Mineral Resources
Consultative Committee

Mineral Dossier No 5

Tungsten

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London
Her Majesty's Stationery Office
1973

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Preface

The Mineral Resources Consultative Committee consists of representatives of interested Government Departments, and specialist advisers. It was set up in 1967 to keep present and future requirements for minerals under review and to identify problems associated with the availability, exploitation and use of mineral resources, both inland and offshore, having regard to competing demands on land use and other relevant factors.

Widespread and increasing interest in the mineral resources of the United Kingdom has led the Committee to undertake the collation of the factual information at present available about those minerals (other than fossil fuels) which are now being worked or which might be worked in this country. The Committee has produced a series of dossiers, each of which was circulated in draft to the relevant sectors of the minerals industry. They bring together in a convenient form, in respect of each of the minerals, data which had previously been scattered and not always readily available. These dossiers are now being published for general information.

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Acknowledgements

This mineral dossier was compiled with the assistance of the field staff and Mineral Statistics and Economics Unit of the Institute of Geological Sciences, the Department of Trade and Industry (including the Warren Spring Laboratory) and the Department of the Environment. The help of the following companies and associations, which commented extensively on the draft, is gratefully acknowledged: British Steel Corporation; British Independent Steel Producers Association; British Hard Metal Association; Consolidated Gold Fields Limited; London and Scandinavian Metallurgical Company Limited; Mullard Limited; Murex Limited.

Metric units are employed throughout this document except where otherwise stated. In most cases this has necessitated the conversion of originally non-metric data. The units and conversion factors used are as follows:

millimetres (mm)	= inches x 25.4
metres (m)	= feet x 0.3048
kilometres (km)	= miles x 1.609344
hectares (ha)	= acres x 0.404686
kilogrammes (kg)	= pounds x 0.45359237
tonnes (1000 kg)	= long tons x 1.01605

Summary

Tungsten is a metal of great industrial and strategic importance. It is valued, in particular, for the hardness and wear resistance of its carbide and as an additive in the manufacture of tool steels to which it imparts high temperature hardness and tensile strength. In the United Kingdom, mine production is confined to the South Crofty property in Cornwall where small quantities of tungsten concentrate are recovered as a byproduct of tin mining. Deposits of economic value are likely to be restricted to those areas in south-west England and Cumberland where tungsten mineralisation is already known. Potential, but as yet unproven, or partly proven, resources include those of the Hemerdon Mine in Devon, the South Crofty property in Cornwall and Carrock Mine in Cumberland.

The most important world resources of tungsten occur in China, the USA, North Korea, South Korea, Bolivia, Portugal, Australia, Burma and the USSR. The United States General Services Administration stockpile is, and has been, one of the world's major sources of tungsten. China, the USSR and North Korea account for more than 50 per cent of world mine production of tungsten concentrates.

United Kingdom requirements are almost entirely imported. Average annual imports during the period 1966-70 amounted to 4,600 tonnes contained tungsten trioxide in concentrate. The net cost to the balance of payments of imported tungsten concentrates (including those of tin-tungsten) averaged £11.8 million per year for the three-year period 1969-71.

Tungsten has numerous applications, the most important of which are those in tool steels, tungsten carbide cutting tools, wear resisting parts , thermionic devices, contacts and electric lamp filaments. Molybdenum, a metal with many properties similar to those of tungsten, has succeeded in capturing appreciable parts of the tungsten market which is distinguished by great fluctuations in price arising from uncertainties over the marketing policies of China and from the lack of vertical integration in the industry.

Methods at present in use for the dressing of tungsten ores are efficient for sand-size fractions but become progressively less satisfactory for recovery at decreasing grain sizes. Work on the electrolytic reduction of fused salts promises some possibility of a direct route from concentrate to metal where the concentrate is substantially free from other metal impurities.

Statistics relating to trade, mine production and overall consumption are readily available, but those for consumption in particular and uses are difficult, if not impossible, to acquire. Similarly, figures for the consumption of secondary tungsten in the United Kingdom, whether in scrap tool steel or as tungsten metal or cemented carbide, are not available.

Problems of land use which might arise from the mining of tungsten ores are similar to those which result from the working of other non-ferrous metals, notably tin; that is, they are likely to stem from the disposal of comminuted rock waste, the siting of surface plant and, perhaps, open pit extraction. Proposals to mine tungsten ores require planning approval and future operations would have to meet conditions laid down in planning consents.

Introduction

Tungsten is a metallic element with the highest melting point (3410° ± 20°C) of all metals and all other elements except carbon. It is exceeded in density (19.35 gm/cc) only by rhenium and metals of the platinum group. In order of abundance it is the twenty-sixth element in the Earth's crust.

Tungsten is of fundamental importance to the mining machinery, machine tool, electronic, electrical and chemical industries and an assured domestic supply of even part of our needs would be of great strategic and economic importance. At present supplies of tungsten and, more important, the stability of prices, are dependent to a large degree on factors over which domestic consumers have little control, notably the scale of offers from China and releases from the United States General Services Administration stockpile. China and North Korea possess about three-quarters of known world reserves and, with the USSR, account for over 50 per cent of world production. Their erratic marketing policies have a disrupting effect on world supplies. For economic and, to some extent, for strategic reasons, therefore, a re-examination of known tungsten-bearing areas in the United Kingdom is indicated.

The two most important ore minerals of tungsten (chemical symbol W) are wolframite, an iron manganese tungstate, (Fe Mn) WO_4, and scheelite, the calcium tungstate, $CaWO_4$. In the wolframite group of minerals iron and manganese may substitute for each other in all proportions, and a complete solid-solution series exists between the two end-members, ferberite ($FeWO_4$, iron tungstate containing less than 20 per cent manganese tungstate) and hubnerite $MnWO_4$ (manganese tungstate containing less than 20 per cent iron tungstate). Wolframite contains about 76.5 per cent WO_3 equivalent to 60.6 per cent W.

Some of the terms used in the tungsten industry may be unfamiliar to the general reader. For instance, the basis on which wolframite concentrates are generally marketed is now the tonne (metric ton) unit of contained tungsten trioxide, the tonne unit being 1 per cent of one tonne, ie 10 kg. In mining and trade the word 'wolfram' is used in a loose sense to denote wolframite, wolframite concentrate and tungsten metal but its use is generally to be discouraged. The incorrect use of the term 'ore' to describe concentrate is as common in trade literature on tungsten as in that on other non-ferrous metals. Ammonium paratungstate, normally formed at an intermediate stage in the processing of concentrates, is commonly designated APT. In trade literature, statistical tables and industrial reviews the term 'scheelite' may not refer to the mineral, but to synthetic scheelite. 'Hard metal' is a term used in industry to describe sintered tungsten carbide (as well as some other carbides) with cobalt as a binder. 'Tungsten melting base' is eutectic alloy, containing 20-30 per cent tungsten with iron, used as an additive in the manufacture of tungsten-bearing steels.

Resources

Domestic resources

Tungsten occurs in south-west England and in Cumberland and has been produced on a limited scale in both areas. In south-west England, which is by far the more important area, it is generally associated with tin in the upper part of the tin zone. Some of the more important lodes and alluvial deposits, which have been worked in and around the granite masses of Carnmenellis, St Agnes, St Austell, Bodmin and Dartmoor, are noted below and are indicated on Fig 1.

Carnmenellis South Crofty, Tincroft, East Pool, Peevor, Killyfreth, Wheal Busy and other mines produced wolframite as a by-product of tin and other minerals. The wolframite generally occurs close to the contact of granite and killas (country rock) at depths between 275 m and 365 m from the surface, in lodes consisting of networks of veinlets infilling spaces between fragments of barren rock. These have been known to yield upwards of 135 kg of wolframite and cassiterite per tonne over stoping widths of as much as 3 m. In the South Crofty Mine some wolframite has been obtained from 'floors', the local term for flat-lying pegmatitic lodes. In the East Pool section of the mine a continuation of the Roger's lode, known to be tungsten-bearing, may be capable of yielding substantial quantities of wolframite. Some prospecting has recently been undertaken in the old Nancegollan Mine, on the western margin of the granite, where at least six tin-tungsten lodes are known. An attempt to open up the mine was abandoned in 1928 as a result of the economic depression.

St Agnes Several attempts have been made to mine the tin-tungsten deposit at Cligga Head where the partly kaolinised apex of a granite cusp is traversed by a swarm of greisen-bordered, wolframite-bearing quartz veins. In an investigation prior to the Second World War it was concluded that the veinlets were grouped in three more or less vertical zones each between 6 and 12 metres wide averaging about 5.5 kg per tonne mixed wolframite and cassiterite. In 1941 sampling was undertaken on behalf of Non-ferrous Mineral Development Limited, established by the Ministry of Supply, to ascertain whether or not open-cast mining would be feasible but it was concluded that the grade, about 1kg per tonne of mixed tin and tungsten trioxide, was too low for economic extraction at that time. Underground mining of the richer zones was carried out by Rhodesian Mines Trust Limited between 1939 and 1945.

