5	17	13
Chemicals.....		6	5	3	3	3	6
Miscellaneous.....		3	10	32	1	3	3

* Includes metal powder.

Stocks

Stocks of tungsten ores and concentrates fall into two groupings: (1) industry stocks, and (2) Government stocks. Industry stocks may be further divided into consumer and producer stocks. Stocks held by these groups constitute the working inventory of industry. Government stocks are held by the Government for future emergencies for the defense of the country. However;

purchases made under the Defense Production Act can be sold to industry at any time.

Industrial stocks.--Data for industrial stocks of tungsten concentrates, as of the end of each year, have been available only since 1939. These stocks are the working inventory for industry, and fluctuate annually between 2 and 6 million pounds of contained tungsten. During World War II, industrial stocks fluctuated between a low of 2 million pounds (tungsten content) in 1944 and a high of 4.3 million pounds in 1945 (see table VI-4 and figure VI-4). During the earlier years, industrial stocks were between 2 and 3 million pounds.

In 1948 expanded industrial production, as reflected by a high level of consumption of tungsten concentrates (see table VI-3), stimulated domestic mine production and imports of tungsten concentrates to such an extent that total industrial stocks at the end of the year (5.8 million pounds) were about 57 percent greater than in 1947. However, the slump in business and industry in 1949 brought a substantial decline in the output of high-speed steel and of tungsten powder and, therefore, a decline in the consumption of tungsten concentrates.

TABLE VI-4.--INDUSTRY AND GOVERNMENT STOCKS OF TUNGSTEN ORES AND CONCENTRATES IN THE UNITED STATES, 1939-1954

(In pounds of contained tungsten)

Year	Consumers and dealers	Producers ¹	Total industrial stocks	Government stockpile ²
1939.....	2,667,738	283,803	2,951,541	144,000
1940.....	2,801,249	93,618	2,894,867	5,417,000
1941.....	2,404,876	263,626	2,668,502	4,117,000
1942.....	3,416,438	355,866	3,772,304	3,532,000
1943.....	2,459,246	48,586	2,507,832	21,000,000
1944.....	1,910,419	49,634	1,960,053	27,281,000
1945.....	3,136,229	257,042	3,393,271	20,000,000
1946.....	3,634,296	285,865	3,920,161	---
1947.....	3,433,392	38,316	3,471,708	---
1948.....	5,284,901	63,414	5,348,315	---
1949.....	4,229,000	82,065	4,311,065	---
1950.....	2,161,205	216,000	2,377,205	---
1951.....	4,310,502	236,282	4,546,784	---
1952.....	2,816,000	32,888	2,848,888	---
1953.....	4,335,000	363,000	4,698,000	---
1954.....	3,313,000	44,000	3,357,000	---

¹ Primary concentrates.
² Excluded stocks held by the Treasury Procurement Division and United States Navy. Figures after 1944 are not available.
 Source: *Mineral Yearbook*, U.S. Bureau of Mines (published annually).

of contained tungsten (6 percent over the 1949 figure of 5 million pounds). As would be expected, the consumers' stock of concentrates increased from 4 million pounds of contained tungsten in 1949 to 5 million pounds in 1950, while producers' stock decreased from 827,000 pounds to 216,000 pounds. In 1951 and 1952 with stepped up need of tungsten bearing products, consumers' stock by 1952 decreased to 2.8 million pounds of contained tungsten. In 1953 and 1954, increased mining production rates and easing supply caused an upswing in both consumer and producer stocks.

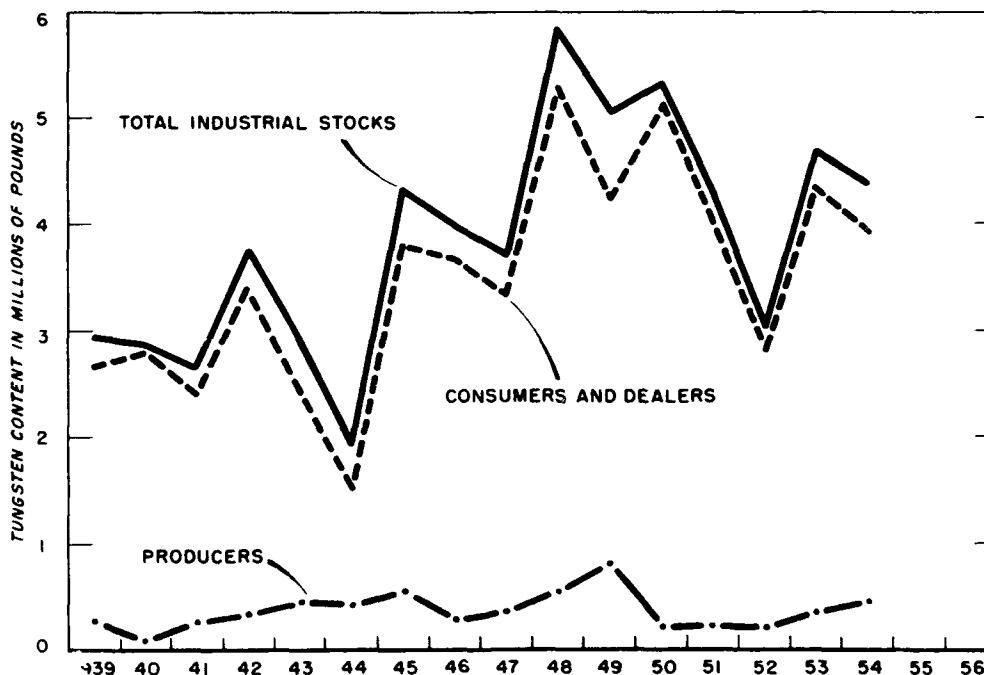
Government Stocks.--At the beginning of World War II the Government began accumulating a stockpile of critical materials, including tungsten, for emergencies during the war. Beginning in 1939 with 144,000 pounds (tungsten content), the Government increased the stockpile each year until a peak of 28 million pounds was reached in 1944. This declined to 21 million pounds in 1945. After this date, stockpile data are not available.

The Government's stocks held at the end of the War by Metals Reserve Corporation were not dispersed to industry. But, in accordance with the Surplus Property Act

Accordingly, industry stocks of concentrates decreased to 5 million pounds by the end of 1949.

The outbreak of Korean hostilities in mid-1950 brought about increased industrial activity. Total industrial stocks of tungsten concentrates increased to 5.3 million pounds

Fig. VI-4. - Industrial Stocks of Tungsten Ores and Concentrates in the United States, 1939-1954



of 1944, Public Law 457 (58 Stat. 765) 78th Cong., Sec. 22-a, approved October 3, 1944, these stocks when declared surplus were to be transferred to the Treasury Procurement Division.

In spite of these large accumulated stocks of tungsten, it appeared early in 1945 that they would be insufficient for the requirements of the tungsten shell-core program. To ease the shortage, the War Production Board, on May 18, 1945, issued Order M-21-j which limited purchases of tool steel having high tungsten content. Meanwhile, the Metals Reserve Corporation resumed tungsten recovery operations at its chemical treating plant at Salt Lake City, Utah, in May. By the time this program got under way, the war in Europe was terminated. Tungsten supplies again became ample for all requirements and the War Production Board revoked Order M-21-j on July 2, 1945. The Government-owned Salt Lake City chemical plant discontinued operations in the third quarter of 1946.

With the outbreak of fighting in Korea in mid-1950, the supply of tungsten again became inadequate to meet demands. To lessen this shortage General Services Administration announced on May 10, 1951, a domestic tungsten purchase program to be carried out according to a policy established by Defense Minerals Administration and Defense Production Administration. The program originally provided for government purchase of standard grades of tungsten concentrates at \$63 per short ton unit for 5 years or until 1,468,750 units were obtained. On June 20, 1951, the number of units was increased to 3 million, or to July 1, 1956, whichever occurred first. There was a penalty schedule outlining deductions from the basic price of \$63 for off-grade concentrate (see table VIII-4). This has since been modified to provide a greater allowance for molybdenum without penalty. In 1953 the termination date was extended to July 1, 1958 unless the 3 million units were delivered before that date (see Public Law 206, 67 Stat. 417, 83rd Cong).

CHAPTER VII
WORLD PRODUCTION AND CONSUMPTION

CHAPTER VII WORLD PRODUCTION AND CONSUMPTION

WORLD MINE PRODUCTION

Tungsten is produced in many areas of the world, and most all continents produce significant quantities. In the United States there is a noteworthy concentration of deposits in a belt bordering the Pacific Ocean.

World production of tungsten ores and concentrates containing 60 percent WO_3 , for the period 1905 through 1954, totalled 1.2 million metric tons. China produced by far the largest portion, accounting for 329,000 metric tons or 28 percent of the world total. The United States was the second largest producing country but it contributed only 13 percent of the world total. Burma ranked third with 10 percent. Largest of the other producing countries were Bolivia with 8 percent, Portugal with 7.5 percent, and Korea with 7 percent. These six countries together produced 73 percent of the total world tungsten production for the period. Twelve countries produced 88 percent of the world production (see table VII-2).

In table VII-1 is shown the production of tungsten ores and concentrates (metric tons of 60% WO_3 content) by countries, from 1905 through 1954. The curves in figure VII-1 show production of Bolivia, China and the United States as compared with world output.

In the last few years, Korea has developed into an important producer of tungsten ores. In 1936 Korea produced only 1,850 metric tons of 60 percent WO_3 concentrates or 7 percent of world production. This soon increased to a peak production in 1944 of 8,400 metric tons, or 17 percent.

With the rearmament boom beginning about 1935, tungsten production increased rapidly during 1936 and 1937 in all major mining countries. By 1943 the United States had become the world's largest producer of tungsten ore, producing 10,800 metric tons of concentrates containing 60 percent WO_3 or 18 percent of world production. Not until 1947 with the production of 6,900 metric tons of tungsten concentrates, or 26 percent of world production, did China regain its lead which it had lost to the United States in 1943. Meanwhile, United States production declined from the high of 1943 to a post war low of 2,500 metric tons, or 7 percent of world production, in 1949. However, with Government encouragement, United States production by 1953 reached 8,700 metric tons to rank second to China as a world producer.

TABLE VII-1. - WOLFRAM PRODUCTION OF TUNGSTEN AND CONCENTRATES CONTAINING 60 PERCENT W₂O BY COUNTRIES, 1905-1959

in metric tons

Year	North America		South America				Europe						Africa	Asia
	United States (shipments)	Canada (shipments)	Argentina	Bolivia (exports)	Brazil (exports)	Chile and Peru	France	Germany	Portugal	Spain	Sweden	Switzerland		
1905	728	--	--	63	--	--	25	38	20	10	--	--	17	2
1906	847	--	706	68	--	--	12	52	201	201	--	--	15	2
1907	1,688	--	460	454	--	--	61	62	137	270	--	--	15	2
1908	1,699	--	497	170	14	--	112	42	62	23	--	--	137	2
1909	1,469	--	817	151	--	--	50	96	551	129	--	--	151	2
1910	1,051	75	769	410	--	14	30	45	1,027	153	--	--	270	2
1911	1,033	--	619	336	--	52	171	81	978	96	--	--	270	2
1912	1,207	15	637	496	--	219	229	92	1,330	143	--	--	196	2
1913	1,394	11	975	297	--	324	160	96	1,116	169	--	--	147	2
1914	1,298	--	439	290	--	213	145	108	607	137	--	--	137	2
1915	2,116	140	169	899	--	413	126	193	953	189	--	--	164	2
1916	2,373	159	85	1,398	5	594	162	115	1,418	429	--	32	27	2
1917	2,574	308	1,085	4,215	--	427	261	295	1,280	441	--	147	27	2
1918	4,591	284	614	1,703	--	256	45	196	1,150	34	3	27	80	2
1919	1,997	103	204	2,161	--	139	70	145	706	30	30	5	17	2
1920	196	82	192	766	--	77	23	45	237	57	5	1	24	2
1921	--	37	52	174	--	2	--	27	306	23	--	--	21	2
1922	--	--	125	9	--	--	--	62	327	--	--	--	27	2
1923	219	--	144	--	--	--	--	40	289	9	--	--	27	2
1924	513	--	137	--	--	--	--	13	306	101	--	--	27	2
1925	1,080	--	4	43	--	5	--	161	207	23	--	--	27	2
1926	1,254	--	11	109	--	--	26	--	358	113	--	26	20	2
1927	1,056	--	1	79	--	--	9	--	174	124	--	26	11	2
1928	1,036	--	14	29	--	--	--	--	151	193	--	26	8	2
1929	753	11	63	1,630	--	--	1	--	352	237	--	26	27	2
1930	637	28	98	888	--	--	--	--	499	156	--	26	174	2
1931	1,274	--	20	410	--	--	--	5	252	120	--	26	101	2
1932	359	--	7	686	--	--	--	--	272	43	--	26	27	2
1933	312	--	--	240	--	--	--	--	158	46	--	26	11	2
1934	1,859	80	392	794	--	11	--	1	110	43	--	26	223	2
1935	2,123	54	579	1,423	--	64	--	--	1,140	--	--	26	270	2
1936	2,173	57	702	1,741	--	95	--	--	1,414	--	--	26	221	2
1937	1,175	11	86	1,481	96	--	--	--	1,069	200	127	26	168	2
1938	2,151	76	1,145	2,534	175	--	--	--	1,810	217	180	26	222	2
1939	1,220	233	1,309	3,137	170	284	--	--	1,411	362	152	1,000	148	2
1940	4,241	285	1,417	4,183	290	138	--	--	2,352	392	145	5,000	201	2
1941	5,107	223	1,720	4,153	338	120	--	--	2,934	412	128	5,000	227	2
1942	4,247	--	1,115	5,136	9	11	--	--	1,115	1,462	217	5,000	148	2
1943	10,526	1,142	2,240	6,902	1,764	129	--	--	2,677	2,402	290	5,000	227	2
1944	7,229	590	2,643	1,335	1,001	62	91	--	2,352	1,493	335	11,000	227	2
1945	5,060	143	1,067	3,851	2,190	523	175	--	--	283	413	11,000	170	2
1946	4,711	95	457	2,120	1,823	510	146	--	680	431	490	11,000	108	2
1947	2,707	472	33	1,639	1,329	591	--	--	1,149	461	322	11,000	17	2
1948	1,659	924	33	2,489	1,144	552	567	--	1,944	876	317	5,000	26	2
1949	2,804	296	(30)	2,543	577	455	794	--	2,701	898	448	5,000	21	2
1950	4,373	382	34	2,485	759	516	45	--	1,500	840	362	7,500	27	2
1951	5,140	327	150	2,718	1,402	469	744	--	2,142	1,451	383	7,500	27	2
1952	6,885	1,572	430	3,707	1,786	584	982	--	2,283	2,479	337	7,500	27	2
1953	2,761	2,535	600	3,825	1,407	608	1,379	--	2,363	2,340	440	7,500	21	2
1954	1,420	2,186	767	4,445	1,373	770	346	--	2,125	2,365	457	7,500	22	2
1955	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1956	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Notes: Figures for a few countries for certain years are exports or shipments instead of production. In 1947 Korea was divided into the Republic of Korea and North Korea; separate figures are obtainable from Minerals Yearbook.

-- Estimates.

Source: In Europe include Austria, Czechoslovakia, Italy, and Norway; in Africa, primarily Southern Rhodesia, Belgian Congo, and Gold Coast (Ghana); and in Asia, India, Indonesia, and Hong Kong.

TABLE VII-1.--WORLD PRODUCTION OF TUNGSTEN ORES AND CONCENTRATES CONTAINING 60 PERCENT WO₃, BY COUNTRIES, 1905-1954--Continued
(In metric tons)

All countries	Asia								Oceania		Total world
	Burma	China	French Indo-China	Japan	Korea	Malaya	Thailand (Siam)	Others ¹	Australia	New Zealand	
--	--	--	--	43	--	--	--	--	1,760	58	3,652
8	--	--	--	43	--	137	--	--	1,259	110	3,963
191	--	--	--	64	--	81	9	5	1,253	139	5,587
36	--	--	--	200	--	75	--	23	756	79	3,736
14	--	--	--	265	--	90	--	28	1,084	71	6,228
--	369	--	17	250	--	95	--	51	1,583	169	6,867
--	1,015	--	--	260	--	186	182	--	1,328	167	6,819
--	1,901	--	74	204	--	323	181	26	1,257	164	8,809
5	1,572	--	127	257	--	362	280	6	848	262	8,123
--	2,166	18	162	204	--	460	273	1	724	242	7,427
1	2,464	35	333	389	67	488	432	6	899	230	10,866
4	3,464	109	343	730	555	884	530	93	1,117	308	20,844
29	4,226	1,361	433	763	919	1,171	726	76	1,306	235	29,869
74	4,138	10,577	378	629	1,000	1,547	231	51	1,367	170	31,992
61	3,673	2,654	284	574	197	1,288	258	1	1,244	146	16,744
17	2,983	4,712	284	170	5	553	137	161	624	47	11,495
17	673	2,657	452	--	--	72	76	80	17	46	4,836
44	1,038	3,873	112	--	14	362	--	--	44	--	6,221
--	960	4,554	129	--	--	434	--	10	119	15	6,953
22	814	3,398	150	--	--	321	--	165	75	18	6,159
22	869	6,708	189	--	--	425	127	27	220	36	10,238
--	1,634	7,989	92	19	--	333	10	9	49	15	12,231
33	1,277	5,666	213	49	5	192	8	22	179	15	9,282
15	863	8,283	175	54	161	144	--	8	238	6	11,647
28	1,484	9,978	198	61	15	513	62	16	248	39	15,811
38	2,699	9,454	220	81	13	1,232	7	15	241	21	16,652
26	2,474	7,492	248	56	17	703	12	1	94	6	13,385
14	2,226	2,249	247	22	62	553	--	--	50	7	6,800
36	3,056	6,000	250	31	144	1,299	--	--	150	10	12,433
140	3,913	5,099	300	70	399	2,011	36	1	419	39	16,447
112	4,527	7,998	417	96	949	2,035	82	1	491	61	22,458
177	5,382	7,638	503	61	1,849	2,037	82	1	426	49	24,867
562	6,894	17,895	648	206	1,590	1,356	221	15	866	28	38,859
591	7,090	13,387	545	300	2,625	1,082	251	12	1,197	54	37,381
663	7,824	12,871	507	299	3,969	587	378	2	1,029	49	42,305
586	8,095	10,141	390	479	4,525	522	400	44	1,126	88	43,592
689	8,300	13,538	333	601	4,650	56	961	77	1,142	79	50,285
1,467	1,346	12,962	213	817	6,062	61	1,653	87	903	73	50,749
2,030	1,346	9,734	107	733	6,932	146	1,738	85	908	121	60,072
2,112	1,346	3,502	83	575	8,402	217	1,135	33	684	159	49,220
1,354	--	2,929	8	193	1,513	29	461	22	1,148	37	22,802
701	--	2,691	--	59	1,180	10	201	3	1,041	30	18,877
960	1,045	6,900	--	19	2,202	50	486	--	1,132	24	26,544
616	1,824	12,200	--	9	2,245	87	(800)	--	1,234	28	(37,400)
1,030	740	(9,000)	--	20	2,448	69	(1,100)	--	1,371	28	(33,200)
809	930	(12,000)	--	24	(1,900)	27	(1,200)	2	1,235	24	(38,400)
1,370	1,647	(15,800)	--	166	(2,500)	54	(1,350)	38	1,883	35	(52,100)
2,078	2,200	(20,000)	--	482	(3,300)	79	(1,600)	114	2,171	63	(68,800)
2,454	2,000	(17,000)	--	730	(9,000)	147	1,750	165	2,413	(40)	(71,700)
2,709	(1,200)	(18,000)	--	780	(5,700)	115	1,200	31	4,325	(30)	(70,500)

¹ Data not available, no estimates included in total.