St Austell The Castle-an-Dinas deposit, which lies to the north of the St Austell granite mass, is unique in being the only lode in Cornwall to have been worked exclusively for wolframite. There is a general absence of other valuable minerals, certainly in economic quantities. The lode was discovered in 1915 and mining was continued, with breaks during periods of low tungsten prices, until 1958. It varies from 0.3 to 1.8 m wide, averaging 0.9 m, and has been productive over a length of 550 m. Since its inception the mine recovered about 13 kg of wolframite per tonne of ore raised, and production from 1938 until it closed ranged between 180 and 250 tonnes of concentrate per year.

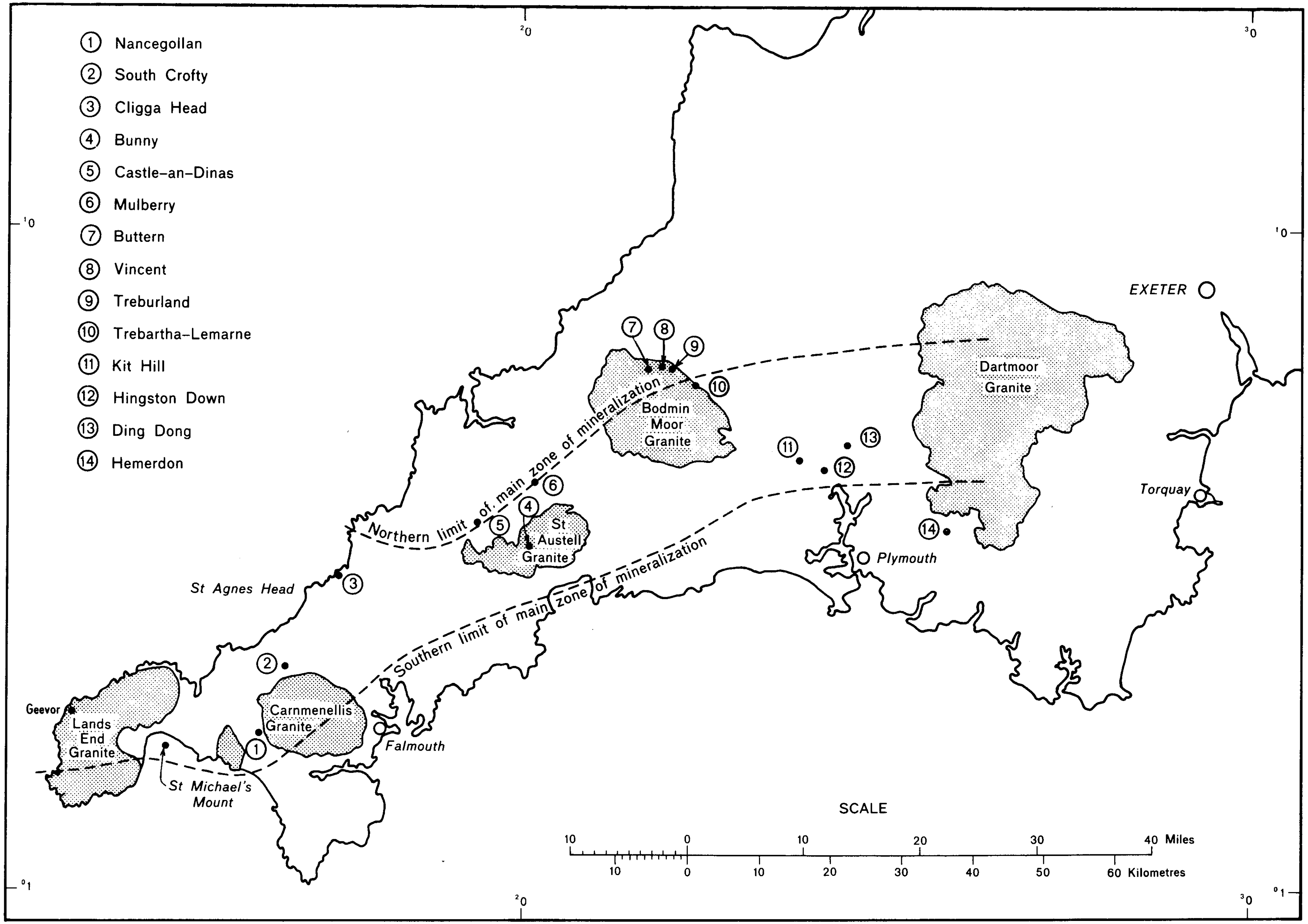

Fig. 1. Principal workings from which tungsten has been produced in south-west England

Overall recovery was reported to have been about 75 per cent to produce 13.4 kg of wolframite concentrate (60 per cent WO_3) per tonne of ore. Grade of ore was therefore moderately high at about 1.1 per cent WO_3. The lode was still productive when work ceased but nothing is known of the quantity of ore remaining. Some reports suggest that significant amounts of ore may still exist in northern extensions of the lode.

The Bunny Mine, about 2½ km south-west of Bugle, is reported to have produced somewhat less than 100 tonnes of wolframite concentrate up to 1918. Some wolframite has been recorded in the tin stockwork at Mulberry open-pit, but its distribution is patchy.

Bodmin Moor Along the north-eastern edge of the granite, and in the granite itself, a number of lodes and alluvial deposits have yielded wolframite. At Vincent Mine near Altarnun wolframite was regarded as a contaminant of the tin ore during the operations in the period 1881 to 1892, but the mine was re-opened to work both tin and tungsten in 1912 and is reported to have produced about 75 tonnes of wolframite annually before closing in 1920. Another small producer was Hawk's Wood Mine, operated by the Pena Copper Co, which closed in 1958. Alluvial deposits occurring in this area are reported to be up to 4.25 m thick and to contain 57,000 cu m grading between 1.2 and 3 kg of mixed cassiterite and wolframite per cu m. These deposits have been worked intermittently during this century, but apparently without success.

At Halvana, also near Altarnun, quartz stringers carrying sporadic tungsten values were worked to produce some 8½ tonnes of wolframite in 1916 and 1917. Treburland Mine to the SSE of Altarnun yielded a little wolframite as a by-product of tin during the two World Wars. Wolframite occurs in the dumps at the Trebartha Lemarne Mine and it has been suggested that the property may have further potential. On Bodmin Moor, eg at Buttern Hill, thin alluvial and eluvial deposits have yielded small amounts of wolframite; trials in these deposits over a wide area are variously reported to have indicated as much as 7 kg of cassiterite and wolframite per cu m. Several tungsten-tin lodes are also known in this area but values appear to be very patchy.

Callington-Gunnislake The mines east of Callington, eg Kit Hill United, produced over 100 tonnes of wolframite at the beginning of the century. In this area wolframite is widely distributed in tin lodes, veinlets and greisenised granite, but values are sporadic and nowhere are true stockworks known to be developed. The lodes in the neighbouring Gunnislake area, notably Hingston Down, were first worked for copper, but later were mined for tin and tungsten and produced about 600 tonnes of wolframite concentrates until working ceased in 1917; the lodes average 1 to 17 per cent of tin and tungsten minerals. At Frementor Mine a lode worked during the First World War is reported to have produced over 11,000 tonnes of ore grading 6.25 kg cassiterite and 1.8 kg wolframite per tonne, but attempts to restart the mine between 1925 and 1929 were unsuccessful; wolframite is patchy in distribution and is said to die out in depth. The old Ding Dong Mine was investigated by Non-ferrous Minerals Development Limited between 1942 and 1944. Values of 1 per cent combined cassiterite and wolframite in the ratio 2:3 were recorded. Other mines in this region, including Hawkmoor, Bedford United and Drakewalls, were primarily tin and copper producers but sold some by-product wolframite from time to time.

Dartmoor A stockwork of greisenised tin-and tungsten-bearing veinlets occurring in a granite boss at Hemerdon is the only known wolframite prospect of any importance near Dartmoor. The body was worked for both metals during both the First and Second World Wars (see below). In 1951 reserves to a depth of 18 m below surface were estimated to be about 4½ million tonnes grading 0.94 kg WO_3, and 0.24 kg tin per tonne, although recent re-assessment based on sampling data obtained before the Second World War suggests that reserves to the same depth are of the order of 5 million tonnes grading 1.78 kg WO_3 and 0.49 kg tin per tonne. The mineralisation has not been bottomed and both the depth and lateral extensions of the deposit are unknown. A number of tin-tungsten lodes in the vicinity were worked for tin during the 19th century.

On St Michael's Mount a stockwork of greisenised veins containing both wolframite and cassiterite has been described as 'subeconomic'. While there is a possibility that lodes occur to seaward, these, if they exist, are more likely to be of interest for their tin, rather than for their tungsten, content.

In *Cumberland*, a United Kingdom subsidiary of World Wide Energy Co Limited of Calgary carried out pre-production trials (see page 8) at Carrock Mine in 1972. This mine was worked in the 19th century and also during the periods 1901 to 1905, 1908 to 1911, 1913 to 1919 and 1942 to 1943. Three main tungsten-bearing quartz veins ranging up to 1 m wide traverse granite, slates and gabbro. The most important of the lodes was thought to contain at least 21,000 tonnes of ore grading 1.29 per cent WO_3 when development by Non-ferrous Minerals Development Limited was abandoned in 1943 following a rapid improvement in the supply position. The full potential is unknown but available reports suggest that considerably larger reserves could be established.

There may be further scope for new discoveries of economically viable tungsten deposits within the regions described above. Prospects for the discovery of workable deposits in other areas of the UK would seem to be poor although a successful outcome to some of the geochemical prospecting work currently being carried out over large parts of the country cannot be ruled out.

The physical characteristics of wolframite are such that it is unlikely to survive transport to form placers of the kind in which cassiterite, for instance, occurs. The outlook for the discovery of unconsolidated submarine deposits, capable of being worked by dredge, is therefore poor.

Exploration and development

The rapidly fluctuating price of tungsten has tended to discourage small producers and on no single property are known reserves sufficiently large to support the employment of large-scale, cost-saving techniques.

Nevertheless, in the last fifty years numerous attempts have been made to mine tungsten in south-west England, both by private companies and government sponsored organisations. Perhaps the most interesting of the deposits to have received attention is that at Hemerdon, south of Dartmoor, where mineralisation was discovered in 1916 as a result of prospecting under-taken on behalf of the Ministry of Munitions. A mill with a capacity of 400 tonnes per day commenced operations in February, 1919, and treated 16,000 tonnes of ore before being forced to close due to adverse economic conditions later in the same year. The property received little further attention until

1935 when a prospecting programme was initiated by the Hemerdon Syndicate, British Mining Corporation, which investigated the deposit by means of shafts and crosscuts to a depth of 18 metres below surface. The results were sufficiently encouraging to justify the formation of an operating company, Hemerdon Wolfram Limited, and the erection of a 250 tonnes per day capacity mill which started production in 1941.

Later in that year an arrangement between Hemerdon Wolfram Limited and the Ministry of Supply enabled the latter to undertake a comprehensive sampling programme with the object of installing a larger capacity mill to meet wartime demand. Assignment of the lease to the Ministry of Supply followed in 1942 and a 3,000 tonnes per day mill was erected by Non-ferrous Minerals Development Limited. Until the completion of the larger plant in October 1943, the original mill continued to operate at an enlarged capacity of 400 tonnes per day, treating 90,000 tonnes of ore with a recovery of 1.09 kg of 65 per cent WO_3 concentrate and 0.20 kg of 65 per cent tin concentrate per tonne. The larger mill, beset by problems arising from hasty design and the use of unskilled labour, operated for only 71 per cent of available time at two-thirds* capacity and closed in June 1944 due to a decreased requirement for domestic ore and high priorities for labour elsewhere. During the eight months of operation it had processed 205,000 tonnes of ore to yield 184 tonnes of mixed wolframite and tin concentrates, the average yield being about 0.59 kg of 65 per cent WO_3 concentrates and 0.14 kg of 65 per cent tin concentrates per tonne. The overall cost of wolframite produced is reported to have been approximately 190/- per unit in the monetary values of that time.

In 1949, the Westwood Report recommended that no further operation be undertaken until a re-assessment of the orebody had been carried out. The sharp rise in prices associated with acute shortages resulting from the Korean War focussed attention on the property again. Subsequently, reports commissioned by the Government suggested that the wartime mill, suitably modified, would be capable of producing 342 tonnes of WO_3 and 65 tonnes of tin a year from 500,000 tonnes of ore. While tests were being completed, however, the price of tungsten collapsed and it was decided that Government operation of the mine would not be justified. After unsuccessful negotiations to dispose of the mine as a going concern it was passed back to the owners of the mineral rights. The mill was disposed of by the Ministry in 1959 and removable machinery put up for sale. The property was leased by the owners of the mineral rights to Richardson Mining Associates, a Canadian enterprise, in 1970.

Recently prospecting activity in Cornwall and Devon has greatly increased, but the search has not been specifically directed towards tungsten. One of the most active companies in areas where tungsten is known to occur has been International Mine Services Limited in the Gunnislake-Kit's Hill district, between the granite masses of Bodmin and Dartmoor, and at Cligga Head.

The Carrock property was leased to a Canadian company, World Wide Energy Co Ltd of Calgary whose United Kingdom subsidiary, World Wide Energy (UK) Limited, installed a mill and commenced pre-production trials in June, 1972. In August, however, all work on the mine was abandoned. It is understood that mill testing was proceeding satisfactorily just prior to closure:

* L G Brown reports that throughput never, in fact, exceeded 1,500 tpd and averaged only 850 tpd.

Secondary sources

A review of domestic resources of any metal must take into account the existence of substantial quantities of secondary materials suitable for re-circulation. Large-scale recovery of secondary tungsten as metal is not practicable as a large proportion of the tungsten consumed in the United Kingdom is used as an alloying addition to steels; these can, however, be reclaimed and recycled without separation of the tungsten. In the United Kingdom tungsten metal scrap and residues are currently used for the manufacture of tungsten melting base which is preferred to ferro-tungsten by some special steel manufacturers because of its high solubility and the fact that its melting point is very close to that of the steels. Tungsten carbide is recovered from tool tips and high speed tungsten grindings but the recovery of tungsten metal from non-ferrous alloy scrap is generally not undertaken.

It is unlikely that substantial amounts of wolframite exist in old mining dumps, largely because, prior to this century, the mineral was regarded as a contaminant of tin ore and was avoided in mining owing to difficulties in separation. In the last fifty years ore dressing techniques have been so improved that there is little prospect of recovery of large amounts of wolframite from dumps originating during that period, although it is understood that Hydraulic Tin Ltd produces small quantities of wolframite from dump material.

Overseas resources and stockpiles

The most important resources of tungsten are in China, USA, North Korea, South Korea, Bolivia, Burma, Australia, Portugal and, probably, USSR. The reserve figures shown in Table 1 are very general approximations and are intended merely to put the world position in perspective. In 1970 the world's leading producers were China, USSR, USA, South Korea, Bolivia, North Korea, Portugal, Canada and Australia in that order.

Table 1 World reserves and production of tungsten

Tonnes W content

	Reserves	*Production, 1970*
Australia	11,000	1,264
Bolivia	39,000	1,879
Brazil	18,000	936
Burma	32,000	274
Canada	11,000	1,386
China	953,000	7,100 *(c)*
Korea (North)	*n.a.*	2,220
Korea (South)	46,000	1,600
Malaysia	15,000	75
Portugal	10,000	1,475
USA	79,000 *(a)*	4,531
USSR	12,000	6,580 *(c)*
Other *(b)*	48,000	2,600
Total	1,274,000	31,920

(n.a.) Not available
(a) Calculated to be workable at or below $43 per s.t.u. ($47 per tonne unit)
(b) Distributed among Argentina, France, Japan, Laos, Mexico, North Vietnam, Peru, Rhodesia, Spain, Thailand and the United Kingdom.
(c) Estimate

Sources: Reserves: US Bureau of Mines
Production: Statistical Summary of the Mineral Industry

Total world production in 1970 was estimated at 40,000 tonnes WO_3, containing about 31,900 tonnes of tungsten.

Tungsten production in the Free World is largely linked with production of other metals, notably molybdenum and tin. For example, in the USA a substantial quantity is produced as a by-product of molybdenum mining and in Bolivia and Burma it is produced jointly with tin. The supply of tungsten is therefore determined not only by current price, but also by factors concerned with the production of associated metals.

One of the major sources of supply to the Free World in recent years has been the US General Services Administration Stockpile, accumulated during the early and middle 1950s when United States policy dictated that sufficient stocks of essential raw materials should be held within the USA to withstand a period of protracted hostilities. The tungsten stocks are held mainly in the form of mineral concentrates of varying grades, but include some tungsten carbide and tungsten metal powder. Disposals of tungsten from the US stockpiles began in 1963 and have since had a significant effect on markets, particularly during 1969 and 1970 when sales by China were at a low level. The relevant figures are as follows:

	1963	1964	1965	1966	1967	1968	1969	1970	1971
				tonnes, tungsten content					
Stockpile disposals	190	344	458	3,719	2,923	1,438	17,408	6,834	626
Stocks remaining at end of year			88,856	85,838	82,625	80,943	73,577	60,517	59,900

Towards the end of 1969 heavy buying by European merchants and consumers helped to run down the stockpile material available for purchase, whereupon an export ban was imposed. A further release of 8,029 tonnes contained tungsten authorised in January 1970 was restricted to domestic use, and in July 1970, as a result of an application to Congress, a further 30,844 tonnes contained tungsten, representing all excess concentrate, was released with limited amounts for export. Disposals from the stockpile in 1970 totalled 6,834 tonnes. The current stockpile objective is 25,245 tonnes. Much of the large quantity sold from US Government stocks in 1969 is believed to be held by traders for sale as opportunity occurs.