Sources: Minerals Yearbook, United States Bureau of Mines; Mineral Trade Notes, United States Bureau of Mines (published monthly).

Fig. VII - 1. - World, Bolivia, China and United States
Output of Tungsten Ores and Concentrates
Containing 60% WO_3 , 1914-1954

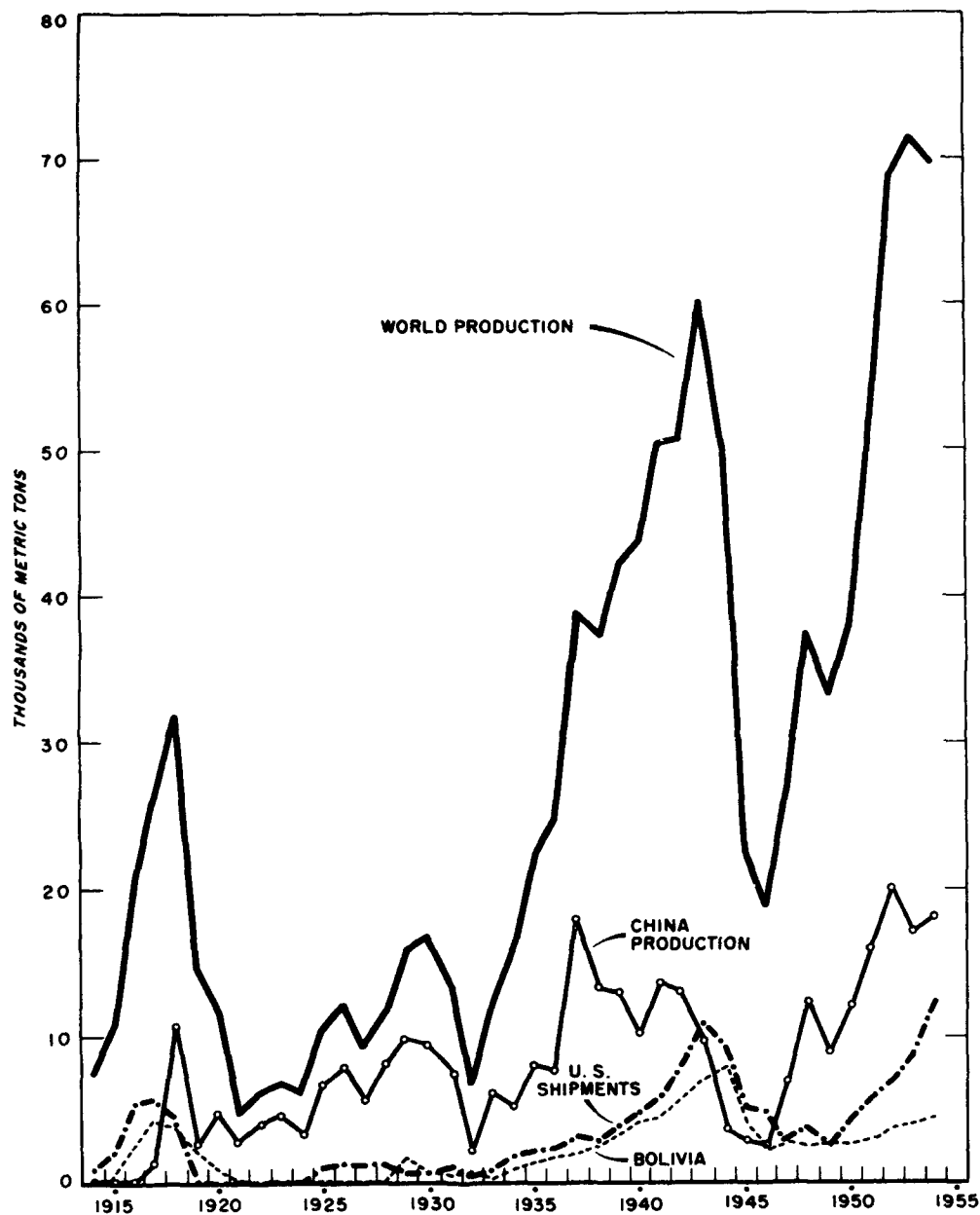


TABLE VII-2.---ACCUMULATIVE WORLD PRODUCTION OF TUNGSTEN ORES BY COUNTRIES

1905-1954

(In metric tons)

Country	60 percent WO ₃ metric tons	Percent of world total		60 percent WO ₃ metric tons	Percent of world total
North America			Africa¹	<u>24,000</u>	<u>2.03</u>
Canada).....	--	--	Asia		
Cuba).....	13,000	1.10	Burma.....	115,000	9.72
Mexico).....	--	--	China.....	329,000	27.81
United States.....	<u>151,000</u>	<u>12.76</u>	Fr. Indo-China.....	9,000	0.76
Total.....	<u>164,000</u>	<u>13.86</u>	Japan.....	12,000	1.01
South America			Korea.....	79,000	6.68
Argentina.....	28,000	2.37	Malaya.....	25,000	2.11
Bolivia (exp.).....	93,000	7.86	Thailand (Siam).....	21,000	1.78
Brazil (exp.).....	17,000	1.44	Others ²	<u>2,000</u>	<u>0.17</u>
Chile.....	--	--	Total.....	<u>592,000</u>	<u>50.36</u>
Peru).....	11,000	0.93	Oceania		
Total.....	<u>149,000</u>	<u>12.60</u>	Australia.....	45,000	3.8
Europe			New Zealand.....	<u>4,000</u>	<u>0.34</u>
France.....	9,000	0.76	Total.....	<u>49,000</u>	<u>4.14</u>
Germany.....	2,000	0.17	World total.....	<u>1,183,000</u>	<u>100.00</u>
Portugal.....	89,000	7.52			
Spain.....	32,000	2.71			
Sweden.....	5,000	0.42			
U.S.S.R. (est.).....	58,000	4.90			
United Kingdom.....	8,000	0.68			
Others ³	<u>2,000</u>	<u>0.17</u>			
Total.....	<u>205,000</u>	<u>17.33</u>			

¹ In Europe include Austria, Czechoslovakia, Finland, Italy, Norway, and Yugoslavia; in Africa, primarily South Rhodesia, Belgian Congo and Union of South Africa; and in Asia, India, Indonesia, and Hong Kong.

Source: Minerals Yearbook

WORLD TUNGSTEN CONSUMPTION

The consumption of tungsten is very sensitive to changing economic conditions and especially to munitions demand in time of war. During World War II, world tungsten consumption reached a high in 1943, when 14,600 metric tons of contained tungsten in ores and concentrates, as well as primary products, were consumed. When the war ended in August 1945, there was a period through 1946 during which industry re-adjusted itself to peacetime production. For this period, the consumption of tungsten was below previous levels. Industrial production swung strongly upward during 1947 and reached a peak in the year 1948, at which time world tungsten consumption was 12,600 metric tons (tungsten content), a quantity close to the 1943 record. The industrial recession in 1949 reduced world consumption to 9,700 metric tons. In 1950, the outbreak of hostilities in Korea stimulated world consumption of tungsten until it reached 13,200 metric tons. World consumption for 1951 was estimated at 13,300 metric tons (tungsten content), not far from the 1943 record high of 14,600 metric tons. The 1952 estimated world consumption, based on allocations of concentrates and primary products, reached a high of 17,600 metric tons of contained tungsten.

The chief tungsten consuming countries have been industrial countries with facilities for the conversion of ore concentrates to primary products such as ferrotungsten, metal powder, tungstic acid and salts. In Europe the largest consumers of tungsten are the industrial nations: Great Britain, Germany, France, and Sweden. It is also known that Russia consumes considerable quantities of tungsten for its expanding industry. Japan, the leading industrial nation of Asia, is the largest consumer of tungsten on that continent. The Union of South Africa in the last few years has been consuming increasing quantities of tungsten as its industry expands. Australia is the largest consumer of tungsten in Oceania. In North and South America, the United States as the world's leading industrial nation is also the world's largest consumer of tungsten (see table VII-3 and figure VII-2).

During recent years, Great Britain and the United States have been the world's largest consumers of tungsten. Together, these two countries in 1943 consumed 10,156 metric tons or 70 percent of the world total. In 1948, 1949, and 1950 these countries consumed 7235, 4942 and 5897 metric tons, respectively, or 57, 51, and

45 percent of total world consumption. Of estimated world consumption in 1951 and 1952, these two countries consumed 59 percent in 1951 and 69 percent in 1952. France and Sweden have each accounted for about 10 percent of world consumption during the years from 1948 through 1950. As Germany's industry recovered, that country in 1950 consumed 14 percent of the world total. Before World War II, Germany was the largest consumer of tungsten in Europe. Altogether, the United States and these European countries have in recent years been responsible for over 80 percent of the total world consumption.

TABLE VII-3.--TUNGSTEN CONSUMPTION BY PRINCIPAL COUNTRIES, 1943, 1948-1952¹

(In metric tons of contained tungsten)

Country	1943	1948	1949	1950	1951	1952
Total.....	14,578	12,586	11,641	13,162	13,276	14,118
Australia.....	255	45	24	24	40	101
Austria.....	n.a.	318	237	12	127	182
Belgium.....	n.a.	5	5	4	14	7
Canada.....	520	19	180	166	350	170
France ²	48	1,753	1,430	1,133	1,150	1,170
Germany.....	n.a.	584	759	1,342	1,440	1,729
Italy.....	129	242	230	247	148	164
Japan.....	2,718	420	280	1,740	500	400
Netherlands.....	n.a.	650	55	8	20	14
Norway.....	n.a.	29	12	12	35	37
Spain.....	180	132	4	12	100	100
Sweden.....	217	1,317	1,147	1,124	760	760
Switzerland.....	0	11	11	21	21	60
South Africa.....	n.a.	n.a.	12	10	50	67
United Kingdom.....	1,390	3,219	2,004	2,779	22,160	17,100
United States.....	3,760	4,740	2,227	3,100	13,180	7,100
U.S.S.R.....	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Yugoslavia.....	n.a.	50	40	40	40	40
Others ³	193	1,004	1,004	100	100	80

¹ / Estimates
n.a. Not available

² Includes primary products such as ferro-tungsten, tungsten wire, tungsten castings, and tungsten powder, as well as ore and concentrates consumed in the "Free World." (Undoubtedly there is some overlapping in figures.)

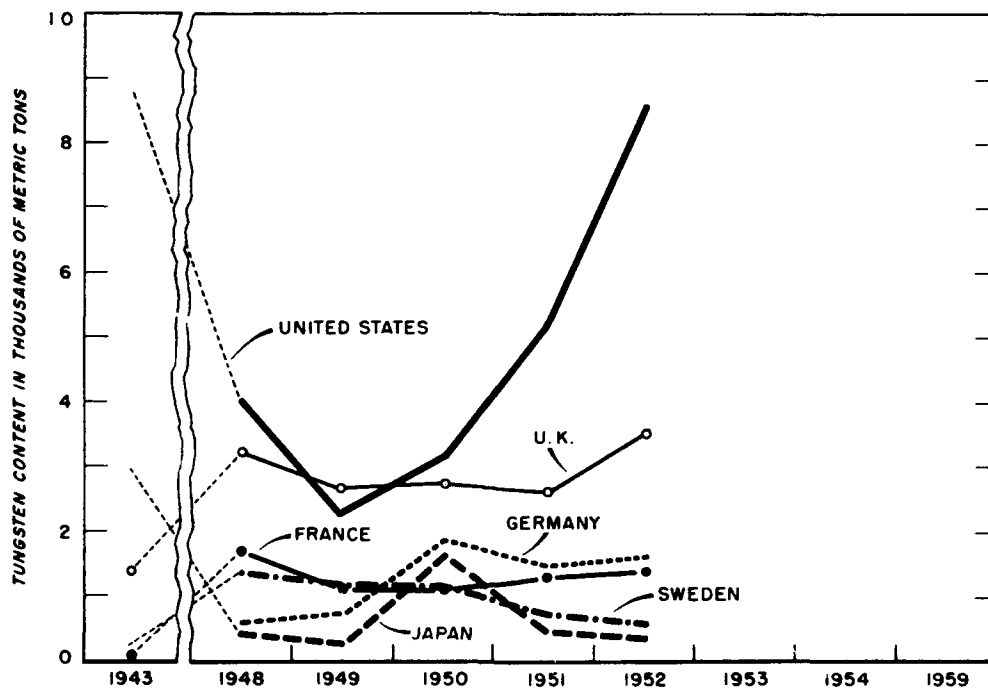
³ Includes French North Africa.

⁴ Includes Argentina, Brazil, Chile, Denmark, Finland, India, Turkey.

⁵ Allocations which can be assumed to approximate consumption.

Sources: Report on Operations, International Materials Conference, Washington, 1952 and 1951.

Fig. VII- 2. - Tungsten Consumption by Principal Countries, 1943, 1948 - 1952



CHAPTER VIII
MARKETING--PRICES AND SPECIFICATIONS

CHAPTER VIII MARKETING--PRICES AND SPECIFICATIONS

MARKETING

Tungsten ores and concentrates are saleable commodities, but must be treated before use. If not performed by the owner, treating to remove impurities and raise the WO_3 content to 60 percent or better may be done on a "toll" basis. In such a case, all desirable products recovered by the treating plant are returned to the original owner who defrays the cost of treatment. More common, however, treating plants buy the ore outright so that all products recovered become the property of the treating plant.

There is no regular market set up to handle tungsten ores or concentrates for the benefit of the miners, such as exists for some other metals, tin for example. Tungsten consumer requirements are either purchased directly from the producer or through a broker. Therefore, ores are shipped from all parts of the world. Shanghai and Hong Kong, China; and Rangoon, Burma, are important shipping points, although their importance has waned in recent years due to political uncertainty and increasing production in other areas of the world. Points of entry are likewise scattered, the principal ones being: Hamburg, Germany; Liverpool and London, England; Marseilles, France; and New York, United States.

Tungsten ores entering commerce are classified into two groups: (1) the so-called "black ores" (wolframite, ferberite, and huebnerite) and (2) scheelite. Scheelite

nominally is on a par with the wolframites, but, where the ore is reasonably free from impurities, it may command a premium.

This classification may be further modified by the buyer on the basis of types of reduction employed. For chemical processing, as in the production of metallic tungsten or chemical compounds, impurities are a minor consideration since they can be almost entirely eliminated; therefore, buyers employing chemical treatment can use almost any ore. Costwise, however, high grade ores are preferred, since cost of purification increases as amounts and types of impurities increase. On the other hand, for the manufacture of ferrotungsten, a high grade concentrate practically free from tin, copper, arsenic, antimony, phosphorus, bismuth, and sulfur is required. These impurities, if present, would enter finished products and are, therefore, considered detrimental. When contained in over specified amounts, impurities are penalized by the buyer because they complicate smelting and refining. The penalties charged vary with individual negotiations between buyer and seller.

Ores are priced according to the amount of valuable metal they contain, plus certain additional requirements--the ore or concentrate must be above a certain grade, impurities must be below certain limits, etc. Sometimes elaborate schedules are necessary to set up prices on various lots of ore.

PRICES

Tungsten ores and concentrates are sold on the basis of the concentrates containing at least 60 percent WO_3 at so much per unit. One unit is equal to one percent WO_3 per ton.

In the United States and Canada quotations are based upon a short ton unit, that is, one percent of 2,000 pounds or 20 pounds of WO_3 . Tungsten ores and concentrates are usually quoted f.o.b. New York. Price

range over a period of years is shown in table VIII-1. Concentrates containing sufficient tungsten trioxide (WO_3) content to meet "Standard Specification" but containing impurities in excess of specifications are priced according to specific penalties. Penalties are also imposed on WO_3 content down to 55 percent, below which level a buyer may reject. (See DMPA purchase specifications, table VIII-4.)

TABLE VIII-1.--NEW YORK PRICES FOR TUNGSTEN ORES AND CONCENTRATES CONTAINING 60% WO₃, 1900-1934(In dollars per short-ton unit of WO₃)

Year	Quoted price range	Year	High-grade domestic scheelite	Chinese wolframite duty paid
1900.....	2.00 @ 3.50	1925	9.50 @ 12.75	9.00 @ 12.50
1901.....	2.50 @ 3.00	1926	10.50 @ 13.50	10.50 @ 12.50
1902.....	2.50 @ 4.50	1927	10.50 @ 11.50	10.25 @ 11.00
1903.....	1.85 @ 3.60	1928	10.50 @ 11.50	10.25 @ 11.25
1904.....	4.00 @ 7.50	1929	12.00 @ 16.50	11.75 @ 18.00
1905.....	5.00 @ 6.00	1930	13.00 @ 16.50	11.50 @ 15.50
1906.....	5.50 @ 9.50	1931	9.50 @ 12.00	11.00 @ 12.00
1907.....	11.00 (Jan.)	1932	9.00 @ 11.50	10.25 @ 11.00
	5.00 @ 7.00 (May)	1933	8.00 @ 10.00	9.00 @ 9.85
	4.25 @ 6.00 (bal.)		- 15.00	(Dec.) 14.50 @ 15.00
1908.....	5.00 @ 7.50	1934	16.50 @ 19.00	14.50 @ 19.00
1909.....	6.50 @ 8.50	1935	14.50 @ 16.50	15.00 @ 17.00
1910.....	6.50 @ 8.50	1936	14.00 @ 16.00	14.00 @ 16.25
1911.....	4.50 @ 7.50	1937	16.00 @ 34.00	15.00 @ 35.00
1912.....	5.50 @ 7.50	1938	16.00 @ 25.00	17.00 @ 25.00
1913.....	6.00 @ 7.50	1939	16.00 @ 25.00	18.00 @ 23.75
1914.....	5.85 @ 9.00	1940	21.00 @ 24.00	23.00 @ 24.50
1915.....	5.80 (Jan.)	1941	23.50 @ 27.00	23.00 @ 26.00
	50.00 @ 67.50 (Dec.)	1942	26.00	24.00
1916.....	45.00 - 50.00 (Jan.)	1943	26.00	24.00
	85.00 (Apr.)	1944	26.00 @ 26.00	24.00
	17.00 - 18.00 (Dec.)	1945	26.00 @ 24.50	24.00
1917.....	16.80 - 26.50	1946	24.00	22.00 @ 24.00
1918.....	12.00 - 26.00	1947	24.00 @ 32.00	22.00 @ 33.00
1919.....	6.00 - 15.00	1948	28.00 @ 30.00	23.50 @ 30.00
1920.....	6.50 - 10.00 (Jan.)	1949	28.50	18.00 @ 25.25
	4.00 - 4.50 (Dec.)	1950	28.50 @ 47.00	17.50 @ 56.00
1921.....	2.00 - 3.00	1951	65.00 @ 73.00	19.33 @ 73.00
1922.....	2.50 - 3.00 (Jan.)	1952	65.00	51.50 @ 65.00
	1.80 - 2.00 (Apr.)	1953	63.00 @ 65.00	24.00 @ 48.00
	7.50 - 8.50 (Dec.)	1954	63.00	16.00 @ 26.00
1923.....	7.50 - 13.00	1955		
1924.....	7.50 - 10.00	1956		

Notes: 1. Equivalent price in December 1933 in gold standard of Jan. 1933 was \$9.51 @ \$9.84.
 2. Concentrates reported at 65% WO₃ from June 1938 through May 1944.
 3. Beginning Oct. 1950, domestic conc. f.o.b., mine or mill.
 Beginning May 1, 1951, foreign conc., duty extra; in July, f.o.b. foreign ports; in April, c.i.f., United States ports.