Strategic stocks of tungsten concentrates formerly held in the United Kingdom were run down over a period of ten years, sales sometimes being suspended for long periods to avoid disruption of the market, until they were finally exhausted in 1966.

The existence of the US stockpiles and the great potential weight of Chinese material which has overhung markets for many years may be seen as factors which have tended to discourage prospecting and the development of new deposits in the Free World.

Land use

In the past tungsten has been obtained chiefly as a by-product from mines which were primarily tin producers. As South Crofty tin mine in Cornwall is the only surviving producer in the United Kingdom, the amount of surface land devoted to the working of tungsten may be regarded as insignificant. Carrock Mine is in the Lake District National Park.

Due to the depth and narrow width of workings in lode mines and the competence of the wall rock, underground mining of tungsten does not normally give rise to subsidence.

The annual return of derelict land statistics sent by Cornwall County Council to the Department of the Environment at the end of 1970 gave a total of 6,474 hectares of derelict land of which 698 hectares justified treatment. This total of almost 65 sq km, comprising 5,499 hectares of spoil heaps, 322 hectares of excavations and pits and 653 hectares of other forms of dereliction, excludes china clay tips and is predominantly the result of former mining, mainly for tin and copper. Of the 5,499 hectares affected by spoil heaps only 679 hectares were considered to justify treatment. Much of the mine waste contains metallic compounds, including arsenides, which contaminate the soil so that much of the dereliction is at present regarded as permanent. However, the economic and social costs attributable specifically to current working for tungsten minerals are negligible. Future operations would have to meet conditions laid down in planning consents.

Although some of the problems arising from the accumulated waste might be overcome by its disposal for construction purposes, the scope is limited. Fresh, unmineralised granite from South Crofty mine is crushed and sold as aggregate in West Cornwall but south-west England has an abundance of waste, particularly for fine aggregate, produced from the china clay workings, and waste from tungsten mining would have to compete for local markets. Furthermore the use of waste from the old tips is limited due to the presence of metalliferous compounds or residues which may be toxic.

Uses

Broadly, the forms in which tungsten is used are as follows:

Tungsten carbide.

Ferrous alloy tool steels, including high-speed steels.

Other tungsten-bearing steels including magnet steels, stainless steels, acid-resisting steels and valve steels.

Non-ferrous tungsten alloys and composites, including stellite-type alloys, tungsten-molybdenum, nickel-tungsten, copper-tungsten, silver-tungsten, tungsten-nickel-copper and lead-tungsten.

Tungsten metal.

Tungsten compounds such as sodium tungstate, tungstic oxide, tungsten acid and sodium and ammonium paratungstate, cadmium tungstate, phospho-tungstic acid etc.

Tungsten carbide

Tungsten carbide, WC, one of the hardest materials known, is made in powder form by the chemical combination of tungsten metal powder (99.8 per cent W) and finely divided lampblack. Cobalt is added as a binder and the mixed material is compacted to the required shapes before sintering. Tungsten carbide is used extensively for lathe tools, milling cutters, drills, reamers, and teeth for circular saws. It is also used for dies for drawing wire, rod and tubing, and for punches and dies for blanking, stamping and forming. Tantalum carbide, niobium carbide, titanium carbide, or combinations of these, are sometimes added to the tungsten carbide-cobalt mixture to lower the coefficient of friction and produce grades suitable for cutting steel. Tungsten carbide tips are used on cutters of coal mining machines, rock drills, masonry drills and oil well drill bits. Tungsten carbide parts are incorporated into many types of machines to resist abrasion and wear. Other applications are in motor car tyre studs and armour-piercing projectiles.

Tungsten-bearing steels

One of the most important applications of tungsten is in the manufacture of high-speed tool steel, the main characteristic of which is that it maintains a sharp cutting edge at high temperature. It is frequently used in combination with other alloying elements eg chromium, nickel and vanadium to impart high-temperature strength. Another important tungsten ferrous alloy is tungsten finishing steel (1.35 per cent C, 3 to 4 per cent W). Some tungsten has been employed in acid resisting steels and die steels and, with chromium and cobalt, in magnet steels. Alloys are generally manufactured by adding tungsten in the form of tungsten melting base, ferro-tungsten (80 to 85 per cent W) or tungsten metal powder (98 to 99 per cent W). Scheelite is also used for this purpose, but not in the United Kingdom.

Non-ferrous alloys

'Stellite' type alloys containing nickel-cobalt-chromium-tungsten are used for making high-speed cutting tools and wear-resistant parts, such as crushing rolls. They are highly resistant to corrosion. Similar alloys are used for turbine blades, engine valves and other components where strength at high temperatures is required.

Metallic tungsten

One of the earliest, and still one of the most important, uses of high purity metallic tungsten is in lamp filaments. An equally extensive application, because of its good electrical conductivity and resistance to mechanical wear, is in electrical contacts, either in the form of pure metal or in combination with copper or silver. Its high melting point and low vapour pressure enable tungsten to resist the destructive effect of arcing as circuits are broken. Tungsten oxide resulting from the heating effect of the arc vapourizes, leaving a clean metallic surface.

Pure tungsten contacts are used universally in motor car and aircraft ignition circuits, in vibrators, inverters, voltage regulators and numerous other devices in which contact operation is rapid. Tungsten discs are also used for spark gaps in some types of high-frequency generators.

Tungsten is used for anodes or targets in X-ray tubes. The high penetration of the short wavelength X-rays produced from a tungsten target is useful in deep therapy and in radiography. The high melting point and low vapour pressure of tungsten make possible a high concentration of energy at the focal point of the target. Tungsten is also used for heaters and filaments in electronic tubes. The pure metal has high emissive qualities, which can be increased by the addition of thorium. Tungsten wires and rods are used as electric furnace windings and as seals through the 'hard' borosilicate glass used for many types of electronic tubes, since tungsten possesses almost the same coefficient of thermal expansion as the glass, and the slightly oxidised surface of the metal makes an excellent bond with it.

Tungsten electrodes are used to sustain the arc in inert gas or atomic hydrogen arc welding where the high melting point and low vapour pressure are useful properties. These properties of tungsten are also advantageous in the application of coatings, both metallic and non-metallic, which are produced by vapour deposition in vacuum. The coating material, eg aluminium in the case of mirrors, automobile headlights, or plastic ornaments, is applied to a tungsten wire 'filament'. When the wire is heated the aluminium is vaporized and deposited as a thin, smooth coating on the exposed surface of the work.

Tungsten is useful for applications in which high density and strength are required in a relatively small space. These include high-speed rotors, such as those used in gyroscopes, counterweights, vibration damping devices and containers for radio-active materials. Simple shapes can be made from pure tungsten, but small amounts of copper and nickel are added where finish machining, threading or tapping are necessary.

Tungsten compounds

Tungsten compounds, mainly sodium tungstate, tungstic oxide, tungstic acid and sodium and ammonium paratungstate, are used widely in the chemical industry. For example, sodium tungstate is used as a mordant in calico and silk dyeing. Tungstic acid is used by the ceramic industry for imparting a yellow colour to glass and porcelain. Complex phosphomolybdotungstic acids are employed in the manufacture of pigments which are used in inks, paints, rubber and paper.

Factors affecting use

The only available figures for consumption of tungsten by end use for the United Kingdom are those for tungsten consumed in steel manufacture (see page 35). The decline in the use of tungsten in steel has been offset to some extent by growth in consumption for other uses. There is for instance a growing demand for the purer forms of tungsten metal, particularly in powder form, mainly for use in high temperature alloys and coatings.

In the last 20 years tungsten carbide has replaced tool steels in many industrial operations involving the cutting and forming of metals. As advances are made in the manufacture of carbides it seems certain that their uses will be extended. Production costs of cutting and forming steel with carbide are reported to average only about 80 per cent of costs where high-speed steel is used. Similarly, during the 1950s carbide drill bits almost completely replaced steel bits in hard rock mining and quarrying. The life of carbide-tipped tools for these purposes is many times that of steel bits, and considerably higher drilling speeds are possible. The growth of flame spraying techniques is likewise leading to greater demands for carbide powders. While the use of carbide studded tyres is unlikely to become as popular in Europe as it is in North America, there may be scope for further growth.

The consumption of tungsten per unit of tool steel has tended to decline owing to large scale substitution by molybdenum. This trend has been brought about by several factors, including the preference of manufacturers in growth industries (eg motor cars) for molybdenum steels due to the relatively greater price stability of molybdenum, and the fact that, except in the highest grades of tool steels, the addition of a given proportion of molybdenum has the same effect as twice that amount by weight of tungsten. Consumption of tungsten-bearing tool steels is directly related to demand for bulk steels as the alloy is primarily required for cutting and forming steel products. The introduction of molybdenum tool steels in World War II and in the Korean War reduced the strategic importance of tungsten in this field. Militarily, the emphasis is now upon armour-piercing projectiles, cored or tipped with tungsten carbide.

Specifications

Until recently, concentrates of wolframite or scheelite were normally traded on the basis of long ton units of contained tungsten trioxide, WO_3 (1 long ton unit containing 17.765 lb of tungsten metal). The tonne unit, containing 7.93 kg of tungsten, has now been adopted.

The normally acceptable standard grade concentrate contains 65 per cent WO_3. The *Metal Bulletin* price, for example, is quoted on the basis of the following analysis:

	per cent
Tungsten trioxide	65
Tin	0 to 1.00
Arsenic	0 to 0.20
Phosphorus	0.03 to 0.08
Sulphur	0.20 to 0.75
Copper	0.08 to 0.40

However, the specifications set by consumers, particularly with regard to impurity limits, vary widely according to the purpose for which the concentrate is required. A typical analysis of wolframite concentrate used by one United Kingdom consumer is as follows:

	per cent
Tungsten trioxide	73.3
Aluminium oxide	0.25 to 0.5
Silica	0.25 to 0.5
Tin	1.5 (maximum)
Niobium/tantalum pentoxide	0.1 to 0.5
Sulphur	0.5
Bismuth	0.1
Molybdenum	0.01 (maximum)
Phosphorus	0.01 to 0.04
Calcium oxide	0.16 to 0.5
Vanadium	0.02
Lead	0.3
Arsenic	Trace to 0.1

The impurities in tungsten concentrates are mainly of two types, one of which passes through the process and reports in the end product while the other tends to interfere with processing without contaminating the end product. The first type includes molybdenum, antimony and bismuth and the second arsenic, phosphorus and sulphur. Tin, copper and manganese are detrimental in high-speed steels but do not usually give rise to problems in chemical plant. Arsenic, phosphorus and silicon tend to result in the formation of colloidal precipitates of tungstic acid leading to significant loss of tungsten.

In the United Kingdom, the larger users of concentrates for the manufacture of ductile tungsten for electric lamp filaments prefer scheelite containing not less than 70 per cent WO_3, but may use wolframite because of its more ready availability. The percentage limits for objectionable impurities are tin oxide 0.1, iron oxide 0.5, manganese oxide 0.5, arsenic oxide 0.05, molybdenum oxide 0.05.

In the manufacture of tungsten-bearing tool steels, tungsten is added in the form of tungsten melting base, consisting of 20 to 30 per cent tungsten in iron, or ferro-tungsten. Consumers of ferro-tungsten normally specify a content of between 75 and 85 per cent tungsten, and between 0 and 0.1 per cent carbon. Typical analyses are as follows:

	per cent	*per cent*
Tungsten	82.5	81.5
Silicon	0.50	0.57
Carbon	0.03	0.05
Sulphur	0.03	0.03
Phosphorus	0.03	0.02
Manganese	0.03	0.28
Tin	0.02	0.05

Over 300 industrial specifications exist for tungsten-bearing ferrous and non-ferrous alloys. Examples of some of the more important alloy compositions are as follows:

High-speed steel (tungsten type, T1)	18W:4Cr:1V.
High-speed steel (molybdenum type, M2)	6W:5Mo:4Cr:2V.
'Stellite'-type alloy	10W:35Co:35Cr:1.5-2C.

Tables of the various compositions of the high-speed steels are given in BS4659:1971 *Tool Steels,* copies of which are available from the British Standards Institution.

Tungsten carbide is normally used in the form of powder cemented by cobalt, with or without the addition of niobium, tantalum and titanium carbides. Numerous specifications exist for mixtures of carbides and binder and the British Hard Metal Association has introduced a system of classification of hard metal grades (*BHMA Technical Publication No 1* of 1967). The National Coal Board has drawn up detailed specifications for mining tools in collaboration with the British Mining and Quarrying Tool Association.

Specifications for tungsten metal powder and tungsten chemicals vary widely. The standard hydrogen-reduced powder contains 99.9 per cent tungsten. Typical analyses of carbon-reduced powders are:

	per cent	*per cent*
Tungsten	98.4	99.3
Silica	0.25	0.25
Iron	0.20	0.10
Carbon	0.05	0.03
Sulphur	0.02	0.02
Phosphorus	0.01	0.01

Typical analyses of, and specifications for, many tungsten products are readily available in the literature but precise information on the maximum levels of deleterious constituents acceptable to consumers of tungsten concentrates is difficult to obtain, partly for reasons of confidentiality, but also because consumers must maintain a certain flexibility in their requirements to enable them to respond to market conditions.

Price and cost

Since the United States periodical *E/MJ Metal and Mineral Markets* (now *Metals Week*) ceased to publish a New York price for tungsten concentrates early in 1966, the only regular prices have been those published by Reuters and the London *Metal Bulletin*. The *Metal Bulletin*, by enquiries to producers, consumers and merchants about current deals throughout the world, but particularly in Europe, formulates a price range which is used as a basis for many commercial contracts, mainly for European delivery. The *Metal Bulletin* price for tungsten concentrates was £14.10-£15.20 per tonne unit contained

WO_3 c.i.f. on 3rd October 1972. This price is quoted on the basis of 'standard grade' concentrates (see p 14) of wolframite. It is generally true that scheelite, even with a low molybdenum content, is sold at a discount, although, in times of shortage and high prices, the price of high grade scheelite may equal that of standard concentrates of wolframite, while discounts for high molybdenum scheelite and low grade wolframite may remain wide. Discounts for scheelite in some contracts are linked mathematically to the wolframite price.

Since April 1972 an alternative price indicator, an index of tungsten ore prices compiled by three European tungsten carbide producers, has been published in the *Metal Bulletin.* This covers wolframite and scheelite individually and gives for monthly and six monthly periods the average price (per tonne unit of WO_3) at which purchases by them have been concluded and at which shipments have been invoiced.

In normal trading, penalties are negotiated for impurities above certain limits. The final price is sometimes based on the standard 'Hamburg' contracts A, B and C or buyers may negotiate specifications and penalties to their own requirements. Although the 'Hamburg' contracts are now relatively unimportant they illustrate the complexity of dealings and may be summarised broadly as follows:

Contract 'A' covers Chinese concentrates with a minimum of 65 per cent WO_3 and maxima of 1.5 per cent tin and 0.2 per cent arsenic. Penalties are clearly defined in the contract if the concentrate fails to meet specifications.

Contract 'B' is similar to Contract 'A' but covers wolframite concentrates from sources other than China with similar penalties but with a different 'force majeure' clause.

Contract 'C' covers ore of the same minimum WO_3 content and maximum arsenic but the maximum permissible tin content for good delivery is only 0.5 per cent. However, it includes a clause to the effect that if the ore is veryclean, having under 0.3 per cent tin the buyer must pay a bonus to the seller of 5p per unit of WO_3 and per tonne of material net dry weight for every 0.1 per cent under 0.3 per cent tin.

On all three contracts, fixed penalties are incurred if the WO_3 content is under 65 per cent (but above 55 per cent) and if the arsenic content is up to 2 per cent; if these specifications are not met the buyer may reject the consignment. Materials containing 1.6 per cent tin must be accepted as good delivery but tin exceeding this figure is penalised for each 0.1 per cent over 1.5 per cent by an agreed amount being deducted from the unit price for the WO_3. All penalties and the value of the ore are based on net dry weight. Impurities such as molybdenum, phosphorus, bismuth and sulphur, not covered in the contract, may affect the saleability of the concentrate and its value.

Prices of metal powder, ferro-tungsten and carbide on 3rd October 1972, were as follows:

Tungsten powder 98 to 99 per cent W	– £2.99 per kg contained W.
Ferro-tungsten 80 to 85 per cent W	– £2.18 to £2.25 per kg contained W.
Tungsten carbide powder (1 micron)	– £4.668 to £5.331 per kg.

The prices of tungsten concentrates (see Fig 2 and Table 2) and, to a lesser extent, tungsten products have always fluctuated greatly, reflecting competition for concentrates during periods of rapidly rising demand, particularly during wars, against a background of relative inelasticity in supply. Instability has been accentuated by uncertainties surrounding sales by China. Chinese trade in tungsten (and other commodities) is conducted largely at the bi-annual Canton Trade Fair, normally held in April and October. With the dwindling sales of recent years, and the lack of advance information on the amounts likely to be offered, the twice yearly wait for the Fair has a disruptive effect on the market. Attempts to stabilise the price of tungsten, including the establishment of an international committee (see Appendix), have not so far met with success.

Until recently sales from the United States General Services Administration stockpile surplus tended to influence prices towards stability but in late 1969 world shortage led to an embargo on the export of stockpile material from the USA. The price consequently rose rapidly, aided by heavy buying and lack of Chinese offers, to a peak early in 1970 but has since fallen due to the economic recession.