Source: Engineering and Mining Journal.
 Prices are f.o.b. New York, unless otherwise noted. After September 1946, quotations cover all foreign ores.

TABLE VIII-2.--LONDON PRICES FOR TUNGSTEN¹ CONCENTRATES, 1925-1954(In shillings per long-ton unit of 65% WO₃, c.i.f. Europe)

Year	Yearly average ² exchange rate (in cents/pound)	Min.	Max.
1925.....	482.89	9/9	24
1926.....	485.82	13	24/6
1927.....	486.10	12/3	17
1928.....	486.62	14/3	20/3
1929.....	485.69	18	35
1930.....	486.21	14	35
1931.....	453.50	12	15
1932.....	350.61	11	16
1933.....	423.68	9/9	30
1934.....	503.93	26	47
1935.....	490.18	29/6	39
1936.....	497.09	25	35/9
1937.....	494.40	32	130
1938.....	488.94	36	82
1939.....	443.54	47	61
1940.....	403.50	50	--
1941.....	403.50	50	--
1942.....	403.50	50	100
1943.....	403.50	55	100
1944.....	403.50	55	100
1945.....	403.50	75	90
1946.....	403.28	75	90
1947.....	402.86	75	150
1948.....	403.13	100	140
1949.....	368.72	75	122/6
1950.....	280.07	90	280
1951.....	279.26	415	675
1952.....	280.59	410	485
1953.....	281.27	180	370
1954.....	280.87	102/6	215
1955.....			
1956.....			

¹ U. K. wolfram buying price.

² Federal Reserve Bulletin, Board of Governors of the Federal Reserve System, Washington, (published monthly).

³ Per unit of WO₃, c.i.f. Europe.

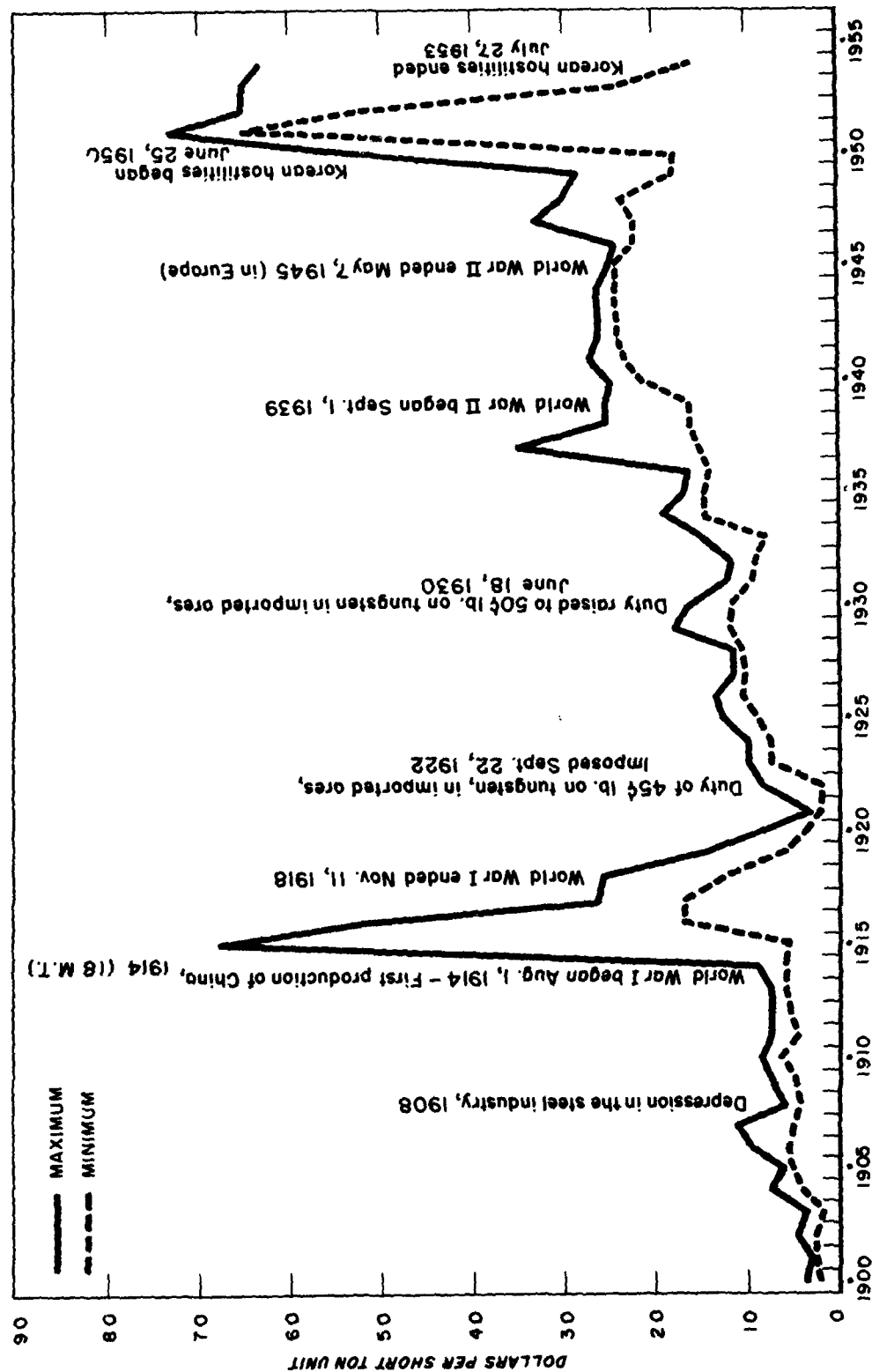
Sources: Quin's "Metal Handbook," Metal Information Bureau, Limited, London, and Mining Journal, London.

World prices of tungsten concentrates are reflected in the London market (see table VIII-2). The prices of tungsten ore and concentrates are quoted in the United Kingdom and British Commonwealth, except Canada, in shillings per long ton unit, or 22.4 pounds of WO₃. A long ton is 2,240 pounds. In China, Germany, and France, the unit is 22.04 pounds, and it is sold at so much per unit of metric ton, which is 2,204 pounds.

As can be seen from tables VIII-1 and -2, and figure VIII-1, the price of tungsten fluctuates with periods of industrial activity and war. Prior to World War I, for the period 1900-14, New York prices per short ton unit varied from \$2.00-3.00 in 1900, and from a peak of \$11.00 in 1907 to \$4.25-9.00 for the years 1908-14 inclusive. During World War I, 1915-18, prices soared to a high of \$85.00 in April 1916, but dropped to \$17.00-26.50 for the years 1917-18. In the period that followed, 1919-30, prices fell to a low of \$1.80 in the first half of 1922. However, with the passage of a protective tariff in the latter half of 1922, the lessening of stocks, and the ever increasing

demand for tungsten in steel, prices for the years 1923-30 were on the upswing. From a start of \$7.50-10.00 in 1923-24, prices climbed steadily to \$16.50-18.00 by the end of 1929. In 1930 a worldwide depression gripped most metals; the tungsten industry, however, remained fairly active until 1932. Prices in early 1930 were \$15.25-16.50, and in late 1931, \$9.50-12.00. In 1932 almost complete collapse of the steel industry occurred. Negligible production continued through the early part of 1933 at which time prices hit a low of \$8.00-9.00. In the spring of 1933 a marked recovery in the steel industry began and was reflected in the tungsten market. In June quotations were \$10.00-10.25, and by the end of the year they were \$14.50-15.00. With the devaluation of the dollar in 1934, prices climbed to \$19.00 in June, and jumped again to a high of \$35.00 in 1937. When the rearmament program got under way, the price of tungsten was stabilized by the Government at \$24.00 per unit by the use of subsidies. There it remained until the end of Government support in 1946. Thereafter, the price increased with the rising price level, to about \$32.00 in 1947. The Korean hostilities in June 1950 brought

Fig. VIII - 1. - Prices of Tungsten Concentrates in the United States,
1900 - 1954



more increases until the price of foreign tungsten concentrates reached \$73.00 duty paid, in 1951. To combat the increased price tendency, the Government, in April 1951, established a uniform ceiling price

of \$65.00 per short ton unit and a Government purchase guarantee on domestic concentrates of \$63.00 to be effective until July 1958, or until 3 million units are acquired.

SPECIFICATIONS

In Europe, Chinese tungsten ores and concentrates are usually purchased or sold on the basis of a standard contract, the so-called "Hamburg Contract A" shown in full in table VIII-3. Standard grade ores and concentrates from other countries are purchased or sold under "Contract B" which, with the exception of the wording of the Force Majeure clause, is similar to "A".

Recently, to meet the needs of British consumers, a "Contract C" has been effected. This limits the penalty-free tin content to 0.5 percent. The acceptable standard grade is 65 percent minimum WO_3 , and 1.5 percent and 0.2 percent maximum tin and arsenic respectively. A scale of penalties is imposed on WO_3 content down to 55 percent, and arsenic content up to 2 percent. Below and above these limits a buyer may reject. Tin contents up to 1.6 percent must be accepted as good delivery, however, each one-tenth percent above 1.5 is penalized by an agreed amount per unit of WO_3 . All calculations are determined on a net dry weight. All weighing and sampling takes place either at port of destination or, if in England, at buyer's works, each side paying half the cost. Not more than 25 tons of ore are to be sampled; assaying is by one of a stated list of assayers and is settled in one lot. Payment is 80 percent of provisional invoice on the basis of 65 percent WO_3 , net cash against documents on arrival of steamer, the balance on rendering of final invoice.

In the United States, ores and concentrates are bought and sold according to standard specifications which may vary among consumers. Specifications under which the Government will purchase tungsten ores and concentrates are shown in table VIII-4, while detailed stockpile specifications are given in table VIII-5. For record purposes, Government specifications for ferrotungsten, metal powder, tungsten carbide powder for armor-piercing cores, and tungsten carbide powder for sintered tools, are shown in tables VIII-6, -7, -8, and -9 respectively.

TABLE VIII-3.—WOLFRAM ORE

CONTRACT (A)

..... 19

Contract No.

Messrs.

We have this day..... you

the following CHINESE WOLFRAM ORE of good merchantable quality, containing minimum 6% WO_3 , maximum 1.5% Sn, maximum 0.2% As, on the undermentioned terms and conditions:—

PRICE per unit of WO_3 , and ton of 2,240 lbs. (1,016 kilos) net dry weight. c.i.f. at buyers' option. Packages to be the property of buyers.

Shipment. — From during Weighing and Sampling. — Including the establishment of MOISTURE: To take place at port of destination, or, if in England, at buyers' works, by or under the supervision of a firm mutually agreed upon, each side paying half cost of same. Not more than 25 tons of ore are to be sampled, assayed and settled in one lot, and each lot under a separate shipping mark shall be sampled and settled separately.

Assay. — To be made by one of the following—to be agreed between the buyer and sellers:

Mr. Alfred H. Knight, Liverpool, or Messrs. Benedict Kitto and Sons, London, and to be final between buyers and sellers, each side paying half cost.

Payment. — 80% of provisional invoice on basis of 6% WO_3 , net cash against documents on arrival of steamer—balance on rendering of final invoice. If documents are not presented by sellers by the date of arrival of steamer, all extra expenses incurred thereby are to be borne by sellers.

Impurity penalties. — For each lot sampled and assayed as above.

Quality. — In case of deviation regarding quality and/or contents buyers have no right to reject the goods, provided the WO_3 contents are not under 5% and/or the As contents are not over 2%, but they have to take delivery with the following allowances to be granted by sellers.

WO_3 contents. — In case the WO_3 contents should be under 6%, the following allowances are to be made:

For each percent WO_3 under 6% to 66% inc. 3d. per unit WO_3 , per ton of 1,016 kilos net dry weight—fractions in proportion.

For each percent WO_3 under 66% to 5% inc. 6d. } 1,016 kilos net dry weight—fractions in proportion.

If the WO_3 contents should be less than 5%, buyers have the option of rejecting the goods or of accepting same at an allowance mutually agreed upon or (failing agreement) fixed by arbitration as below mentioned, such option to be declared by buyers within 8 days after receipt of the assay certificate.

Sn contents. — If the Sn contents exceed 1.5% but do not exceed 1.6% buyers have to accept the goods as good delivery. Should the Sn contents exceed 1.6% sellers have to allow to buyers for each one-tenth percent over 1.5% 2d. per unit WO_3 , per ton of 1,016 kilos net dry weight—fractions in proportion.

As contents. — Sellers have to grant to buyers the following allowances:

Over 0.2% - 0.25% inc. 3d. per unit of WO_3 , and per ton of 1016 kilos net dry weight.

Over 0.25% - 0.30% inc. 6d. } net dry weight.

Over 0.30% - 0.70% inc. 3d. } For each further 1/2% or part thereof over 0.70% an additional 3d. per unit WO_3 , per ton of 1016 kilos net dry weight.

If the assay exceeds 0.2% a second assay is to be made by another laboratory mutually agreed upon by the two parties, the mean of the two results being final. The cost of the second assay is also to be equally divided between buyers and sellers.

If the As contents exceed 2% buyers have the option of rejecting the goods or of accepting same at an allowance mutually agreed upon or (failing agreement) fixed by arbitration as below mentioned, such option to be declared by buyers within 8 days after receipt of the assay certificate.

Buyers have the right to deduct the before-mentioned allowances from the payment of the final invoice.

Advice of shipment. — For all contracts for forward shipment sellers are obliged to obtain at their expense cable advice from the port of shipment giving quantity shipped and steamer's name when shipment is effected.

On ores to arrive. — Vessel lost, contract void for such portion as is lost.

Arbitration. — Any difference or dispute under this contract (or as to the allowances to be given by the sellers to the buyers in the case of deviation regarding quality and/or contents beyond the scales) to be settled by arbitration in the country to which the ore is delivered, in England according to the rules and regulations of the London Metal Exchange in London, in France by friendly arbitration in Paris, and in Germany by friendly arbitration in Hamburg.

TABLE VIII-4.--TUNGSTEN ORES AND CONCENTRATES PURCHASE SPECIFICATIONS
(As established for the Domestic Tungsten Program of General Services Administration and Defense Materials Procurement Agency)

1. Chemical Requirements (in percent)

	Ferberite	Huebnerite	Wolframite	Scheelite and/or synthetic scheelite
Standard-WO ₃	60	60	65	60
Minimum-WO ₃	55	55	60	55
Tin (Sn) max.....	0.20	0.25	1.50	0.10
Copper (Cu) max.....	0.10	0.10	0.05	0.05
Arsenic (As) max.....	0.15	0.10	0.25	0.10
Antimony (Sb) max.....	0.10	0.10	0.10	0.10
Bismuth (Bi) max.....	1.00	1.00	1.00	0.25
Molybdenum (Mo) max.....	0.50	0.50	0.40	2.75
Phosphorus (P) max.....	0.07	0.05	0.05	0.05
Sulphur (S) max.....	0.50	0.50	0.50	0.50
Manganese (Mn) max.....	1.00	--	--	1.00
Lead (Pb) max.....	0.20	0.20	0.20	0.10
Zinc (Zn) max.....	0.10	0.10	0.10	0.10

2. Penalties

(1) Deduct 20 cents per STU (short-ton-unit) for each per cent below standard requirements. No concentrates accepted below 55 per cent.

(2) For each STU of WO₃, a deduction of 25 cents will be made for each of the following increments in excess of maximum allowances as to each of the following elements:

	Per cent
Copper (Cu)	0.01
Phosphorus (P)	0.01
Arsenic (As)	0.10
Bismuth (Bi)	0.50
Molybdenum (Mo)	0.10
Tin (Sn)	0.10
Sulphur (S)	0.10
Antimony (Sb)	0.10
Manganese (Mn)	1.00
Lead (Pb)	0.10
Zinc (Zn)	0.10

Dated: July 28, 1952

TABLE VIII-5.--NATIONAL STOCKPILE SPECIFICATION P-57-R3
15 September 1954

TUNGSTEN ORES AND CONCENTRATES

1. Description

This specification covers tungsten ores and concentrates in three classes and five mineral types.

a. Classes:

- Class I - High-grade ores and concentrates intended for but not restricted to the production of tungsten metal, tungsten carbide, and tungsten chemicals.
Class II - High-grade ores and concentrates intended for but not restricted to the production of tool steels, die steels, and other ferrous alloys containing tungsten and molybdenum.
Class III - Medium-grade ores and concentrates intended for but not restricted to the production of ferro tungsten with a high molybdenum content or other intermediate products.

b. Mineral types:

- A. Ferberite: Defined as containing tungsten primarily as FeWO₄, with not more than 20 percent of the tungsten as MnWO₄.
B. Huebnerite: Defined as containing tungsten primarily as MnWO₄, with not more than 20 percent of the tungsten as FeWO₄.
C. Wolframite: Defined as containing tungsten as both FeWO₄ and MnWO₄ in any proportions from 80 percent FeWO₄ and 20 percent MnWO₄ to 20 percent FeWO₄ and 80 percent MnWO₄.
D. Natural Scheelite: Defined as containing, in nature, tungsten as CaWO₄.
E. Synthetic Scheelite: Defined as chemically precipitated scheelite.

2. Chemical and Physical Requirements

Each lot of tungsten ores and concentrates purchased under this specification shall conform to the following applicable chemical and physical requirements.

TABLE VIII-5.--NATIONAL STOCKPILE SPECIFICATION P-57-R3--Continued
a. Chemical Requirements:

CLASS I--TUNGSTEN ORES AND CONCENTRATES
(Percent by Weight--Dry Basis)

		Mineral types A, B, or C ferberite, huebnerite, or wolframite		Mineral type D natural scheelite	Mineral type E synthetic scheelite
		For carbide powder	Pure metal		
Tungsten Trioxide ¹ (WO ₃)	Min.....	65.00	65.00	65.00	65.00
Tin (Sn)	Max.....	1.50	1.50	0.10	0.05
Copper (Cu)	Max.....	0.50	0.50	0.10	0.05
Arsenic (As)	Max.....	2 0.20	2 0.20	0.10	0.05
Bismuth (Bi)	Max.....	0.50	0.50	0.25	0.25
Antimony (Sb)	Max.....	0.05	0.05	0.10	0.05
Molybdenum (Mo)	Max.....	0.10	0.025	0.10	0.10
Phosphorus (P)	Max.....	0.05	0.05	0.05	0.05
Sulphur (S)	Max.....	0.50	0.05	0.50	0.50
Lead (Pb)	Max.....	1.00	1.00	0.10	0.10
Zinc (Zn)	Max.....	1.00	1.00	0.10	0.10
Calcium (Ca)	Max.....	0.20	0.20	--	--
Manganese (Mn) ⁴ plus Iron (Fe)	Max.....	--	--	2.00	0.50

¹ Corrected for columbium and tantalum, if present.

² Maximum .1 percent arsenic for processed Government-owned material returned under beneficiation contracts.

CLASS II--NATURAL AND SYNTHETIC SCHEELITES
(percent by Weight--Dry Basis)

		Type D, natural	Type E synthetic scheelite
Tungsten Trioxide ¹ (WO ₃)	Min.....		65.00
Tin (Sn)	Max.....		0.05
Copper (Cu)	Max.....		0.05
Arsenic (As)	Max.....		0.05
Antimony (Sb)	Max.....		0.05
Bismuth (Bi)	Max.....		0.25
Molybdenum (Mo)	Max.....	(²)	(²)
Phosphorus (P)	Max.....	0.05	0.05
Sulphur (S)	Max.....	0.50	0.50
Manganese (Mn)	Max.....	0.50	0.25
Lead (Pb)	Max.....	0.10	0.10
Zinc (Zn)	Max.....	0.10	0.10
Iron (Fe)	Max.....	(²)	(²)

¹ Corrected for columbium and tantalum, if present.

² Not specified but to be determined for each lot and reported.

CLASS III--TUNGSTEN ORES AND CONCENTRATES
(Percent by Weight--Dry Basis)

	Type A ferberite	Type B huebnerite	Type C wolframite	Type D natural scheelite	Type E synthetic scheelite
Tungsten Trioxide ¹ (WO ₃)	Min....	50.00	60.00	60.00	65.00
Tin (Sn)	Max....	0.25	0.25	0.25	0.10
Copper (Cu)	Max....	0.10	0.10	0.10	0.05
Arsenic (As)	Max....	0.20	0.20	0.20	0.10
Antimony (Sb)	Max....	0.10	0.10	0.10	0.10
Bismuth (Bi)	Max....	1.00	1.00	1.00	0.25
Molybdenum (Mo)	Max....	(²)	(²)	(²)	(²)
Phosphorus (P)	Max....	0.07	0.05	0.05	0.05
Sulphur (S)	Max....	0.50	0.50	0.50	0.50
Lead (Pb)	Max....	0.25	0.25	0.25	0.25
Zinc (Zn)	Max....	0.50	0.50	0.50	0.50
Manganese (Mn)	Max....	2.50	--	--	3.00
Iron (Fe)	Max....	--	3.00	--	--
Calcium (Ca)	Max....	(²)	(²)	(²)	(²)

¹ Corrected for columbium and tantalum, if present.

² Not specified but to be determined for each lot and reported.

TABLE VIII-5.--NATIONAL STOCKPILE SPECIFICATION P-57-R3--Continued

- b. Physical Requirements:**
- (1) Ores and concentrates, including synthetic scheelite, when packed, shall not contain more than 0.5 percent free moisture by weight.
 - (2) Each of the types may be in the form of lumps or fines or a mixture of the two, subject to the following requirements:
 - (a) Lumps - Shall not be more than one inch in the largest dimension.
 - (b) Fines for Type E, Classes II and III - Not more than 10 percent by weight of any lot shall pass a U.S. Standard Sieve No. 40 (A.S.T.M. No. 40 or Tyler Standard Sieve Mesh No. 35).
- 3. Packaging and Marking**
- a. Packaging:**
- (1) Ores and concentrates shall be packed equal to the following:
 - (a) Preferable: New 15-gallon drums which shall be of 16-gauge steel, shall have baked-on enamel or lacquer finish inside and outside, two rolling hoops, and an open head with bolt-type ring closure or other positive fastening, with a suitable gasket to prevent sifting or wetting. The inside coating of the drums may be plastic similar to a triple plastic, cross-film coating of 70/30 epoxypol, plus straight phenol, after an application of zinc phosphate.
 - (b) Minimum acceptable: Same as in Section 3a (1) (a) except the drums may be of 18-gauge steel.
 - (2) All containers comprising any lot shall be of the same nominal size and shape.
- b. Marking:**
- (1) Each container shall be permanently marked and shall include the name of the product, Government contract number, class, mineral ores and concentrate types, and gross weight, tare, and net weight. The containers in each lot shall be serially numbered (e.g., 1 of 20, 2 of 20, etc.). The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership.
 - (2) Appropriate identifying documents shall accompany each shipment.
- 4. Sampling, Inspection and Testing**
- Each lot of tungsten ores and concentrates shall be subject to sampling, inspection, and testing by the purchaser or his designee.

TABLE VIII-6.--NATIONAL STOCKPILE SPECIFICATION P-57a-R
20 June 1952FERROTUNGSTEN**1. Chemical Requirements:**

	% by weight (Dry basis)
Tungsten..... (W).....	70.00 to 80.00
Carbon..... (C).....	0.60
Manganese..... (Mn).....	0.75
Phosphorus..... (P).....	0.06
Sulfur..... (S).....	0.06
Silicon..... (Si).....	1.00
Copper..... (Cu).....	0.10
Arsenic..... (As).....	0.10
Antimony..... (Sb).....	0.08
Tin..... (Sn).....	0.10
Arsenic, Antimony and Tin..... (As+Sb+Sn).....	0.20

2. Physical Requirements:

Ferrotungsten shall be crushed to a size one inch and less.

3. Packaging, Marking, and Shipping

- a. Packaging:**
- (1) Not more than 1,000 pounds of ferro-tungsten shall be packed in a 14 to 15 gallon drum which shall be not less than 16-gauge steel; shall have a full-open head or a single opening 9 inches or larger in diameter in one of the heads, with a siftproof gasket and screw-thread or other satisfactory fastening. The exterior of the drum shall have a standard baked-on finish.
 - (2) All containers comprising any lot shall be of the same nominal size and shape.
- b. Marking:**
- (1) Each container shall be permanently marked and shall include the name of product, Government contract number, gross and net weights, and lot number. The containers in each lot shall be serially numbered (e.g., 1 of 20, 2 of 20, etc.). The containers shall not carry a security classification or any marking other than the contract number, indicating National Stockpile ownership.
 - (2) Appropriate identifying documents shall accompany each shipment.
- c. Shipping:**
- Shipments in railroad cars shall be secured in accordance with "Methods for Loading, Bracing, and Blocking Carload Shipments of Commodities in Barrels, Drums, or Kegs in Closed Cars," Pamphlet No. 4, Association of American Railroads.

4. Inspection and Analysis

Each lot of ferrotungsten shall be subject to inspection and analysis by the purchaser or his designee.

TABLE VIII-7.--NATIONAL STOCKPILE SPECIFICATION P-59-R
7 October 1952TUNGSTEN METAL POWDER
HYDROGEN-REDUCED**1. Description**

These specifications cover two types of hydrogen reduced tungsten metal powder to be used in the manufacture of tools, dies, and armor-piercing cores.

2. Chemical and Physical Requirements**a. Chemical Requirements:**

Each lot of tungsten metal powder shall conform to the following chemical analysis:

	Percent by weight
Tungsten..... (W)..... Minimum	99.7
Oxygen..... (O ₂)..... Maximum	0.5 (See Note)
Iron..... (Fe)..... Maximum	0.1
Molybdenum..... (Mo)..... Maximum	0.1
Nonvolatile residues..... Maximum	0.1

Note: The contained oxygen is not considered when computing the percent by weight of the other constituents listed above.

b. Physical Requirements:

Each lot of tungsten metal powder shall be either Type I (fine powder) or Type II (coarse powder) and shall conform to the following particle sizes:

(1) Type I (Fine Powder)

Micron size	Percent particle count	Percent particle volume
1/2 and 1.....	70 to 85	15 to 40
2 and 3.....	15 to 30	45 to 85
4, 5, and 6 (Maximum 6).....	0 to 5	0 to 15

(2) Type II (Coarse Powder)

Micron size	Percent particle count	Percent particle volume
1/2 and 1.....	15 to 35	0.2 to 0.6
2, 3, and 4.....	50 to 80	25 to 65
5, 6, and 7.....	5 to 15	20 to 55
8 and over.....	1/2 to 3	6 to 30

Particle size distribution should be established by microscopic examination of the powder, and preferably by projection providing magnification in the order of 3,000 diameters.

3. Packaging and Marking**a. Packaging:**

Tungsten metal powder shall be carefully protected from oxidation and (container) iron contamination. Preferred packaging shall be equal to 15 or 20-gallon drums which shall be of 16-gauge or heavier steel; shall be zinc-coated inside and outside; shall have two rolling hoops; and shall have a full removable cover with single-bolt closure or a solid head with 9-inch or larger opening and bolt-type cover, either type of closure to be made airtight with a synthetic rubber or other type gasket.

The minimum acceptable packaging shall be equal to the above except the drums may be 30-gallon of 16-gauge steel and the heads may be 18-gauge.

All drums shall be fully packed. Before each drum is closed, sufficient heavy anticorrosive gas, such as carbon dioxide or carbon tetrachloride, shall be added to displace the air in the head space.

b. Marking:

Each drum shall be permanently and legibly marked. Such marking shall include the name of the product, gross and net weights, date packed, Government contract number, and, where applicable, the container serial number. All drums shall be marked: "KEEP AIRTIGHT" "TREATED with CO₂ or CCl₄". The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Appropriate identifying documents shall accompany each shipment.

c. Substandard Packages:

Any tungsten metal powder acquired previous to date of and not packaged in accordance with these specifications shall be repacked as specified in Section 3a at first sign of container deterioration.

4. Inspection and Analysis

Each lot of tungsten metal powder shall be subject to inspection and analysis by the purchaser or his designee.

TABLE VIII-8.--NATIONAL STOCKPILE SPECIFICATION P-92
6 April, 1954

TUNGSTEN CARBIDE--CRYSTALLINE

1. Description

This specification covers coarse crystalline tungsten carbide, produced directly from low-grade tungsten concentrates, to be used in the manufacture of armor-piercing cores after further reduction in particle size.

2. Chemical and Physical Requirements

a. Chemical Requirements:

Each lot of crystalline tungsten carbide shall conform to the following chemical analysis:

		Percent by weight
Total Carbon.....	(C)..... Maximum....	6.10 ± 0.10
Free Carbon.....	(C)..... Maximum....	0.10
Cobalt.....	(Co)..... Maximum....	0.50
Iron.....	(Fe)..... Maximum....	0.25
Molybdenum.....	(Mo)..... Maximum....	0.25
Tantalum and Columbium.....	(Ta + Cb)..... Maximum....	1.00
Titanium.....	(Ti)..... Maximum....	0.10
Silicon.....	(Si)..... Maximum....	0.05
Oxygen.....	(O)..... Maximum....	0.25
Tungsten.....	(W)..... Maximum....	92.00

b. Physical Requirements:

All crystalline tungsten carbide shall pass a U.S. Standard Sieve No. 60.

3. Packaging and Marking

a. Packaging:

The preferred packaging is first quality new 15 or 20-gallon drums of 16-gauge or heavier steel, zinc coated inside and outside, two rolling hoops, and either a full removable cover with single-bolt closure or a solid head with 9-inch or larger opening and bolt type cover. Closure shall be made airtight with a synthetic rubber or other equivalent sift-proof gasket.

The minimum acceptable packaging shall be equal to the above except the drums may be 30-gallon of 16-gauge steel and the heads may be 18-gauge.

Crystalline tungsten carbide shall be carefully protected from container contamination. Each drum, before filling, shall be thoroughly inspected for flaking of coating or other defects. All drums shall be fully packed (approximately 500 to 550 pounds net per gallon drum).

b. Marking:

Each drum shall be permanently and legibly marked. Such marking shall include the name of the product, gross and net weights, Government contract number, and, where applicable, the container serial number. The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Appropriate identifying documents shall accompany each shipment.

4. Sampling, Inspection, and Testing

Each lot of crystalline tungsten carbide shall be subject to sampling, inspection, and testing by the purchaser or his designee.

TABLE VIII-9.--NATIONAL STOCKPILE SPECIFICATION P-93
5 August, 1954

TUNGSTEN CARBIDE POWDER

1. Description

This specification covers two types of tungsten carbide powder, produced from tungsten metal powder, to be used in the manufacture of cemented or sintered carbide tools, dies, and armor-piercing cores.

TABLE VIII-9.--NATIONAL STOCKPILE SPECIFICATION P-93--continued

2. Chemical and Physical Requirements

a. Chemical Requirements:

Each lot of tungsten carbide powder shall conform to the following chemical analysis:

		Percent by weight
Tungsten.....	(W)..... Minimum....	92.00
Total Carbon.....	(C)..... Minimum....	6.10
Total Carbon.....	(C)..... Maximum....	6.10
Free Carbon.....	(C)..... Maximum....	0.10
Iron.....	(Fe)..... Maximum....	0.25
Molybdenum.....	(Mo)..... Maximum....	0.25

b. Physical Requirements:

Each lot of tungsten carbide powder shall be either Type I (fine powder) or Type II (coarse powder). The average particle size of the powder, when tested by a Fisher Sub-Sieve Sizer, shall be as follows:

	Type I	Type II
Minimum	1.3 microns	4.7 microns
Maximum	1.6 microns	5.0 microns

3. Packaging and Marking

a. Packaging:

Tungsten carbide powder (produced from tungsten metal powder) shall be packed in polyethylene bags which have been inserted in steel drums. All drums shall be new 15 or 20-gallon size of 16-gauge or heavier steel; shall have two rolling hoops; and shall have a full removable cover with single-bolt closure or a solid head with 9-inch or larger opening and a bolt-type cover, either type of closure to be made airtight with a synthetic rubber or other equivalent gasket. The drums shall receive an application of zinc phosphate prior to a triple plastic, cross-film coating on the inside surfaces equal to the 70/30 epox-phenol, plus straight phenol, method. The outside drum surfaces shall be painted with two coats of weather resistant O.D. paint.

The polyethylene bag shall be carefully inspected in the drum and after filling with tungsten carbide powder, the bag shall be heat sealed. While the bag is being filled, the powder shall be treated with carbon dioxide, argon, or similar inert gas for the purpose of minimizing oxidation during long term storage.

All drums shall be in perfect condition, carefully handled to prevent denting or other damage, and securely braced in the carriers.

b. Marking:

Each drum shall be permanently and legibly marked. Such markings shall include the name of the product, type, gross and net weights, Government contract number, and, where applicable, the container serial number. The drums shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Each drum shall be further marked "Keep Airtight" and if not completely filled, "Off Balance Package Keep Upright" with vertical arrow.

Appropriate identifying documents shall accompany each shipment.

4. Sampling, Inspection, and Testing

Each lot of tungsten carbide powder shall be subject to sampling, inspection and testing by the purchaser or his designee.

CHAPTER IX
GOVERNMENT CONTROLS AND POLICIES

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WORLD WAR I

Recognizing the possibility of the United States being drawn into the war, and therefore the need for an adequate defense program, the 64th Congress on June 3, 1916 approved the National Defense Act, Public Law 85 (39 Stat. 166). Of even greater importance to the civilian economy was the provision in Section 2 of the Army Appropriations Act, Public Law 242 (39 Stat. 611) approved August 29, 1916. Under the latter was created on August 29, 1916 the Council of National Defense which was charged, among other things, with increasing domestic production of materials necessary to support the military and the general public, if interruption of foreign commerce occurred, and to be able to concentrate and utilize, if necessary, the resources of the country. However, the Council of National Defense had no executive power and therefore acted primarily in an advisory capacity. Within the Council, the War Industries Board was set up April 9, 1917 (became a separate agency May 28, 1918) to: (1) determine war requirements and resources, and to balance resources against requirements, (2) determine deficits, and fill them by increasing production, and (3) conserve by restricting the use of critical materials, and encouraging imports. Within that framework the Ferro-Alloy Section, to handle ferro-alloys including tungsten ores, and the Conservation Division were established in March and May of 1918 respectively. (The Conservation Division carried on the activities of the Commercial Economy Board which was formed March 24, 1917.) The chief function of the Ferro-Alloy Section was to obtain statistical information in regard to domestic production, consumption and imports.

Between the two, sufficient supplies for all necessary needs were maintained. The Ferro-Alloy Section furnished the tungsten trade with information relative to prospective consumption, thereby stimulating production, while the Conservation Division took steps to increase foreign production so as to conserve domestic supplies. To

conserve tungsten, the latter encouraged the welding of tool bits to low alloy steel shanks.

With the signing of the Armistice on November 11, 1918, the programs of the War Industries Board were discontinued. The Ferro-Alloy Section and the Conservation Division concluded their work on December 31, 1918. By July 22, 1919, all activities were terminated.

Direct legislation to meet the need of promoting production of certain minerals which had acquired major war importance was passed by the 65th Congress on October 5, 1918, in the form of the Minerals Control Act, Public Law 220 (40 Stat. 1009). The act provided for authority to contract for the production of needed supplies, and for the control of distribution of the ores, metals and minerals which formerly were largely imported or were inadequate in supply. On November 11, 1918, the Secretary of the Interior was directed by the President to exercise the power and authority, except that relating to imports, given under the Act to the President. However, this directive was issued on the day of the Armistice so it was too late to take action under it inasmuch as there no longer was any need to stimulate production to meet war requirements.