In the US domestic market producer prices apply. A price was established in 1966 at which sales are made from US Government stocks and this, in effect, provides an upper limit to the US domestic price. The price of US stockpile concentrate remained at $43 per short ton unit (£19.75 per tonne unit) from 1966 until the end of 1969. A revised programme for disposals was announced in October, 1970, whereby material restricted to domestic use only is released at an 'off the shelf' price while certain additional quantities, set aside for export, are sold on a sealed bid basis with a cut-off price equivalent to the domestic price, currently (October, 1972) $55.00 per short ton unit (about £25.00 per tonne unit).

Little information is available on the elements in the final price arising from the various processing stages. The price of the concentrates fluctuates rapidly and costs vary greatly from one mine to another throughout the world. Mining and milling costs for an equivalent underground tin operation might be about £7 per tonne of ore raised. Large scale open-pit mining might reduce costs to about £1.00 per tonne. It is worth noting that gross realisation from ore grading 1 per cent WO_3, assuming 70 per cent recovery would, at October 1972 prices, be about £10 per processed tonne, but would have been as high as £25 at the peak prices in early 1970.

Manufacturers of tungsten products are unwilling to give any breakdown of processing costs, but clearly one of their greatest difficulties is to maintain a reasonably stable price structure for their products despite wild fluctuations in tungsten ore prices.

It should be noted that processing costs are increased by the variation in quality and composition of concentrates from different sources but, while seeking material of a uniform and specific composition, manufacturers are frequently obliged to accept the optimum specification available on the market.

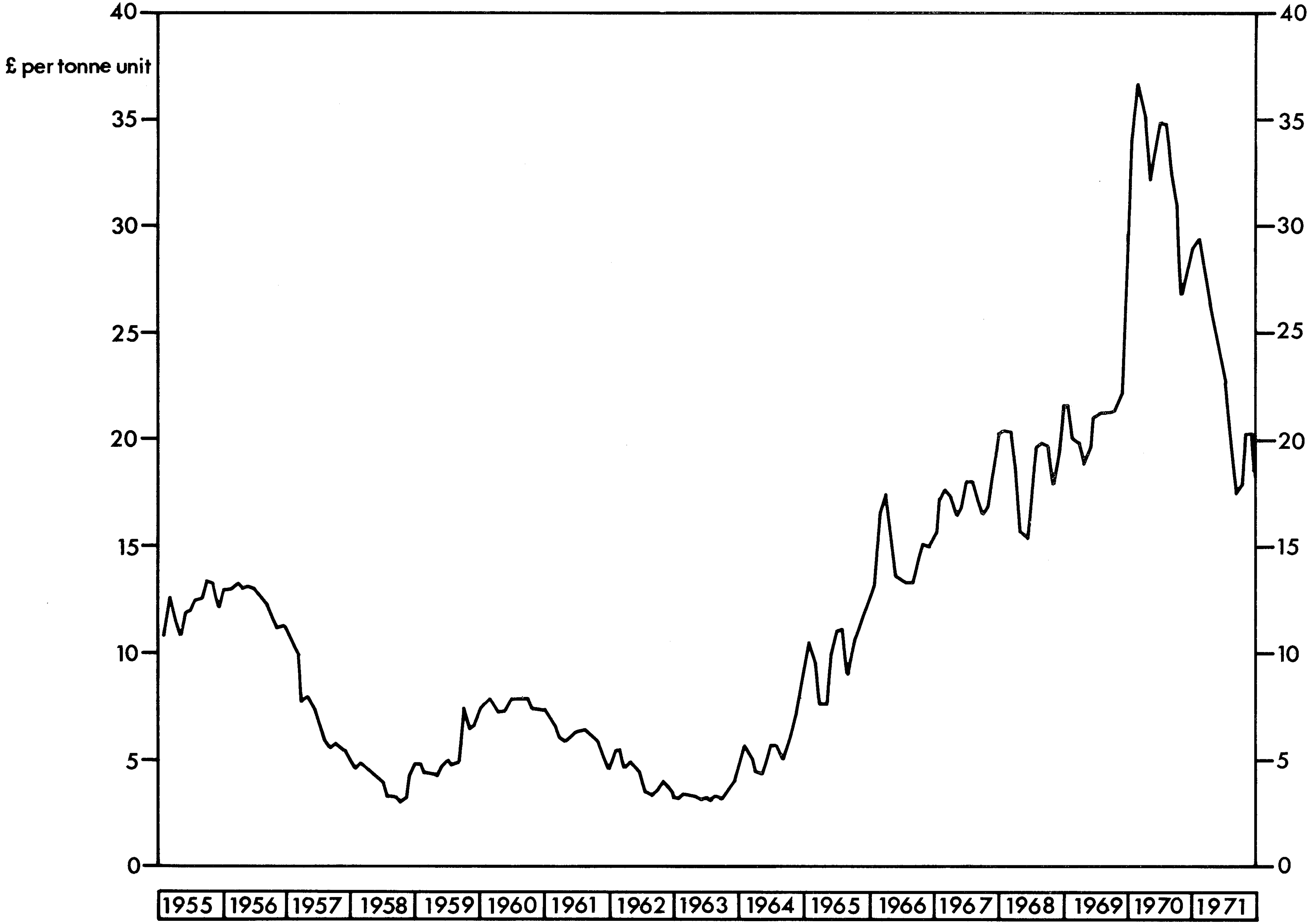

Fig. 2. Monthly average prices of tungsten concentrates in the United Kingdom, 1955-71

The high absolute price of tungsten is mainly attributable to the low grade of its ores, the small individual size of deposits, the high grade of concentrate demanded by consumers and the fact that the world's largest reserves are not open to private investment.

The element of cost attributable to the price of tungsten in any manufactured tungsten-bearing article varies very substantially. Between 80 and 90 per cent of the cost of metallic tungsten powder is attributable to the price of tungsten-in-concentrate, depending on the price of concentrates. Over half the price of high speed steel (18 per cent W) is represented by the cost of the tungsten addition. However, the cost of tungsten forms only a minute part of the cost of electric lamps as it has been estimated that 1 tonne of the metal is sufficient for about 10 million bulbs.

Table 2 London prices of tungsten concentrates

(65 per cent WO_3 basis, c.i.f. European ports)

Yearly average, 1955–1971

	£ per tonne unit		*£ per tonne unit*
1955	12.256	1964	5.836
1956	12.402	1965	10.276
1957	6.878	1966	14.644
1958	4.028	1967	17.592*(a)*
1959	5.389	1968	18.853
1960	7.596	1969	21.416
1961	6.046	1970	32.334
1962	4.194	1971	22.464
1963	3.459		

(a) 14.3% sterling devaluation, 19 November 1967

Monthly average, 1971

	£ per tonne unit
January	29.370
February	28.416
March	26.472
April	25.594
May	24.176
June	22.776
July	19.817
August	17.400
September	17.900
October	20.333
November	20.264
December	17.047

Sources: *Tungsten Statistics,* UNCTAD Committee on Tungsten
Metal Bulletin

Technology

Primary tungsten deposits, like those of tin, are invariably associated with granites, and occur in fissure and pegmatite veins, often with cassiterite, or in irregular masses, particularly at the contacts of granite and limestone. In England, tungsten minerals have mainly been mined from fissure veins. Common mining practice is to crosscut to the lodes from a shaft, drive along the lodes from the crosscut and extract the payable vein material (that is the ore) by overhand stopping. In some areas wolframite has been recovered from alluvial deposits by excavation and treatment of sands, and from stockworks by open-pit quarrying of, for instance, kaolinised granite containing tungsten-bearing veinlets. Wolframite occurring in pegmatites or 'floors' in the South Crofty Mine has been worked as part of the normal mining operation.

While lode ores may generally be regarded as valuable if they contain more than 0.5 per cent WO_3, factors other than ore grade, notably potential throughput and recovery, as well as impurities and mode of operation, are of equal importance.

Mineral dressing

As the densities of both wolframite (7.0) and scheelite (6.0) are high, the primary stages of mineral recovery invariably involve gravity methods of concentration. The most common types of separators used are jigs and tables although the sink-float process has been tried in some plants. For the recovery of values in fines, tilting frames and 'buddles' have been used in conjunction with tables. For low grade ores a pre-concentration step is frequently necessary; low costs and high capacities can be achieved with spirals and sluices.

High grade concentrates (65 per cent WO_3 or more) can be produced directly from simple ores by gravity processing. However, most tungsten ores contain other heavy minerals such as cassiterite, sulphides and iron oxides and in some ores wolframite and scheelite occur together, so that further processing is usually necessary before a marketable grade of concentrate can be produced.

Sulphides may be removed either by flotation or agglomeration tabling, the latter process being convenient when further grinding of the concentrate must be avoided in order to facilitate magnetic or electrostatic separation at a later stage.