However, as a direct consequence of anticipated Government stimulation, production was increased and preparations were made to increase it further. With the signing of the Armistice, demand and prices fell; there was practically no market for domestic ore. Many mining firms faced bankruptcy, and under the belief that the Government was partly responsible for the stimulation, they asked Congress for financial relief. As a result, the War Contracts Act, Public Law 322 (40 Stat. 1272) was passed by the 65th Congress on March 2, 1919. Under Section 5 of the act, the Secretary of the Interior was authorized to adjust, liquidate and pay net losses suffered by any person, firm or corporation by reason of production or preparation for production of tungsten ores in compliance

with the request or demand made by an officer or agent under his authority for the need of the Nation in the prosecution of the

war. To be considered for adjustments, all claims had to be made prior to June 30, 1919.

WORLD WAR II

In 1922 tungsten was placed on the first official Government list of strategic minerals. However, with the exception of the Fordney-McCumber Tariff Act of 1922 and the Smoot-Hawley Tariff Act of 1930, which were Government attempts to protect domestic mining against imports, no further regulations were issued until foreign imports were threatened by the war in China in 1937 and the beginning of World War II in Europe. The Government considered a program to stockpile tungsten, purchase foreign ore where possible, and encourage the production of domestic ores. In order to implement this program, the Strategic Materials Act, Public Law 117, (53 Stat. 811) of June 7, 1939 was passed. Shortly after this, the Army-Navy Munitions Board placed tungsten on the list of strategic materials along with eight other commodities.

Under provision of the above act, the Metals Reserve Corporation, a subsidiary of the Reconstruction Finance Corporation, was established on June 28, 1940 and given authority to procure strategic materials and minerals both for the national stockpile and for sale to industry. Funds were available to the Procurement Division of the Treasury Department for purchases for stockpiles also.

The Defense Plants Corporation was established to handle details of construction projects necessary for increasing the output of domestic ores. Early in 1941 the War Production Board and the Office of Production Management issued orders concerning policy and details for the regulation and distribution of tungsten. The excessive demands made upon tungsten for tool steels, special applications, and the bullet core program which came later during World War II, necessitated strict orders for regulated distribution and conservation. These orders, given by number, date, and intent, were as follows:

Order M-3, March 21, 1941 placed partial priorities control over producers of ferro-tungsten, metal powder and intermediate tungsten compounds. Revoked by M-29, August 31, 1941.

Order M-14, June 11, 1941 required the substitution of molybdenum high-speed steels for tungsten high-speed steels to the extent of 50 percent of use requirements. Expired November 30, 1941.

Order M-14, amended November 29, 1941 raised the percentage of molybdenum type steels (Class A) to 75 percent of total. Expired December 31, 1942.

Order M-21h, December 14, 1942 defined high-speed steels, Classes "A" and "B", limited the use of tungsten, molybdenum, chromium, vanadium, and prescribed minimums of carbon and cobalt in the various grades of the two classes. Revoked January 21, 1944.

Order M-21h, as amended May 10, 1943 restricted the melting of Class "B" (tungsten type high-speed steels) to 35 percent by weight of the total high-speed steel melted per quarter.

Order M-21h, Dir. 1 (August 4, 1943), and as amended November 18, 1943, limited the use of certain alloys in melting of alloy tool steel to those specified for various grades. (The amended copy appears at the end of this chapter.)

Order M-29, August 30, 1941 was issued to control and regulate the distribution of tungsten in all forms including scrap. Allocation was to be based upon essentiality of use and restriction of inventories. Revoked December 30, 1943.

Order M-29a, October 31, 1941 permitted the delivery of 100 pounds or less of tungsten in specified forms without filing.

Order M-29b, February 14, 1942 was used as a conservation measure. This order placed certain use limitations on tungsten for certain intervals of time and listed the various prohibited uses as well as exemptions.

Order M-29, as amended June 30, 1942 placed pure tungsten, ferro-tungsten, tungsten alloys and ores and concentrates (ore 20 percent or more WO_3) under allocation for purposes of production of tool blanks, tools and hard-facing materials.

Order M-29, Amendment 1, August 18, 1942 removed the limitation of 20 percent WO_3 previously established on ores and concentrates.

Order M-29, as amended November 27, 1942 permitted delivery of tungsten during any one calendar month in any form except wire, rod, sheet or metal, in quantities of 25 pounds or less, by any person to any person, but limited supply from all sources to the 25 pounds. Revoked December 30, 1943.

Order M-29b, as amended February 9, 1943 exempted from restrictions, orders for the Army or Navy of the United States, the Maritime Commission, the War Shipping Administration, and the Coast Guard, where the use of tungsten is required. Revoked August 23, 1943.

Order L-223, December 2, 1942 placed restrictions on use in delivery of hard-facing materials in any form containing 4 percent or more of any alloy element, or combination of elements including tungsten, molybdenum, chromium, nickel, etc., in combination with carbon, boron, or any other metal. Restricted inventories to a 60-day supply. Revoked January 12, 1944.

Order M-369, December 31, 1943 required War Production Board authorization to deliver or accept tungsten products. Revoked July 20, 1945.

Order M-369, as amended February 7, 1944 changed the controlling division from Ferro-Alloys Branch of the Steel Division to the Radio and Radar Division. Also established reports and requests for allocation for two months in advance rather than one.

Order M-369a, April 10, 1945 restricted deliveries to specific allocations, except delivery of the following items between affiliates or within the same enterprise, without an allocation, for the purposes specified--

1. Ingots for any purpose.
2. Rod for manufacture of wire.
3. Sheet for any purpose.
4. Tungsten compounds for production of metal powder.
5. Any item for any purpose specifically authorized in writing by W.P.B. Exempted orders of 100 pounds of contained tungsten in tungsten compounds or powder during one calendar month.

Order M-21J, April 7, 1945, and as amended May 18, 1945, restricted melting and delivery of Class "B" high-speed to 15 percent of the total high-speed melted in one quarter. Revoked July 2, 1945.

Before World War II was ended, domestic sources had made up for the lack of foreign imports. An ore treatment plant in Salt Lake City, completed in 1943, was able to upgrade five million pounds of tungsten in low grade material to acceptable commercial standards. Domestic mine production had increased due to the encouragement given miners by increased prices, especially to small producers who thereby found it profitable to work their mines to full capacity.

The situation was eased and W.P.B. restrictions were relaxed in the latter part of 1943. However, the shell-core program, which was implemented by the Army, made large demands upon tungsten stocks, and controls were again instituted in 1944, lasting until the end of the war.

POSTWAR PERIOD

The postwar period did not necessitate a continuation of wartime regulations, controls, or subsidies in order to supply the needs of civilian economy. Nevertheless the Government was determined to see that no recurrence of shortages of critical materials would happen again, and consequently passed the Strategic and Critical Materials Stockpiling Act, Public Law 520 (60 Stat. 596) on July 23, 1945, which provided for the acquisition and retention of stocks to prevent whenever possible a dangerous and costly dependence of the United States upon foreign nations for supplies of these materials in times of national emergency.

The responsibility for determining the Nation's need for critical items, and for issuing orders for stockpiling, was assigned to the Munitions Board (formerly the Army-

Navy Munitions Board). This board was supposed to determine the needs of the military and to keep abreast of developments which would necessitate change in demand. The Secretary of the Interior also had to concur in decisions concerning stockpiling of materials. The Bureau of Federal Supply, Treasury Department, supplied funds and actually bought the materials.

It was found that in the time between the initiation of stockpiling by the above-mentioned act and the Korean hostilities, not enough had been accomplished. The Twenty-Seventh Report of the Preparedness Subcommittee of the Armed Forces, United States Senate, on Tungsten, printed in 1951, severely criticized the limited stockpiling activities since 1946 and made a number of recommendations for correcting the situation.

KOREAN HOSTILITIES

The Korean situation which began in 1950 caused the Government to broaden the scope of its policy of conservation, procurement, and regulation of critical materials. The Defense Production Act, Public Law 774, 81st Congress (64 Stat. 798), approved September 8, 1950, gave the President price, wage, allocation, priority, and requisition control powers to deal with the emergency. The Secretary of the Interior was given "authority to establish loans, procurement contracts and other commitments relative to metals and minerals."

The Reconstruction Finance Corporation was authorized to make loans, and the General Services Administration was required to enter into purchase contracts and commitments which the Secretary certified to be necessary. The Defense Minerals Administration was created for the purpose of encouraging exploration, development and mining. This agency also exercised priority and allocation controls on tungsten, as well as other minerals.

The authority to certify loans was later given to the Defense Production Authority.

This agency was charged with establishing policies relative to the encouragement of industrial expansion and production. Co-operating with it was the National Production Authority, with the power of control over allocations of metals, ferro-alloys, chemicals, rubber and other essential commodities.

Under the National Production Authority, tungsten was allocated and regulated (see Orders M-80 and M-81) in many forms, namely: ferrotungsten, steel or alloy scrap containing one percent or more of tungsten, ores and concentrates when used as alloy additions, and "pure" tungsten which is the element after having been processed into the standard commercial forms known as hydrogen or carbon-reduced powder, ingot, wire, rod, sheet, and chemicals. The National Production Authority program for tungsten was successful enough to permit relaxation of the controls over pure tungsten products as far as quantity available for purchase was concerned. N.P.A. insisted, however, that the restricted end uses be observed. The following orders were issued by N.P.A.--

Order M-30, January 22, 1951 limited the production and shipment of high-speed steels to percentages of total for Classes "A" and "B", not less than 80 percent of Class "A" high-speed steel (0.75 percent or less tungsten) and not more than 20 percent Class "B" (12 percent or more tungsten content). It substituted Class "A" for Class "B" for all applications where possible. It permitted the sale of 25 pounds or less to customers per month without allocation. Revoked October 1, 1951.

Order M-80, Schedule 3, August 15, 1951 placed ferrotungsten, tungsten scrap, tungsten ores and concentrates under allocation. Revoked December 9, 1952.

Order M-81, August 15, 1951 placed "pure" tungsten under complete allocation as well as "pure" molybdenum. "Pure" included tungsten "in substantially pure form, processed to the extent that it is hydrogen-reduced powder, ingot, wire, rod, sheet and chemicals and compounds, or carbon reduced powder." It required substitution for tungsten and molybdenum, where possible, and prohibited use of tungsten for pigments (except printing inks) and as a coloring or coating for rubber, linoleum, and paper (including wallpaper), and for use in grinding wheels. Certain exceptions were granted where use by the Government was necessary. A maximum of 50 pounds of contained tungsten was permitted for consumption for any three consecutive periods. Other exceptions were the purchase of fabricated parts and the sale of pure tungsten welding rod by a person other than a pure metal processor. Revoked April 6, 1953.

Order M-81, as amended March 4, 1952 exempted from allocation requirements the "role for analytical laboratory use of packaged reagent chemicals containing pure tungsten which have been allocated in bulk for the purpose of packaging and resale." The exception was limited to standard packages which did not exceed five pounds net weight. Limits were placed on inventories on the basis of 60 days operation.

Order M-81, as amended September 12, 1952 "eliminated the requirement that deliveries of pure tungsten and pure molybdenum be made permanent to allocation authorization only" and permitted N.P.A. to issue directives as to deliveries and uses of pure tungsten.

The Defense Minerals Administration, later the Defense Materials Procurement Agency, regulated and controlled the distribution of tungsten ores and concentrates through various orders which are briefly described below:

D.M.A. Mineral Order MO-4, February 13, 1951 required the suppliers of tungsten concentrates to make deliveries to specific purchasers at the direction of the Defense Minerals Administration. "Concentrate" was defined as natural tungsten concentrates and all synthetic scheelite containing 40 percent or more of tungsten trioxide. Revoked April 5, 1951.

D.M.A. Mineral Order MO-5, April 10, 1951, amended July 10, 1951, superseded by D.M.E.A. Order 1, March 7, 1952 as amended May 15, 1953, October 30, 1953, March 21, 1954, and May 29, 1956, set forth procedures under which Government aid could be obtained to finance the cost of exploration projects for unknown or undeveloped sources of strategic or critical metals and minerals. For tungsten exploration the Government would contribute 75 percent of the total cost of the project. This order is still in force as of November, 1956.

D.M.A. Mineral Order MO-6, April 5, 1951 subjected tungsten ores and concentrates to allocation on a monthly basis, requiring monthly reports of inventories and anticipated needs. Ores and concentrates with as little as 20 percent tungsten trioxide were included in the definitions. Exemptions were provided for stockpiling, ore beneficiation, and for resale. Revoked August 20, 1953.

D.M.P.A. Mineral Order MO-7, April 16, 1951, revised May 4, 1951, as amended May 23, 1952, established the serialization of mines in order to provide a more efficient method of giving priorities and allocation assistance. This order included tungsten but was not restricted to it. Revoked August 7, 1953.

D.M.P.A. Mineral Order MO-6 (D.M.A. Order MO-6), as amended February 13, 1953, suspended the allocation of tungsten ores and concentrates, with exception of tungsten ores of foreign origin for sale by General Services Administration.

The United States Government, with the cooperation of the Governments of France and the United Kingdom, was instrumental in creating the International Materials Conference which began operations on January 12, 1951. The purpose of the Conference was to study the problems connected with supply and distribution of available strategic materials which could be used for promoting the security of the "free" nations. Tungsten was among the commodities chosen for consideration. To help solve the problem of supply of tungsten, the following recommendations were made:

1. That a system of long term contracts be adopted to stimulate production of tungsten;

2. That attempts be made to stabilize the tungsten market (spot purchase prices were to be established at not less than \$55 and not more than \$65 per short ton unit);

3. That attempts be made at the conservation of tungsten by all nations that could do so, the pattern for which has been discussed under substitution in this survey.

In 1952, increased production throughout the "free" world, eased world supply to the extent that the IMC was no longer thought necessary. It was therefore disbanded as of December 31, 1952.

During 1953, and up to the present time, domestic mine production has exceeded consumption. Despite the eased supply, however, Government encouragement is still being given to both domestic and foreign producers of tungsten. The domestic program is implemented by increased base prices set for various grades of ores, and by financial aid to mining companies for stimulating increased production. Procurement of foreign ores is made by General Services Administration and authorized by the Office of Defense Mobilization (originally the Defense Production Authority) making use of a revolving fund of \$13,950,000.

TABLE IX-1.--USE OF ALLOYS IN MELTING ALLOY TOOL STEELS

Order M-21-b, Dir.1, as Amended Nov. 18, 1943

(No Producer shall use alloys in the melting of alloy tool steel except within the limits specified below, or as otherwise authorized by the War Production Board.)

GRADES I-IIIc--CLASS A HIGH SPEED STEEL

Grade	C	Cr	W	Mo	V	
	Min.	Max.	Max.	Max.		
I.....	0.50	4.5	6.0	5.5	--	1.0 max.
Ib.....	.40	4.5	6.5	6.0	--	1.0 min.
Ic.....	.60	4.5	6.5	5.5	1.5 min.	1.0 max.
II.....	.60	4.5	1.8	8.75	--	1.0 max.
IIc.....	.60	4.5	1.8	8.75	--	2.0 max.
III.....	.60	4.5	--	8.75	--	2.0 max.
IIIc.....	.60	4.5	--	8.75	3.0 min.	2.0 max.

GRADES IV-IVc--CLASS B HIGH SPEED STEEL

	C	Cr	W	Mo	V	
IV.....	0.55	4.5	14.0	--	--	1.0 max.
IVb.....	.55	4.5	14.0	1.0	--	2.0 min.
IVc.....	.55	4.5	14.0	1.0	1.5 min.	2.0 max.

GRADE V--HOT WORK STEEL

Class	C	Mn	Si	Cr	W	Mo	V
							Max.
A.....	0.25/0.55	0.15/0.45	0.15/0.45	1.5/4.5	16.0/18.0	--	1.00
B.....	.25/.55	.15/.45	.15/.45	1.5/4.5	13.0/15.0	--	1.00
C.....	.25/.55	.15/.45	.15/.45	1.5/4.5	10.0/11.0	--	1.00
D.....	.25/.55	.15/.45	.15/.45	1.5/4.5	7.5/9.5	--	1.00
E.....	.30/.45	.15/.45	.80/1.35	4.5/6.0	1.0/1.5	1.0/1.5	1.00
F.....	.30/.45	.15/.45	.80/1.35	4.5/6.0	1.0/1.5	1.0/1.5	1.00

GRADE VI--HIGH CARBON, HIGH CHROME AND AIR HARDENING DIE STEELS

Class	C	Mn	Si	Cr	W	Mo	V
					Max.	Max.	Max.
A.....	1.7/2.4	0.15/0.60	0.15/1.0	10.0/14.0	11.05	1.0 max.	1.00
B.....	1.6/1.9	.15/.40	.15/.40	17.0/19.0	--	--	1.00
C.....	1.2/1.7	.15/.40	.15/.75	11.0/14.0	--	.90/1.0	1.00
D.....	.90/1.1	.15/.40	.15/.45	7.5/9.5	--	.75/1.25	1.00
E.....	.90/1.35	1.75/4.25	.80/.40	2.0/2.5	--	.80/1.1	1.00

GRADE VII--ALL OTHER ALLOY TOOL STEELS

Class	C	Mn	Si	Cr	W	Mo	V
						Max.	Max.
A.....	0.70/1.0	0.9/1.2	0.15/0.45	0.60 max.	0.60 max.	0.30	1.00
B.....	.85/1.25	.15/.45	.15/.45	1.1/1.85	.60 max.	.5	1.00
C.....	1.0/1.3	.15/.40	.15/.45	.25/.80	1.0/1.5	.30	1.00
D.....	.60/1.35	.15/.45	.15/.45	--	--	--	1.00
E.....	.40/.60	.15/.70	.15/1.15	.30/2.0	.15/2.75	--	1.00
F.....	.40/.70	.30/1.1	.70/1.25	.90 max.	--	.50	1.00
G.....	.40/1.0	.20/.7	.15/.55	.05/1.1	--	--	1.00
H.....	.90/1.3	.10/.45	.10/.40	--	.80/1.3	--	1.00

CHAPTER X
DIRECTORY OF U. S. AND FOREIGN PRODUCERS, CONSUMERS,
IMPORTERS, AND EXPORTERS

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AND EXPORTERS*

UNITED STATES

Ore Producers

Many mining concerns contribute to the Nation's production of tungsten ore, but most of the ore comes from a relatively small number of major mines. In 1952, for example, 84 percent of total domestic production was by the following 8 companies: Bradley Mining Co., Idaho; Climax Molybdenum Co., Colorado; Getchell Mine, Inc., Nevada; Nevada-Massachusetts Co., Nevada; Nevada Scheelite, Inc., Nevada; Surcease Mining Co., California; Tungsten Mining Corp., N.C.; and Union Carbide Nuclear Corp., Calif. These companies are included by States in the following alphabetical listing.

Alaska

Riverside Mine, Merchants Exch. Bldg., San Francisco, Calif.; a gold-silver-tungsten mine, 7 mi. N. of Hyder, Alaska; mill at mine, selective flotation, 100 ton daily capacity.
U. S. Tin Corp., Jones Bldg., Seattle, Wash.; tin-tungsten mine at Lost River, Seward Peninsula, N. of Nome, Alaska; mill at mine, 125 ton daily capacity.

Arizona

Black Pearl Mining Co., Bagdad, Ariz.; mine 10 mi. N. of Bagdad, Yavapai County, Ariz.
Boriana Mine, Box 1069, Kingman, Ariz.; mine 18 mi. E. of Yucca, Mohave County, Ariz.; mill at mine, gravity, 100 ton daily capacity.
Las Guijas Mine, Arivaca, Ariz.; mine in Pima County, Ariz.
Tungsten Reef Mines Co., c/o J. J. Seaman, 622 Sonora Ave., Glendale, Calif.; mine in Hartford Mining District, 14 mi. from Hereford, 36 mi. W. of Bisbee, Ariz.; mill at mine, 20 ton daily capacity.

California

Atolia Mining Co.; property acquired by Surcease Mining Co., Calif. (see listing).
Bason View Mine, Bodfish, Calif.; mine at Havilah, in Kern County, Calif.
Benton Division (Wah Chang Mining Corp.), Box 517, Bishop, Calif.; mines (1) Black Rock Mine at Benton, Mono County, Calif., (2) Lincoln Mine, 40 mi. W. of Hiko, Tern Piute District, Lincoln County, Nev.; mill in Bishop, flotation, 500 ton daily capacity.
Blue Ridge Midway Gold Mines Co., Ltd., Box 2540, Reno, Nev.; Sugar Hill, and Big Blue Mines (gold-copper-molybdenum) 6½ mi. from Callahan, Siskiyou County, Calif.; Tip Top, and Hilton Creek Mines near Bishop, Calif.
El Diablo Mining Co., Box 567, Bishop, Calif.; mine 4 mi. W. of Bishop, Inyo County, Calif.; mill at mine, magnetic concentrator, 50 ton daily capacity.
Fresno Mining Co., 1739 Terrace Ave., Fresno, Calif.; Strawberry Tungsten Mine, Madera County, Calif.; mill at mine, gravity and flotation, 100 ton daily capacity.
Hanging Valley Mining Co., 1545 W. 87th St., Los Angeles, Calif.; mine at Bishop, Calif.
Hilton Creek Mine (see Blue Ridge Midway Gold Mine Co., Ltd.).
Hi Peake Tungsten Mine, 12300 Montague St., San Fernando, Calif.; mine 5 mi. W. of Inyokern, Kern County, Calif.; mill at mine, gravity concentrator, 50 ton daily capacity.
Lucky Spaid Mine (see Richardson Properties).
Mineral Materials Co., 1145 Westminster Ave., Alhambra, Calif.; Starbright Scheelite Mine, near Barstow, Calif.; 30 ton daily capacity.
Pine Creek Tungsten Mine (see Union Carbide Nuclear Corp., Calif.).

*Sources: Minerals Yearbook, Bureau of Mines, Washington, published annually; Mines Register, 1952 edition, Atlas Publishing Co., New York; and others.

Pine Tree Mine, Bear Valley, Mariposa County, Calif.; owner: Pacific Mining Co., Room 1022, Crocker Bldg., San Francisco, Calif.

Richardson (Guy O.) Properties, Star Route, Box 25, Fresno, Calif.; Shady Rest, and Lucky Spaid Mines, Madera County, Calif.

Shady Rest Mine (see above).

Starbright Mine (see Minerals Materials Co.).

Strawberry Mine (see Fresno Mining Co.).
Surcease Mining Co., 214 30th St., Sacramento, Calif.; mine office at Red Mountain, Calif.; Atolia Mine in San Bernardino County, Calif.; mill at mine.

Tip Top Mine (see Blue Ridge Midway Gold Mines Co., Ltd.).

Union Carbide Nuclear Corp. (Div., Union Carbide and Carbon Corp.), 30 E. 42nd St., New York, N.Y.; mine at Pine Creek, Inyo County, Calif., 21 mi. NW. of Bishop; mill at mine, custom mill, 1,000 ton daily capacity.

Colorado

Boulder Tungsten Mines, Inc., 207 E. 32nd St., New York, N.Y.; mines: Dorothy Katie Group, Gold Corn Group, and Princess Group, in Sugar Loaf Mine District, Boulder County, Colo.; all mines inactive; mill at mines, custom, 50 ton daily capacity.

Climax Mine (see below).

Climax Molybdenum Co., 500 Fifth Ave., New York, N.Y.; Climax Mine, Lake County, Colo.; mill at mine, flotation, 15,000 ton daily capacity.

Dorothy Mine, c/o Geo. H. Teal, 3134 Sixth St., Boulder County, Colo.; property at Sugarloaf.

Hetzer Mines Inc., Boulder, Colo.; Hoosier Mine, Nederland, Boulder County, Colo.; mill at mine; mill and mine leased to Vanadium Corp. of America.

Hoosier Mine (see above).

Minerals Engineering Co., Box 1951, Grand Junction, Colo.; Ivanhoe Mine at Beaverhead, Mont., operates Salt Lake Tungsten Co. Mine at Salt Lake City, Utah; mill at Beaverhead, flotation, 800 ton daily capacity; mill at Salt Lake City, chemical process.

Vanadium Corp. of America, 420 Lexington Ave., New York, N.Y.; leases Hetzer Mine (above).

Idaho

Bradley Mining Co., 1022 Crocker Bldg., San Francisco, Calif.; Yellow Pine Mine,

Valley County, Idaho (not operating in 1955), mill at mine, flotation, 200 ton daily capacity, crushing plant and 4 ball-mills; Ima Mine, Lemhi County, Idaho, mill at mine, flotation, 150 ton daily capacity.

Ima Mine (see Bradley Mining Co., above).
Yellow Pine Mine (see Bradley Mining Co., above).

Montana

Alps Mining & Milling Co., Box 1364, Missoula, Mont.; silver-gold-tungsten mine in the Harvey Creek Mining District, Granite County, 20 mi. SE. of Clinton, Mont.; mill at mine, flotation, 150 ton daily capacity.

American Alloy Metals Inc., 401 Symons Bldg., Spokane, Wash.; mine at Beaverhead County, Mont.

Ivanhoe Mine (see Minerals Engineering Co., Colo.).

Nevada

Alpine Mine (see Rare Metals Corp., below).

Alpine Tungsten Mine (see Getchell Mine Inc., below).

Cherry Creek Tungsten Mining Co., Box 158, East Ely, Nev.; mine at Cherry Creek, Nev.; mill at mine, flotation, 50 ton daily capacity.

Combined Metals Reduction Co., Room 218, Felt Bldg., Salt Lake City, Utah; Comet Mine (gold-silver-lead-zinc-tungsten), 25 mi. W. of Pioche, Nev.; mill at Pioche, Lincoln County, Nev., selective flotation, 100 ton daily capacity.

Comet Mine (see Combined Metals Reduction Co., above).

Gabbs Exploration Co., Box 4, Gabbs, Nev.; mine 21 mi. N. of Gabbs, Lodi District, Nye County, Nev.

Getchell Mine Inc., Box 2520, Reno, Nev.; plant address, Red House, Nev.; mines: Getchell, Alpine, Moly Hill, Pacific, Tip Top; mines located near Red House, in Paton Mining District, Humboldt County, Nev.; mill at mines, flotation, 1,000 ton daily capacity.

Lincoln Mine (see Benton Division, Wah Chang Mining Corp., Calif.).

Lakeview Tungsten Corp., Lovelock, Nev.; mine in Humboldt Canyon, Pershing County, Nev.; mill at mine, gravity, 50 ton daily capacity.

Lindsay Mining Co., Box 150, Mina, Nev.; mine 24 mi. SE. of Mina, in Esmeraldo

County, Nev.; mill at mine, gravity concentrator.

M G L Mine, Virginia City, Nev.; operator, Fred Vollmar; mine in Nightingale District, Pershing County, Nev.; mill at mine, flotation, 150 ton daily capacity.

Mill City Mine (see Nevada-Massachusetts Co., below).

Minerva Scheelite Mining Co., c/o Robert Stopper, Ely, Nev.; mine in Osceola, White Pine County, Nev.; mill at mine, 20 ton daily capacity.

Nevada-Massachusetts Co., Sonora, Calif.; Mill City Mine, Tungsten P.O., 8 mi. W. of Mill City, Pershing County, Nev.; mill at mine, 500 ton daily capacity.

Nevada Scheelite, Inc. (Div., Kennametal Inc.), 545½ S. Taylor St., Fallon, Nev.; Nevada Scheelite Mine in Mineral County, Nev.; mill at mine, 100 ton daily capacity.

Nevada Tungsten Corp, Box 137, Mina, Nev.; mines: (1) 5 mi. N. of Coaldale, Columbus District, Esmeraldo County, Nev., (2) Silver Dyke Mine, in Mineral County, Nev.; mill in Esmeraldo County, 200 ton daily capacity.

Nightingale Mine (See Rare Metals Corp., below).

Rare Metals Corp., Sonora, Calif.; mines: Nightingale, Star, and Alpine, in Nightingale District, Pershing County, Nev.; mill at mines, 125 ton daily capacity.

Star Mine (see Rare Metals Corp., above).

Silver Dyke Mine (see Nevada Tungsten Corp., above).

Tungsten Minerals Inc., Tungstonia, Nev.; mine in Regan District, White Pine County, Nev.

North Carolina

Hamme Mine (see Tungsten Mining Corp., below).

Tungsten Mining Corp., 500 Fifth Ave., New York, N.Y.; Hamme Mine, Vance County, N.C.; mill at mine, gravity-flotation, 13,000 units monthly.

Oregon

Ashland Mine, 835th N. Main St., Ashland, Oreg.; owners, Dewey and Fred Varr Curler; gold-tungsten mine, 1½ mi. NW. of Ashland, Jackson County, Oreg.; mill at mine, 50 ton daily capacity.

Bratcher Mining Corp., Route 2, Box 394 D, Ashland, Oreg.; open pit mine, 3 mi. SW. of Ashland, Jackson County, Oreg.; mill at mine, gravity.

South Dakota

Black Crystal Mine, Keystone, S. Dak.; owners, D. H. G. and Bert Hardesty; mine 5 mi. NE. of Hill City, Pennington County, S. Dak.

Utah

Old Hickory Mine (see Prosper Mining Co., below).

Prosper Mining Co., Milford, Utah; Old Hickory Mine (gold-silver-copper-zinc-tungsten), 5½ mi. N. of Milford, Beaver County, Utah; mill at mine, flotation, 50 ton daily capacity.

Salt Lake Tungsten Co. (see Minerals Engineering Co., Colo.).

Star Dust Mines Inc., Gold Hill, Utah; Gold Hill Mine, Tooele County, Wash.

Washington

Addy Mining Co., N. 633 Madelia St., Spokane, Wash.; mine near Addy, Stevens County, Wash.

Germania Consolidated Mines Inc.; 401 Empire State Bldg., Spokane, Wash.; mine in Deer Trail District of Stevens County, near Hunters, Wash.; mill at mine, 40 ton daily capacity.

Concentrate Treatment Plants

Salt Lake City Tungsten Co. (owned jointly by Minerals Engineering Co. and Sylvania Electric Products, Inc.), Salt Lake City, Utah.

U.S. Vanadium Corp., 30 E. 42nd St., New York, N.Y.; mill address, Bishop (21 mi. NW.) Calif.

Wah Chang Corp., 233 Broadway, New York, N.Y.; plant address, Glen Cove, Long Island, N.Y.

Ferrotungsten Producers

Electro-Metallurgical Co. (Div., Union Carbide & Carbon Corp.), 30 E. 42nd St., New York, N.Y.; plant address, 137 47th St., Niagara Falls, N.Y.; other products--carbon reduced powder and chemicals.

Molybdenum Corp. of America, 500 Fifth Ave., New York, N.Y.; Pittsburgh office, Grant Bldg., Pittsburgh, Pa.; plant address, Washington, Pa.; other products--chemicals, carbon reduced powder, rod, wire, sheet, electrical contacts.

Metal Powder Producers

Hydrogen Reduced Powder

- Cleveland Tungsten Incorporated (subsidiary, Molybdenum Corp. of America), 1020 Meech Ave, Cleveland, Ohio; other products--rod, wire, sheet, tungstic acid, sodium tungstate, tungsten contacts, electrodes.
- Cleveland Wire Works, General Electric Co., 1331 Chardon Rd., Euclid, Ohio; other products--rod, wire, sheet, chemicals.
- Fansteel Metallurgical Corp., 2200 Sheridan Rd., North Chicago, Ill.; other products--rod, wire, sheet, hard facing metals, welding electrodes, chemicals.
- Firth Sterling Inc., 3113 Forbes St., Pittsburgh, Pa.; other products--sintered carbides.
- North American Phillips Co., Inc., 100 E. 42nd St., New York, N.Y.; plant address, Elmet Division, Lisbon Rd., Lewiston, Maine; other products--rod, wire, sheet.
- Reduction & Refining Co., Kenilworth, N.J.; other products--chemicals.
- Sylvania Electric Products Inc., 1740 Broadway, New York, N.Y.; plant address, Tungsten & Chemical Div., Towanda, Pa.; other products--rod, wire, chemicals.
- Tungsten Corp. of America, Washington and Oak Sts., Conshohocken, Pa.; other products--tungstic acid, sodium tungstate.
- Wah Chang Corp., 232 Broadway, New York, N.Y.; plants at Glen Cove, Long Island, N.Y., and Union City, N.J.; other products--chemicals, rod, wire, concentrates to buyers' specifications, crystalline tungsten carbide powder.
- Westinghouse Electric Corp. (Lamp Div.), 2 MacArthur Ave., Bloomfield, N.J.; other products--rod, wire, sheet.

Carbon Reduced Powder

- Electro-Metallurgical Co., 30 E. 42nd St., New York, N.Y.; plant address, 137 47th St., Niagara Falls, N.Y.; other products--ferrotungsten, chemicals.
- Firth Sterling Inc., 3113 Forbes St., Pittsburgh, Pa.; other products--sintered carbides.
- Molybdenum Corp. of America, 500 Fifth Ave., New York, N.Y.; plant at Washington, Pa.; other products--ferrotungsten.

Carbide Powder Producers

- Adamas Carbide Corp., Market & Passaic Sts., Kenilworth, N.J.
- Allegheny Ludlum Steel Corp. (Ferndale Plant), Ferndale, Mich.
- Carboloy Dept., General Electric Co., 11155 E. Eight Mile Dr., Detroit, Mich.
- Fansteel Metallurgical Corp., 2200 Sheridan Rd., North Chicago, Ill.
- Firth Sterling Inc., 3113 Forbes St., Pittsburgh, Pa.
- Haynes Stellite (Div., Union Carbide & Carbon Corp.), Le Van Bldg., Kokomo, Ind.
- Kennametal Inc., Latrobe, Pa.
- Metal Carbides Corp., 103 E. Indianola Ave., Youngstown, Ohio.
- Multi-Metals, Inc., 715 E. Gray St., Louisville, Ky.
- Stoody Co., Whittier, Calif.
- Wah Chang Corp., 233 Broadway, New York, N.Y.; plant at Glen Cove, L.I.

Chemical Producers and/or Sellers

Ammonium Paratungstate

- Electro-Metallurgical Co. (Div., Union Carbide and Carbon Corp.), 30 E. 42nd St., New York, N.Y.
- Reduction & Refining Co., Boulevard, Kenilworth, N.J.

Calcium Tungstate

- Bram Chemical Co., 820 65th Ave., Philadelphia, Pa.
- Electro-Metallurgical Co. (Div., Union Carbide & Carbon Corp.), 30 E. 42nd St., New York, N.Y.
- Harshaw Chemical Co., 1945 E. 97th St., Cleveland, Ohio.

Phosphotungstic Acid

- E. I. DuPont de Nemours Co., Inc. (Pigment Dept.), Dupont Bldg., Wilmington, Del.
- General Chemical Div., Allied Chemical & Dye Corp., 40 Rector St., New York, N.Y.

Sodium Tungstate

- J. T. Baker Chemical Co., Phillipsburg, N.J.; products--reagents.
- Bram Chemical Co., 820 65th Ave., Philadelphia, Pa.

Harshaw Chemical Co., 1945 E. 97th St., Cleveland, Ohio.
 Mallinckrodt Chemical Works, Second & Mallinckrodt Sts., St. Louis, Mo.; product--reagent.
 Merck & Co., Inc., Rahway, N.J.
 Molybdenum Corp. of America; plant address, York, Pa.
 North Metal & Chemical Co., 600 E. Mason Ave., York, Pa.; products--crystals, reagents.
 Prior Chemical Corp., 420 Lexington Ave., New York, N.Y.
 S. W. Shattuck Chemical Co., 1805 S. Bannock St., Denver, Col.
 Sylvania Electric Products, Inc. (Tungsten & Chemical Div.), Towanda, Pa.
 Tungsten Corp. of America, Conshohocken, Pa.

Tungstic Acid

J. T. Baker Chemical Co., Phillipsburg, N.J.
 Bram Chemical Co., 820 65th Ave., Philadelphia, Pa.
 Fansteel Metallurgical Corp., 2200 Sheridan Rd., North Chicago, Ill.
 Harshaw Chemical Co., 1945 E. 97th St., Cleveland, Ohio.
 Mallinckrodt Chemical Works, Second & Mallinckrodt Sts., St. Louis, Mo.
 Molybdenum Corp. of America; plant address, York, Pa.
 Prior Chemical Corp., 420 Lexington Ave., New York, N.Y.
 Reduction & Refining Co., Kenilworth, N.J.
 Tungsten Corp. of America, Conshohocken, Pa.

Tungsten Chloride

Cooper Metallurgical Association, 13600 Deisc St., Cleveland, Ohio.

Tungsten Oxide

Bram Chemical Co., 820 65th Ave., Philadelphia, Pa.
 Fansteel Metallurgical Corp., 2200 Sheridan Rd., North Chicago, Ill.
 Foote Mineral Co., Inc., 18 W. Chelton Ave., Philadelphia, Pa.
 Molybdenum Corp. of America; plant address, York, Pa.
 Prior Chemical Corp., 420 Lexington Ave., New York, N.Y.
 Reduction & Refining Co., Boulevard, Kenilworth, N.J.
 S. W. Shattuck Chemical Co., 1805 S. Bannock St., Denver, Col.

Sylvania Electric Products, Inc. (Tungsten & Chemical Div.), Towanda, Pa.