The separation of wolframite from cassiterite, iron oxide and/or scheelite is usually achieved by the use of high-intensity dry magnetic separation. The magnetic properties of cassiterite are directly related to its iron content. Where the dark brown and black varieties of cassiterite have magnetic properties similar to those of wolframite the separation of the two minerals is difficult or impossible on a commercial scale. The cross-belt type of magnetic separator is commonly used, haematite or siderite being first removed by the permanent magnet followed by separation of the wolframite on the induced magnets. This machine is generally preferred to the induced roll separator but its application is limited to +200 mesh particles and its capacity is extremely low. For simple two-mineral separation, and for separation of finer fractions, the induced roll separator is superior.

Concentrates containing cassiterite and scheelite are treated by high-tension separators in which the non-conductors (scheelite) are easily separated from the conductors (cassiterite). Flotation of the scheelite from the finer fractions of concentrates is also possible using mixed fatty acid/sulphate collector systems at an alkaline pH.

Flotation can also be applied directly in the recovery of scheelite from fine ore fractions (if wolframite is not present), except where the concentrate is contaminated with apatite and calcite when a chemical leaching stage is required.

The physical processing of most tungsten ores is very efficient in the sand-size ranges, in which wolframite, scheelite and cassiterite can be separated with a high degree of selectivity.

The main problem associated with tungsten production is the high purity required for the final concentrate. Concentrates containing less than 65 per cent tungsten trioxide, that is equivalent to minima of 85 per cent wolframite or 81 per cent scheelite, are not normally acceptable. In addition a heavy penalty is applied to cassiterite content: concentrates assaying more than 1 per cent tin are often not marketable.

It is clear, therefore, that any problems associated with liberation and separation of the minerals may severely handicap the commercial viability of a tungsten deposit.

Extractive metallurgy

The extractive metallurgy of tungsten, only a brief account of which follows, may be divided into four stages.

Decomposition of the concentrate Wolframite concentrate (to which a certain amount of secondary material may be added), finely ground to 2 to 2.5 microns, can be treated by an alkali carbonate fusion process at 800^{o} to 850^{o}C, or by digestion with aqueous caustic, to form soluble tungstates and insoluble iron and manganese oxides or hydroxides. Variations of these processes employ digestion under pressure. Scheelite concentrates are usually treated with hydrochloric acid, yielding insoluble tungstic acid and water-soluble metal salts. There are many patents covering variations of these processes.

The purification of a tungstate before final conversion into tungstic acid can be carried out by several methods. Soluble tungstate may be recrystallized and treated to precipitate calcium tungstate which, upon reaction with hydrochloric acid, yields tungstic acid.

Impurities in crude tungstic acid can be removed by solution in an excess of ammonium hydroxide, followed by settling and filtration. On evaporation or neutralization of the excess ammonia, the tungsten is recovered in the form of insoluble ammonium paratungstate which can be further purified by crystallization and decomposed by heat to tungstic trioxide.

Among other processing techniques, solvent extraction has been applied successfully in the USA. The tungsten is extracted from an acid sulphate solution with a tertiary or secondary alkylamine and backwashed from the organic phase with ammonium hydroxide, thus precipitating ammonium paratungstate.

Preparation of a pure oxide The preparation of the tungstic acid used for reduction to metal, usually by treatment of soluble tungstate solution with an excess of strong hydrochloric acid, is carried out under carefully controlled conditions. The physical state of the acid, eg crystal size and purity, can determine the properties of the finished massive metal. The tungstic acid is thoroughly washed by decantation to remove soluble chlorides and then filtered, dried and milled to break up lumps. Ignition of tungstic acid or ammonium paratungstate produces an oxide ready for reduction to tungsten powder.

Reduction to a metal powder Hydrogen reduction of the oxide is used for the preparation of tungsten of the purity required for making ductile metal. Other reducing agents have been tried but leave contaminating traces which reduce the quality of the powder. However, there is a limited use for carbon-reduced tungsten as an alloying material by virtue of its lower cost. Careful control of the reduction process is necessary as the properties of tungsten metal powder are highly susceptible to the reducing environment.

Tungsten powder produced from a number of batches is usually blended before further processing.

Conversion of the powder to massive metal Tungsten powder is converted into solid metal by compacting into ingots which are heated by passage of an electric current, the ingots being made with steel dies in a two or three-way hydraulic press. Practical limitations are placed on the length of the ingot by its low green strength and by the engineering problems of press construction. The maximum cross-section of the ingot is determined by the problems of handling high amperages.

Ingots are friable after pressing but sufficient strength for subsequent handling may be imparted by heating to 900° to 1200°C in a reducing atmosphere, during which some impurities are volatilized and the oxide film on the particle surfaces is reduced. The green strength ingots are then sintered in a hydrogen atmosphere at a temperature of approximately 3000°C, the optimum temperature depending to some extent on the powder size and size distribution. This sintering operation is carried out in two stages. Initially the temperature is raised by specified increments of current to allow for the escape of volatile impurities while the ingot remains porous, and in the second stage the ingot is held at the maximum temperature for a specified length of time.

Ferro-tungsten manufacture

In the United Kingdom ferro-tungsten is manufactured from scheelite or wolframite, or mixtures of these in a ratio of about 4 parts wolframite to 1 part scheelite. Tin and arsenic are removed prior to processing by magnetic separation and roasting. Effective control of other deleterious elements is maintained by blending.

Reduction of tungsten concentrates is carried out by the thermit reduction process, the charge containing iron turnings or scale in addition to the reductant, i.e. ferro-silicon and aluminium, and the tungsten-bearing roasted material. Scheelite is self-fluxing but for wolframite such fluxes as hydrated lime or fluorspar are added.

Reduction takes place in a firebrick crucible banked with sand. When it is complete, the bulk of the slag is tapped off; later the metal is quenched in cold water to hasten cooling and facilitate breaking of the alloy.

Tungsten carbide manufacture

In the United Kingdom tungsten carbide is manufactured by mixing tungsten metal powder of a grain size suited to the end use of the carbide with the correct ratio of fine carbon powder. The mixture is pressed into bars which are slowly passed through electric furnaces at 1500 - 1600°C in a hydrogen atmosphere. The total carbon content of the finished material is controlled to between 6.05 and 6.2 per cent with free carbon not exceeding 0.1 per cent. For the manufacture of hard metal, tungsten carbide powder is mixed with cobalt and other additions in ball mills. The mixture is then pressed into required shapes with wax before presintering. Machining is carried out after the presinter and before final sintering.

Research

The trend of research is towards improving the performances of high-temperature, tungsten-bearing non-ferrous alloys and increasing the oxidation resistance of tungsten coatings at high temperatures. Research in aerospace applications is centred upon ultra-high temperature components. Considerable advances have recently been reported by a British company in depositing coatings of tungsten and tungsten carbide on metal and plastic surfaces by means of a plasma arc spray. The production of high-speed steels by powder metallurgical techniques is under investigation in the United Kingdom as well as in other countries.

Research into prospecting methods is being undertaken by major companies. The Radioactive and Metalliferous Minerals Unit of the Institute of Geological Sciences has conducted a limited amount of applications research on the value of portable radio-isotope X-ray fluoresence instruments both to the *in situ* determination of tungsten in underground workings and to the analyses of powdered rock samples. While the *in situ* analyses gave promising results, they were shown to be of only limited value in deposits in which the tungsten occurs sporadically in a quartz gangue. Further research would be necessary fully to assess the value of the technique in other types of deposit. The portable X-ray fluorescence technique is satisfactory for the determination of tungsten in powdered samples of low to medium tungsten content to an accuracy of 0.1 to 0.2 per cent tungsten, employing calibration standards of similar composition.

Since recovery of tungsten within the sand sizes is so effective by conventional methods, future mineral processing research is likely to be concerned mainly with treatment of finer fractions of ores. Machines such as the Bartles-Mozley Concentrator (developed by R H Mozley and financed by the National Research Development Corporation) are designed to treat large volumes of fine sizes, and are likely to be effective in recovering wolframite as well as cassiterite.

Flotation, the most efficient process for recovering fine scheelite under present conditions, is effective for most scheelite ores. The selectivity achieved in flotation testwork aimed at recovery of fine wolframite does not compare with that attained with scheelite.

Work on fused salt chemistry is included in the pyrometallurgy programme at the Warren Spring Laboratory. The aim of this project is to produce relatively pure metals, including tungsten, directly from concentrate by electrolytic reduction in fused salt media, thus by-passing a number of preliminary processing stages that are necessary at present.

Research on the processing of tungsten ores containing molybdenum would seem to be essential in view of the decreasing world availability of high grade tungsten ores. Molybdenum is a highly undesirable impurity which shortens the life of filament wire due to the ease with which it volatilises and consequently blackens the bulb. The presence of molybdenum may also shorten the useful life of contacts but is not necessarily disadvantageous. Its volatility may facilitate 'starting up' after the formation of a surface oxide film. Attempts have been made to apply solvent extraction technology to tungsten/molybdenum separation in the USA, but reports suggest that improvements in the existing process are required.

In the United Kingdom, perhaps the most pressing field of research lies in determining more precisely the extent of known occurrences and in the investigation of methods of optimising concentrate grade and recovery from the Hemerdon stockwork.