Tungstated Lakes and Toners

Calco Chemical Div., American Cyanamid Co., Bound Brook, N.J.
 General Dyestuff Corp., 435 Hudson St., New York, N.Y.
 Hilton-David Chemical Co., 2235 Langdon Farm Rd., Cincinnati, Ohio.
 Imperial Paper & Color Corp. (Pigment Color Div.), Glenn Falls, N.Y.
 Magruder Color Co., Inc., 2385 Richmond Ter., Staten Island, N.Y.
 Sherwin Williams Co., 115th & Cottage Grove Ave., Chicago, Ill.
 Sun Chemical Corp. (Pigment Div.), 309 Sussex St., Harrison, N.J.

Importers and Exporters*

Importers (does not include producers)

African Metals Corp., 25 Broad St., New York, N.Y.; imports from Congo for resale.
 Caswell Straus & Co., Inc., 17 State St., New York, N.Y.; imports from Australia, China, Europe, Japan, Malaya, Thailand; other imports--nonferrous metals, scrap, metallic residues.
 Continental Ore Co., 500 Fifth Ave., New York, N.Y.
 Cosmo Metal Alloys Corp., 150 Broadway, New York, N.Y.; imports from Africa, Australia, Central America, Europe, Far and Middle East, and South America; other imports--nonferrous metals, scrap, metallic residues.
 Derby & Co., 285 Madison Ave., New York, N.Y.; imports from all countries; other imports--nonferrous metals, residues.
 Felix Kromarsky Corp., 39 Broadway, New York, N.Y.
 W. R. Grace & Co., 7 Hanover Sq., New York, N.Y.; imports from Bolivia.
 Fred H. Lenway & Co., Inc., 112 Market St., San Francisco, Calif.
 Metallurg, Inc., 100 Park Ave., New York, N.Y.
 Metal Traders, Inc., 67 Wall St., New York, N.Y.; imports from Australia, Japan, South America, United Kingdom; other imports--nonferrous metals.
 Miles Metal Corp., 150 Broadway, New York, N.Y.; imports from all countries; other imports--nonferrous metals.

*Source: Directory of New York Importers and Related Services, Commerce & Industry Association of New York, Inc., New York, 1952.

Philipp Brothers, Inc., 70 Pine St., New York, N.Y.; imports from Africa, Australia, Europe, Far East, South America; other imports--metals, ferro-alloys, scrap metals, metallic residues.
 Frank Samuel & Co., Inc., Lincoln-Liberty Bldg., Philadelphia, Pa.
 South American Mineral & Merchandising Corp., 445 Park Ave., New York, N.Y.
 C. Tennant Sons & Company, 100 Park Ave., New York, N.Y.
 Wah Chang Corp., Woolworth Bldg., 233 Broadway, New York, N.Y.
 H. A. Watson Co., 105 Chestnut St., Newark, N.J.

Exporters

Holden International Co. (export agents), 30 Church St., New York, N.Y.
 Keljikan Commercial Corp. (export agents) 475 Fifth Ave., New York, N.Y.

Scrap Buyers

Paul Blum Co., 317 Larkin St., Buffalo, N.Y.
 Metallurgical Products Co., 3500 Moore St., Philadelphia, Pa.; type--grindings, sludge, residues, etc.
 Max Zuckerman, 4018 W. Strathmore Ave., Baltimore, Md.; type--wire, grindings, sludge, etc.

Consumers of Ferrotungsten

Allegheny Ludlum Co., Henry W. Oliver Bldg., Pittsburgh, Pa.
 American Brake Shoe Co., 230 Park Ave., New York, N.Y.
 Blaw-Knox Co., Farmers Bank Bldg., Pittsburgh, Pa.
 Braeburn Alloy Steel Corp., Braeburn, Pa.
 Bethlehem Steel Co., 1701 E. Third St., Bethlehem, Pa.
 Carpenter Steel Co., 101 W. Bern St., Reading, Pa.
 Columbia Tool Steel Co., Lincoln Highway & State St., Chicago Heights, Ill.
 Cooper Alloy Foundry, Bloy St., Hillside, N.J.
 Crucible Steel Co. of America, Oliver Bldg., Pittsburgh, Pa.
 Duraloy Co., Box 81, Scottdale, Pa.
 Firth Sterling Inc., 3113 Forbes St., Pittsburgh, Pa.
 Haynes Stellite (Div., Union Carbide & Carbon Corp.), 30 E. 42nd St., New York, N.Y.; home office, Kokomo, Ind.
 Heppenstall Co., 4620 Hatfield St., Pittsburgh, Pa.

Jessop Steel Co., 500 Green St., Washington, Pa.
 Latrobe Steel Co., 2626 Ligonier St., Latrobe, Pa.
 Lebanon Steel Foundry, Lincoln Ave. & Lebanon St., Lebanon, Pa.
 Midvale Co., Nicetown, Philadelphia, Pa.
 Simonds Saw & Steel Co., 470 Main St., Fitchburg, Mass.; steel plant at Lockport, N.Y.
 Universal-Cyclops Steel Corp., Station St., Bridgeville, Pa.
 Vanadium-Alloys Steel Co., Latrobe, Pa.
 Vulcan Crucible Steel Co., 1 Main St., Aliquippa, Pa.

Purchasers of Tungsten Concentrates

Clifford Ach, 2709 Birch St., Alhambra, Calif.
 Bishop Concentrate & Cleaning Co., Bishop, Calif.
 Black Rock Mining Co., Bishop, Calif.
 Braeburn Alloy Steel Co. (Div., Continental Copper & Steel Industries, Inc.), Braeburn, Pa.
 Columbia Tool Steel Co., Chicago Heights, Ill.
 Electro Metallurgical Co. (Div., Union Carbide & Carbon Corp.), 30 E. 42nd St., New York, N.Y.
 Fansteel Metallurgical Corp., North Chicago, Ill.
 E. Fernstrom, 648 W. Ord St., Tucson, Ariz.
 Firth Sterling Inc., McKeesport, Pa.
 General Electric Co., Cleveland Wire Works, Lamp Dept., 1331 Chardon Rd., Euclid, Ohio.
 Jessop Steel Co., Washington, Pa.
 C. W. Jones, Bishop, Calif.
 Kennametal Inc., Latrobe, Pa.
 Latrobe Electric Steel Co., Latrobe, Pa.
 Molybdenum Corp. of America, 500 Fifth Ave., New York, N.Y.
 National Hardware & Supply Co., 3618 Ventura Ave., Fresno, Calif.
 North Metal & Chemical Co., York, Pa.
 Reduction & Refining Co., Kenilworth, N.J.
 Simonds Saw & Steel Co., Lockport, N.Y.
 Sylvania Electric Products Co., Tungsten & Chemical Div., Box 70, Towanda, Pa.
 David Taylor Co., 17 E. 42nd St., New York, N.Y.
 Universal-Cyclops Steel Corp., Bridgeville, Pa.
 U. S. Vanadium Co. (Div., Union Carbide & Carbon Corp.), 30 E. 42nd St., New York, N.Y.

Vanadium-Alloy Steel Co., Latrobe, Pa.
Vulcan Crucible Steel Co. (Div. H. K. Porter Co., Inc.), Aliquippa, Pa.

Wah Chang Corp., Woolworth Bldg., New York, N.Y.
Westinghouse Electric Corp., 1-71 MacArthur Ave., Bloomfield, N.J.

AMERICAS

(Excluding United States)

Canada

Ore Producers

Burnt Hill Tungsten Mines Ltd., 510 McGill St., Montreal, P.Q.; mine at Nadogan, N.B.; type ore--wolframite.
Canadian Exploration, Ltd., 100 Royal Bank Bldg., Vancouver, B.C.; Emerald Mine, Salmo, B.C.; type ore--scheelite.
Hollinger Consolidated Gold Mines, Ltd., Nova Scotia; type ore--scheelite.
Western Tungsten-Copper Mines, Ltd., 604 Hall Bldg., Vancouver, B.C.; agent: Derby & Co., Madison Ave., New York, N.Y.; Red Rose Mine, near Hazelton, B.C.; type ore--scheelite.

Powder Producer --Electro Metallurgical Co. of Canada, Ltd., Welland, Ont.

Carbide Producer --Macro (Exploration Div., Kennametal Inc.), Port Coquitlam, B.C.

Ferrotungsten Producer --Electro Metallurgical Co. of Canada, Ltd., Welland, Ont.

Mexico

Ore Producers

American Smelting & Refining Co., Av. Madero 55, Desp. 404, Mexico, D.F.
Cia Minera de Sonora, S.A., Av. 5 de Mayo 37-51, Mexico, D.F.; mines at Bacanora, Yecora, Sahuaripa.
Cia Minera Tres Brazos, S.A., Atoyac de Alvarez, Juerrero.
Compania Minera Moctezuma, S.A., Mexico, D.F.; agent: Continental Ore Corp., 500 Fifth Ave., New York, N.Y.; mine at La Guadalupeana (S.W. of Real de Morales, Chihuahua).
Fresnillo Ltd., Desp. Juarez 7C-9, Mexico, D.F.
Minera Continental, S.A., Av. Juarez 14-1012, Mexico, D.F.
Minerales de Nacozari, S.A., Apdo. 7, Nacozari de Garcia, Sonora; mine at Nacozari de Garcia.
Wolframeo y Derivados, S.A., Morelos, Chihuahua.

Exporters

American Trading Co., S.R.L., Av. Juarez No. 30, Mexico, D.F.
Credito Mineral y Mercantil, S.A., San Juan de Letran No. 11, Mexico 1, D.F.
Soc. Financiera de Industrie, y Desuento, S.A., Av. Madero 47, Mexico, D.F.
Wolframio y Davivados, 58 Monte No. 73, Mexico, D.F.

Argentina

Ore Producer --Minerales y Metals, S.R.L., Solis 227, Buenos Aires; controlled by Thomas J. William; Sominar Mine; type ore--wolframite.

Brazil

Ore Producers

Baixios Mine, Santana do Matos, Rio Grande do Norte.
Barra Verde Mine (Jose Leonidas, owner), Currais Noras, Rio Grande do Norte.
Brejui Mine (Tomas Salastino Gomez de Melo, owner), Currais Noras, Rio Grande do Norte.
Bodo Mine (Servulo Pereira, owner), Santana do Matos, Rio Grande do Norte.
Bonito Mine (Dinarte Mariz, owner), Jucuruto, Rio Grande do Norte.
Cafuca Mine (Aristofanes Fernandes, owner), Santanado, Matos, Rio Grande do Norte.
Malhada dos Angicos Mine (Florencio Luciano, owner), Parelhas, Rio Grande do Norte.
Malhada do Limpa Mine (Servule Pereira, owner), Cerro Cora, Rio Grande do Norte.
Mauricio Hochschild, S.A.M.I.; agent: South American Minerals & Mechanize Corp., 445 Park Ave., New York, N.Y.
Quixaba Mine (Francisco Araujo and Mario Pergentino Araujo, owners), Santa Luzia, Paraiba.
Quixero Mine (Jose Maderas, owner), Serra Negra, Rio Grande do Norte.

Wah Chang Corporation, Woolworth Bldg., New York, N.Y.; mine at Inhanjara, near Jundiai, Sao Paulo.

Powder, Rod, and Wire Producer.--General Electric Co., S.A., Rio de Janeiro.

Bolivia

Ore Producers

(Note: All large mines were nationalized in October 1952; their products are sold by the Bolivian government. Concentrates from small producers are collected and marketed by Banco Minero de Bolivia, La Paz.)

Corporacion Minera de Bolivia (former mines of Mauricio Hochschild), La Paz; mines at Viloco, San José, Cerro de Potosi, Bolsa Negra, Huanhaca, Santa Fé, Unificado.

Corporacion Minera de Bolivia (formerly Compagnie Aramayo de Mines en Bolivia), La Paz; mines at Pacuni (Caracoles Dist.), Tasna, Chorolque, Animas, Province North Chicas, Dept. of Potosi; type ores--wolframite, scheelite, cassiterite, arsenopyrite, other common sulfides.

Corporacion Minera de Bolivia (formerly Patino Interests which included: Patino Mines & Ent. Cons. Inc.; Bolivian Tin & Tungsten Mine; Cia Minera Agricola Oploca de Bolivia; and Sociedad Empresa Estaña Araca), La Paz; mines at Araca, Catavi, Colquiri, Huanuni, Kami.

International Mining Co. (W. R. Grace & Co.), La Paz; Chojlla Mine; type ore--mixture wolframite and cassiterite.

Peru

Ore Producer--Sociedad Anonima Fermin Malaga Santolalla e Hijos, 224 Apurimas, Lima; Pasto Bueno Mine.

EUROPE

England

Ore Producers

(Note: Ore is produced in the districts of Land's End, Camborne and Redruth, St. Austell, Bodmin Morr, Hingston Down, Collington, in Cornwall, and in part of Devonshire.)

Powder Producers

Blackwell's Metallurgical Works, Ltd., Garston, Liverpool.
High Speed Steel Alloys, Ltd., Ditton Rd., Widnes; London office, 96 Victoria St., S.W. 1.
Minworth Metals, Ltd., Minworth, Birmingham.
Murex, Ltd., Rainham, Essex.
Tungsten Mfg. Co., Ltd., 64 Victoria St., London.

Wire Producers

Murex Ltd., Rainworth, Essex.
Stubs, Peter, Ltd., Scotland Rd., Warrington.
Tungsten Mfg. Co., Ltd., 64 Victoria St., London.

Carbide Powder Producers

High Speed Steel Alloys, Ltd., Dutton Rd., Widnes; London office, 96 Victoria St., S.W. 1.

McLeod, R. G., Ltd., King's Cross N. 1, London.

Murex, Ltd., Rainham, Essex.

Powderloys, Ltd., Torrington Ave., Coventry.

Carbide Tool Tip Manufacturers

The Halifax Tool Co., Ltd., West Lane, Southowram, Halifax.
Jessop (Wm.) and Sons, Ltd., Brightside Works, Sheffield.
Lenchs (Birmingham) Ltd., Great Hampton St., Birmingham 18.
Murex, Ltd., Rainham, Essex.
Saville, J. J. & Co. Ltd., Triumph Steel Works, Sheffield.
Wickman, Ltd., Banner Lane, Tile Hill, Coventry.

Chemical Producers

Blackwell's Metallurgical Works, Ltd., Garston, Liverpool 19.
High Speed Steel Alloys Ltd., Ditton Rd., Widnes; London office, 96 Victoria St., S.W. 1.
London & Scandinavian Metallurgical Co., Ltd., 39-41 Hill Rd., Wimbledon, London, S.W. 19.
Murex, Ltd., Rainworth, Essex.

Ferrotungsten Producers

Blackwell's Metallurgical Works, Ltd., Garston, Liverpool.
Everitt & Co., Ltd., 40 Chapel St., Liverpool 3.
Ferro-Alloys & Metals, Ltd., Surrey St., Glossop, Derbyshire.
High Speed Alloys, Ltd., Ditton Rd., Widnes; London office, 96 Victoria St., S.W. 1.
Minworth Metal, Ltd., Minworth, Birmingham.
Murex, Ltd., Rainham, Essex.

Importers, Exporters or Brokers

Brandhurst Co., Ltd., Vintry House, Queen Street Place, London, E.C. 4; buyers and sellers--tungsten ores and concentrates.
British Tungsten, Ltd., London; handles Ministry of Supply business.
Caswell Straus & Co., Ltd., London.
Commercial Metal Co., Ltd., 66 Gresham St., London, E.C. 2; exporters--tungsten metal.
Derby & Co., Ltd., 11/12 St. Swithins Lane, London, E.C. 4; buyers--tungsten ores and concentrates.
Metal Traders, Ltd., 7 Grace Church St., London, E.C. 3; buyers--tungsten ores and concentrates.
Rawstron & Co., Ltd., 25/26 Lime St., London, E.C. 3; brokers.
C. Tennant Sons & Co., Ltd., 4 Copthall Ave., London, E.C. 2; buyers--tungsten ores and concentrates.

France

Ore Producers

Cie des Forges et Acieries de la Marine et d'Homecourt, 12, rue de la Rochefoncauld, Paris (9); mine at Leucamps (Cantal).
Metaux & Products Industrial, 22, Place de la Madeleine, Paris.
Soc. Anonyme de Recherches et d'Exploitations, Minieres "Mines de Montmins", 25, Passage de l'Ameraute, Vichy (Allier).
Soc. des Mines de Puy-les-Vignes, S.A., St.-Leonard-de-Noblat, Puy-les-Vignes (Haute Vienne).
Soc. des Mines de Cuivre de Tenes, 39, Av. de Friedland, Paris (8).
Soc. des Mines d'Etain de Vaulry et Cieux, Vaulry (Hte-Vienne).
Powder Producer--Metaux Speciaux (Ste. de), 142, r. de L'Esolle d'Aloi, Tassin (Rhône).

Wire Producers

Cristallerie de Villejuif, 80, rue Pasteur, Villejuif (Seine).
Cie Industrielle de Metaux Electroniques (C.I.M.E.), 8, rue Cognacq - Jay, Paris (7).
Eclairaquisne Rationnel, 36 bd. Michelet, Marseille.
Fabriques Reunies de Lampes Electriques, 64, rue M. Gunsbourg, Ivry.

Ferrotungsten Producers

Electricite de France (Usine a Laval de Cere), Firminy, 79, rue de Montceau, Paris (8).
Manufactures de Produits Chimiques du Nord (Etats Kuhlmann), 11, rue de la Baume, Paris (8).
Montricher, 66, rue de la Chaussee-de-Antin, Paris (9).
Saint Beron, 101, rue de L'Hotel-de-Ville, Lyon (Rhône).
Sidelor (Exports), 1 r. Georges-Beger, Paris (8).

Buyers, Sellers and/or Brokers

Cie Franco-Americaine des Metaux et des Minerais, 69, Boulevard Haussmann, Paris (8).
Rene Weil, Societe Anonyme, 77 rue de Monceau, Paris (8).

Germany

Powder Producers

Chem-Metallurg Fabrik, Goslar (Harz).
Dr. E. Durwachter, Westliche 61, Pforzheim.
F. Krupp, A/G, Wuppertal.
Starck, Hermann C., A/G, Goslar (Harz).
Wire, Rod and Sheet Producer--Bayerische Metallwerke, A/G, Dachau.

Carbide Producers

Deutsche Edelstahlwerke, A/G, Krefeld.
Gebruder Bohler, A/G, Dusseldorf.
Friedrich Krupp, A/G, Widia plant, Essen (Ruhr).
Poldihutte, Kladno.
Rheinmetall Borsig, Dusseldorf.
Stahlwerke Rochling, Buderus, Wetzlar.
Stahlwerke Scholla-Bleckmann, Tarnitz.

Salts and Chemical Producers

Chem. Fabrik Runmetall (Dr. Klimmer & Co.), Wendscherdstr 17, Berlin-Charlottenburg 5.

Chem-Metallurg Fabrik, Goslar (Harz).
Merck, Darmstadt.
Starck, Hermann C., A/G, Goslar (Harz).

Ferrotungsten Producers

Badische Wolframerz Gessellschaft, Soellingen bei Karlsruhe.
Gesellschaft fuer Elektrometallurgie, Duesseldorf.
Metallhutte Work, A/G, Fahistr 114-116, Hamburg-Wilkelmsburg.
Starck, Hermann C., A/G, Goslar (Harz).

Brokers, Importers and/or Sellers

Metallgesellschaft, A/G, Frankfurt, (Main), Reuterweg 14.
Willy Bodensiek, Hamburg 1, Curienstr 8.

Italy

Ferrotungsten & Chemical Producer--
S.A.L.E.M. (Soc. p.Az. Leghee Metalli);
office at Genoa; Plants at Gapollo & Spegno.

Netherlands

Wire Producer--N. V. Hollandsche, Tungstendraad-Fabriek, 149 Oudedijk, Rotterdam.

Chemical Producer--N. V. Hollandsche, Metallurgische Bedrijven, Arnhem.

Norway

Ore Producer--Norsk Bergverck Co., Ørdsalen; mines: (1) Ørdsalen, in S.W. Norway--ore is a mixture of wolframite and scheelite; (2) Østerstrand, in Nordland County, N. Norway--ore is primarily molybdenite.

Portugal

Ore Producers

Alfredo Machado, Arco de Baulke, Cabeceiras de Basto; mines at Vila Nune (Cabeceiras de Basto), and Cerva (Riberia de Peno); type ore--wolfram and tin.
Beralt Tin and Wolfram Ltd., 8 Great Winchester St., London E. C. 2, Eng.; mine: Minas da Panasqueira in the province Beira Baixa; type ore--wolfram and tin.
Companhia Portuguesa de Minas, S.A.R.L., Rua de Alecrim 39, Lisbon; mines: Reguoufe, Muro, Cerva, and Ramhalhosa in province Tras os Montes e Alto Douro.
Companhia do Estanho do Vale do Vouga, S.A.R.L., Rua do Alecrim 39, Lisbon;

mines in Janarde (Arouca), and Queiriga (Vila Nova de Parva); type ore--wolfram and tin.

Companhia Mineira do Norte de Portugal, S.A.R.L., Rua Fernandes Tomas 415-2, Oporto; mines in Cabreiras (Arouca), Figueiro da Serra (Gouveia), Meixedo (Viana do Castelo), Vilar (Boticas), Souto Maior (Sabrosa), and S. Lourenco de Ribapinhao; also smelter and exporter; type ore--wolfram and tin.

Empresa Mineira do Pomar, Lda., Rua dos Correeiros 71-, Lisbon; mines in Serzedas (Castelo Branco); type ore--wolfram and antimony.

Empresa Mineira de Segura, Lda., Rua da Vitoria 38-2-Oto, Lisbon; mines in Segura and Idanha-a-Nova; type ore--wolfram, tin, lead and barium.

Empresa Tecnica e Administracoes, Lda., Rua Nova da Trindade 1-2, Lisbon; mines in Coelhoso (Braganca); also exports; type ore--wolfram.

Empresa Volframio Portugal, Lda., Avenida Sidonio, Paris, France; mine in Beira Baixa.

Minas do Barranco, Lda., Rua de Miguel Bombarda 16, Vizeu; mines in Figueiro da Serra (Gouveia); type ore--wolfram and tin.

Minas de Boralha, S.A., Rua do Castilho 5-2, Lisbon; mines in the province of Tras os Montes e Alto Douro; also exporter, smelter and ferrotungsten producer; type ore--wolfram.

Minas de Cerva, S.A.R.L., c/o P.C. Bastid, 96 Blvd. Haussmann, Paris, France; mines in the province of Tras os Montes e Alto Douro.

Minas Minerios e Metais, Lda., Rua do Carmo 43-2, Lisbon; mines in Coelhoso (Braganca); type ore--wolfram and tin.

Minas de Riba de Alva, Lda., Rua la Noronha 82-20, Porto.

Minas de Tibaes, Lda., 128-8 Praca Carlos Alberto, Oporto; owners--Silva Barbosa and Marques, Lda.

Mineira Gouveense, Lda., Praca Sac in Munes, Lisbon; mine in the province of Beira Baixa.

Minero-Agricola do Norte, Lda., Vilar do Paraíso, Vila Nova de Gaia; mine in the province of Minho type ore--wolfram and tin.

Nazarius, S.A.R.L., Av. Pedro Alvares Cabral 22, Lisbon; mine in the province of Beira Alta; type ore--wolfram.

Soc. das Minas do Gerez, Gerez; mine in the province of Tras os Montes e Alto Douro.

Soc. Mineira do Cabril, Lda., Rua de Sa da Bandeira, 605-2 Porto; mine in the province of Beira Alta.

Soc. Miniere General de l'Etain, Rua do Contumil 160, Oporto; mine in Parada (Braganca); type ore--wolfram and tin.

Ferrotungsten Producer--Minas de Borralha, S.A., Rua do Castilho, Lisbon.

Smelters (some are producers)

Antonio Mourae de Sousa, Belmonte.

Manual Costanheura, Jr., Rua do Mousinho, Castelo Branco.

Empresa Mineira de Sabrosa, Lda., Rua da Constituicao 441, Oporto.

Manuel de Araujo Ribeiro, Rua Alfonso de Albuquerque 174, Vila Nova de Gaia.

Ramiro da Costa Cabral Nunes de Sobral, Vizeu.

Soc. Mineira de S. Martinho, Lda., Routar, Toiredeita, Vizeu.

Soc. Mineira Volesta, Lda., Rua da Vitoria 7, Vizeu.

Exporters (some are producers)

Soc. Mineira do Paiva, Lda., Castro D'Aire; also smelter.

Comine, Praca D. Filipa de Lencastre 22, Oporto.

Empresa Mineira das Chaos, Lda., Rua de Trindade Coelho 1C-1, Oporto.

Fomento Nacional de Industria, S.A.R.L., Ave. Antonio Augusto de Aguiar 138, Lisbon.

Laureano Otero Piay, Rua do Duque de Palmela 41-1, Oporto.

M. Fontes, Lda., Rua Elisio de Melo 28-2, sala 20, Oporto.

Renato Dario A. Maissa, Rua Fialho de Almeida 15-3 Esq., Lisbon.

Spain

Ore Producers

Abdon Merladet (doing business under the name Coto Minero de Barneco, S.A.), Arerilza 10, Bilbao; mines: Josefiro, Luisita, Alejandria, and Socorro, in the province of Salamanca; type ores--wolfram and scheelite.

Compania Minera Celta, S.A., Clavel 3, Madrid; mine office in Santiago de Compostela (La Coruna); mines: Santa Comba group, in the province of Coruna; type ore--wolfram.

Compania Minera Balaina, Barruecopardo (Salamanca); mines: (1) Una, S. of village Barruecopardo in the province Salamanca, (2) Carballo group, N. of Carballo near

the city of La Coruna in the province Coruna.

Compania Vasco Salmantina, Barruecopardo (Salamanca); mine: Josefita y Luisita, adj. to Una mine in province Salamanca. Estanifera de Silleda, Silleda (Pontevedra); mine: Silleda, 40 kilometers from Santiago in province Coruna.

Industrias Gallegas, S.A., Noya (La Coruna); mines: San Finx group, 12 kilometers S. of Noya in province Coruna.

Minerales de Compostela, Alcola 10, Madrid.

Minero Metalurgia del Estano, S.A.E., Neguel Moya 4, Madrid.

Montez de Galicia, S.A.C., Aranda 22, Orense; mine: San Nicolas, 8 kilometers SE. of Villanueva de la Serna in province Badajoz.

Russell & Co., Inc., 1741 de Salle St., N.W., Washington, D. C. (representative for Spanish mines).

Sociedad de Estanos de Silleda, S.A., Silleda (Pontevedra); type ores--wolfram, scheelite and tin.

Ferrotungsten Producers

Altos Hornos de Vizcaya, S.A., Alameda de Recalde, 27, Baracaldo.

Electrometalurgia del Agueda, Salamanca. Ferroaliaciones Espanolas, S.A., Plaza V. de Melba 5, Madrid; plant at Medina del Campo, Valladolid.

Reinosa Works, Sociedad Espanola de Construcccion Naval, Santander.

Sociedad Anonima Echevarria, Alameda de Urquijo 4, Bilbao; plant in Santa Aguecla, Baracaldo.

Siderurgica del Norte, S.A., Valmaseda 7, Madrid.

Powder and Chemical Producer--Almuso, S.A., Madrid.

Exporters

B. Bruna, Av. Jose Antonio 57-50, Madrid. Corusa, Madrid.

Iberic de Exportacion Comercial, Madrid.

Ricardo Medem y Cia, La Coruna.

Sweden

Ore Producers

Tjallmo Gruvor, Berglund & Co., Stockholm 16; mine in Tjallmo, Ostergotland Province, A/B Yxsjo Gruvor, Yxsjoberg.

Wire Producer--Lumalampan, A/B, Stockholm 20.

Carbide Tool Producers

A/B Bofors, Bofors.
Fagersta Bruks, A/B, Fagersta.
A/B Hardmetallverktyg, Ockelbo.
C. O. Oberg & Co's., A/B, Eskilstuna.
Sandvikens Jernverks, A/B, Sandviken.
Söderfors Bruk, Söderfors.
Wedevags Bruks, A/B, Vedevag.
Wikmanshytte Bruks, A/B, Vikmanshyttan.

Ferrotungsten Producers

A/B Ferrolegeringar, Stockholm.
Gullspangs Elektrokemiska, A/B, Gullspang.
Stockholms Superfosfatfabrika, A/B, Stockholm 5.
Wargöns, A/B, Vagön.

Exporters

I. Ahmberg & Co., Vallgatan 27; exports--tools.
Associated Sales Promoters, A/B, Norrlandsgatan 2, Stockholm; exports--hard metal, finished products, ferro-alloys.

Bengt Wrenke A/B, Stockholm; export--ferrotungsten.
A/B Bonthron and Ewing, Box 632, Stockholm 1; exports--machine tools.
Hj. Edwards & Co., A/B, Göteborg; exports--carbide tools.
Elof Hansson, Göteborg; exports--carbide tools.
Kjellbergs Successors A/B, Stockholm; exports--carbide tools.
Eric Lindblom & Co., Stockholm; exports--colors, dyes, chemicals, metals, ferrotungsten.
Linden & Linström A/B, Göteborg; export--ferrotungsten.
A. B. Metall-och Bergprodukter, Stockholm; exports--ferrotungsten, tungsten metal.
Carl Setterwall & Co. A/B, Stockholm; exports--carbide tools.
A/B Transfer, Stockholm; exports--carbide tools.
C. M. Truedsson, Uddeholm; exports--carbide tools.
Western Trading Co. A/B, Stockholm; export--ferrotungsten.

AFRICA, ASIA, AND OCEANIA

Belgian Congo

Ore Producers

African Metals Corporation (agents), 25 Broad St., New York, N. Y. Mines in Belgian Congo as: Mangobo Mine of the Belgikaor Co.; Les Mines d'Etain de Kindic; Mr. Robert Marchol, Korotshekia; Mr. Andre Stenghlamber, Goma; Compagnie de Recherches et d'Exploitations Minières au Ruanda-Urundi, Usumhura; Compagnie Minière des Grande Lacs Africains, Goma, S.W. Africa.
O'okiep Copper Co., Ltd., 14 Wall St., New York, N. Y.; mine in Namaqualand, S.W. Africa; Natas Mine in Kuisib Mts., S.W. Africa.

Southern Rhodesia

Ore Producer --Strathmore Consol Investments, Ltd., Hippo Mine in Southern Rhodesia.

South West Africa

Ore Producers

N. H. Van Zyl, Warmbad.
Peter Weidner, P. O. Box 12, Warmbad.

South West Africa Co., Ltd., P.O. Box 2, Lalkfontein.

Union of South Africa

Ore Producers

Associated Tungsten Mines, Ltd., P.O. Box 204, Upington.
Braude Tungsten Syndicate, P.O. Box 28, Upington.

Burma

Ore Producers

Consolidated Tin Mines of Burma, Ltd.; head office--Rangoon; mines in Mergui and Tavoy.
Kanbauk Mines, Ltd., 50 miles N. of Tavoy.
Mawchi Mines Ltd. (not open), Rangoon, Burma.

Japan

Ore Producers

Arakawa, 1 Baraki Pref.; mine: Takatori.
Mitsubishi Metal Mining Co., 1 Kumo, Hyogo Pref.; mine: Okenobe.
Nitakozan Co., Kagoshimi Pref.; mine: Yakushima.
Owamura Kogyo K.K., Kyoto Pref.; mines: Otana and Wachi.

Rokuichi Nakamura, Hiroshima Pref.; mine:
Setoda.
Shigea Murata, Kyoto Pref.; mine: Kaneuchi.

Powder Producers (company, plant, and locations)

Fujijura Densen K.K., Fukagawa Works,
Fukagawa, Tokyo.
Fuji Vacuum Industry Co., Ltd., Aichi
Works, Aichi, Aichi.
Kawanishi Kikai Seisakusho, Ltd., Kobe
Works, Kobe, Hyogo.
Koa Kagaku Kogyo K.K., Amagasaki Works,
Amagasaki, Hyogo Pref.
Kyoritsu Gokin Seisakusho, Nishinomiya
Works, Nishinomiya, Hyogo.
Mitsubishi Kogyo K. K., Shinagawa Works,
Shinagawa, Tokyo.
Mitsubishi Kogyo K. K., Niigata Works,
Niigata, Pref.
Nippon Electric Co., Ltd., Takasaki Works,
Gumma Pref.
Nippon Tungsten Co., Ltd., Chikogyo,
Fukuoka.
Nippon Tungsten Co., Ltd., Fukuoka Plant,
Fukuoka Pref.
Sumitomo Electric Industry Ltd., Itami
Works, Itami, Hyogo.
Tokyo Shibaura Electric Co., Ltd., Hori-
kawacho Plant, Kawasaki, Kanagawa.
Tokyo Shibaura Electric Co., Ltd., Suna-
machi Works, Sunamachi, Tokyo.
Tohaku Metal Industry Co., Sendai Works,
Miyagi Pref.
Tokyo Electric Co., Kamata Metal Works,
Kamata, Tokyo.
Toa Yakin K.K., Katayama Plant, Katayama,
Saitama.
Tokyo Tungsten Co., Sakata Works, Yama-
gata Pref.
Tokyo Tungsten Co., Aoto Works, Katsu-
shika, Tokyo.

Carbide Producers

Fujirura Densen K.K., Fukagawa, Tokyo.
Kotobuki Sangyo K.K., Honsha Works, Osaka
Pref.
Kyoritsu Gokin Seisakusho, Nishinomiya
Works, Nishinomiya, Hyogo Pref.
Mitsubiski Kogyo K.K., Tokyo Kinzoku
Kogyojo, Tokyo.
Mitsubishi Kogyo K.K., Niigata Kinzoku
Kogyojo, Niigata Pref.
Sumitomo Denki Kogyo K.K., Itami Works,
Hyogo Pref.
Tokyo Tungsten K.K., Ooto Works, Tokyo.

Ferrotungsten Producers (plant name and prefecture)

Awamura Kogyo K.K., Tsukuda, Osaka.
Awamura Kogyo K.K., Uji, Kyoto Pref.
Awamura Kogyo K.K., Kanzakiagawa, Hyogo
Pref.
Fujikoshi Yozaj Kogyo K.K., Kokura,
Fukuoka.
Nichinan Kogyo K.K., Wachi, Kyoto.
Mitsubishi Metal Mining Co., Ltd., Osaka.
Nippon Kogyo K.K. (Nippon Mining Co.,
owner), Saganoseki, Oita.
Nippon Denko Co., Ltd., Oguni, Yamagata
Pref.
Nippon Koshuha Jukogyo K.K., Toyama,
Toyama.
Nippon Senki Yakin K.K., Shiragikucho,
Ishikaw.
Showa Denko K.K., Shiojiri, Nagano.

Exporters and Importers

Hosoda Trading Co. Ltd., 5,2 Chrome
Kasumigaseki; Chiyoda-ku, Tokyo; rep.--
E. Kanakubo, Y. Takei; exp. and mfg.;
prod.--wire.
Kawanishi Machine Mfg. Co., Ltd., 5,1
Chrome Wadayama-dou, Hyogo-ku, Kobe;
rep.--Shigezo, Takao; exp. and mfg.;
prod.--cemented carbide tools.
Mutual Trading Co., 43, Yamashita - cho,
Naka - ku, Yokohama; imp.; prod.--
filament wire.
Sumitomo Electric Industries, Ltd., 60,
Okijima Minamino - cho, Konchana - ku,
Osaka; rep.--Kanome Kishi.

Korea

Ore Producer--Korean Tungsten Mining
Co.; Chief Eng., Herbert Kim; mines in
S. Korea: (1) Sangdong (scheelite), (2)
Dalsung (wolframite).

Ferrotungsten Producers (company, plant name and location)

Kobayashi, Kogyo K.K., Keijo Seirenscho
Plant, 40 Sosha-yu Keikido, S. Korea.
Nakagawa Kogyo K.K., Seiyo Seirenscho
Plant, S. Korea.
Nihon Kogyo K.K., Chinnanpo Seirenscho
Plant, Chinnanpo Fu, Feiannando, Korea.
Nihan Koshuha Jukogyo K.K., Joshin Plant,
Futsura-machi, Joshin Kankyo-hoku-do,
N. Korea.

Thailand

Ore Producers

Maa Luma Mining Co., 176 Chaiyabhoum Rd., Chiangmai, Thailand.

Suphorn Company, Ltd., Bangkok, Thailand; (controlled by Samer Maghingbongs); mine at Pilok.

Yip In Tsoi & Co., Ltd., Box 23, Bangkok, Thailand; mines: Khoa Nora, Ronglek, Sin San, Wang Phro, and Khao Kiam.

U-Tong Thai, Ltd., 539 Luang Rd., Bangkok, Thailand; mines located in Songhla and Ranong districts.

Tasmania

Ore Producers

King Island Scheelite Ltd., 450 Collins St., Melbourne, Victoria, Australia; Mgr. Dir., A. R. Bruhn; mine in King Island, Australia.

Storey's Creek Tin Mining Co., N.L., 42 George St., Launceston, Tasmania; Dir., C.K.R. Stackhouse; mine in locality of Storey's Creek.

CHAPTER XI
BIBLIOGRAPHY

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