Production

Production of tungsten concentrates in the United Kingdom has been irregular and small, as shown in Table 3, total known production having amounted to only about 12,000 tonnes of concentrates containing about 8,000 tonnes WO_3. Production statistics are available from 1859: those from 1873 are summarized conveniently in the *Home Office, Chief Inspector of Mines Report,* for 1913.

Most of the tungsten concentrate produced in the United Kingdom has been a by-product or co-product of tin. Production of the mineral between 1914 and 1930 was dictated mainly by the activity of the tin mining industry in Cornwall and was adversely affected by the closure of many of the mines in the nineteen-twenties. After 1930 United Kingdom production largely reflected the output of Castle-an-Dinas Mine which closed during the price fall of 1957-58. During the Korean War very high prices, upwards of £25 per unit, encouraged interest in the alluvial deposits of Bodmin Moor and led to a reassessment of the capabilities of the 3000 tonnes per day mill at Hemerdon, but interest lapsed with falling prices during 1953-54. Tungsten concentrate is currently produced only as a by-product of tin mining at South Crofty Mine.

Table 3 United Kingdom: Production[1] of tungsten concentrates, 1901–1971

Tonnes of approximately 65% WO_3

1901 – 1910 (Annual average)	214	1937	129
1911	270	1938	221
1912	196	1939	157
1913	185	1940	203
1914	208	1941	130
1915	336	1942	174
1916	400	1943	210
1917	245	1944	362
1918	307	1945	112
1919	169	1946	90
1920	96	1947	67
1921	–	1948	40
1922	3	1949	66
1923	2	1950	62
1924	2	1951	52
1925	1	1952	40
1926	19	1953	55
1927	12	1954	81
1928	98	1955	63
1929	27	1956	53
1930	130	1957	50
1931	102	1958	2
1932	2	1959 – 1966	*n.a.*
1933	11	1967	16
1934	193	1968	12
1935	223	1969	16
1936	192	1970	21
		1971	10

[1] Excluding production from tin streaming.

n.a. = not available: production over a number of years, but sold in 1966, is recorded as 132 tonnes.

Sources = The Westwood Report
Digest of Energy Statistics, Department of Trade and Industry
Tungsten Statistics, UNCTAD Committee on Tungsten

It is notable that more than half of the world's production comes from Communist countries, the major producers being China and the USSR (see Table 1). In Europe only Portugal can be classified as a moderately large producer (Beralt Tin and Wolfram Limited, a subsidiary of Charter Consolidated Limited). As the mineral is a deficiency commodity of fundamental importance to industry, denial of overseas supplies would be serious, particularly as all the United Kingdom requirements of molybdenum, the chief substitute for tungsten, are imported, Although some domestic deposits might be exploited to provide a substantial output, knowledge of the size and grade of the known deposits, and the most favourable processing methods, is insufficient to enable even approximate assessments of potential production to be made. In an emergency deficiencies might be partly made up by the scrap which is currently uneconomic to collect and process. Quantities arising at each location are small but, in total, could make a significant contribution to supplies: at present the organisation of collections is improving and the larger steelmakers in Sheffield recycle their scrap arisings or collect them for sale to melting-base producers. Sludges, grindings and tungsten-bearing slags are being recycled in increasing quantity.

Overseas trade, consumption, demand trends and statistics

Imports and re-exports

Almost all UK requirements of tungsten concentrates are at present imported. The most important sources in 1971 were Bolivia, Portugal, Thailand, the USA and Peru. Details are shown in Table 4, which illustrates the considerable variations in the pattern of world trade from year to year including, for example, the fluctuation in imports from China and the USA. The level of total imports also fluctuates widely; over the period 1966 to 1971 (Table 5) they averaged about 4,560 tonnes WO_3 content per year with an average value of £10 million.

As tungsten ore production in the UK has been insignificant, exports of concentrate have, in effect, been re-exports of imported material. Between 1966 and 1971 (Table 5) re-exports averaged about 880 tonnes WO_3 content per year with an average value of £1.5 million. A breakdown by destination is given in Table 6.

Net imports in 1966-1971 thus averaged about 3,680 tonnes a year with an average value of £8.5 million. It is, however, difficult to make an accurate assessment of the effect of overseas trade in tungsten on the balance of payments as overseas trade is carried on in other tungsten-bearing commodities, in some of which the tungsten content is not specified. Furthermore, the balance of payments may benefit from the handling of contracts by London merchants who arrange the shipping of concentrates directly from producers to European customers. These consignments do not, of course, figure in United Kingdom trade accounts.

There is a valuable export trade in tungsten, ferro-tungsten, carbide and hard metal (Table 7) as well as in machinery and equipment of which tungsten materials form an important element. For instance, the export value of mining tools tipped with sintered carbides and other carbide tool tips, probably largely, if not entirely, tungsten carbide, amounted to £4,745,000 in 1971.

Since 1971, overseas trade in wolframite, scheelite and other ores and concentrates has been separately identified (Table 8).

Consumption

Tungsten has been used industrially since the late 19th century. A considerable processing industry exists in the UK, particularly for the manufacture of high speed steel and tungsten carbide tools.

Consumption of tungsten concentrates in the production of tungsten semi-manufactures and goods, some of which were exported, is given in statistics published by the UNCTAD Committee on Tungsten as follows:

Tonnes

	WO_3 content	*W content*		*WO_3 content*	*W content*
1962*(a)*	3,434	2,723	1967	2,798	2,219
1963*(a)*	3,613	2,865	1968	3,059	2,426
1964*(a)*	4,268	3,385	1969	4,049	3,211
1965	4,308	3,416	1970	4,971	3,942
1966	3,802	3,015	1971	2,757	2,127

(a) Apparent consumption

No statistics on the consumption of tungsten in particular end-uses are available for the United Kingdom, except for those relating to consumption in the public and private sectors of the steel industry, published by the British Steel Corporation (page 35). Although United Kingdom consumption of tungsten in tungsten carbide is not known, a recent estimate puts it at 1400 tonnes annually. On the other hand, one industrial source has estimated annual consumption of tungsten carbide to be as low at 650 tonnes.

Table 4 United Kingdom: Imports of tungsten concentrates 1968–1971

	Quantity tonnes (WO_3 content)				*c.i.f. value £ thousand*
	1968	*1969*	*1970*	*1971*	*1971*
From					
Bolivia	886	812	915	961	2,865
Portugal	606	590	771	635	1,509
Thailand	93	96	292	494	1,000
USA	218	657	1,728	314	718
Peru	8	190	341	274	845
Western Germany	114	857	416	220	472
Netherlands	280	231	454	199	439
Republic of Korea	253	344	278	164	369
Australia	290	266	180	143	331
Rwanda	18	34	97	136	270
Spain	38	78	117	119	303
Malaysia	20	58	35	104	234
Canada	25	35	34	72	132
Kenya	70	67	65	40	86
Argentine Republic	29	30	59	38	75
Belgium	93	87	65	38	66
Czechoslovakia	131	123	59	26	60
China	199	259	281	21	52
Japan	83	26	29	12	29
North Korea	22	21	5	4	9
Republic of South Africa	26	27	14	2	4
Other countries	124	165	256	158	353
Total	3,626	5,053	6,491	4,174	10,221

Source: HM Customs and Excise

Table 5 United Kingdom: Trade in tungsten concentrates 1966–1971

	Imports		*Exports & Re-exports*		*Net Imports*	
	Tonnes WO_3 content	*Value £ million*	*Tonnes WO_3 content*	*Value £ million*	*Tonnes WO_3 content*	*Value £ million*
1966	4,392	6.7	1,747	2.2	2,645	4.5
1967	3,627	6.6	480	0.8	3,147	5.8
1968	3,626	7.2	1,247	2.1	2,379	5.1
1969	5,053	10.9	679	1.3	4,374	9.6
1970	6,491	18.3	407	1.1	6,084	17.2
1971	4,174	10.2	732	1.7	3,442	8.5

Source: HM Customs and Excise

Table 6 United Kingdom: Exports and re-exports of tungsten concentrates 1968–1971

	Quantity tonnes (WO_3 content)				*F.o.b. value £ thousand*
	1968	*1969*	*1970*	*1971*	*1971*
To:					
Western Germany	549	288	110	456	1,080
Netherlands	21	53	68	108	250
Poland	138	56	35	73	172
France	106	85	26	35	80
Belgium	61	28	53	22	36
Czechoslovakia	194	28	15	–	–
Eastern Germany	55	40	–	–	–
Other countries	123	101	100	37	53
Total	1,247	679	407	731	1,671

Source: HM Customs and Excise

Table 7 United Kingdom: Trade in tungsten, ferro tungsten and tungsten carbide 1970-71

Imports		*Quantity: tonnes*		*C.i.f. value: £*	
		1970	*1971*	*1970*	*1971*
Tungsten:	unwrought or wrought				
from:	USA	52	56	362,338	438,291
	Australia	1	21	4,884	31,851
	France	9	9	46,568	41,759
	Netherlands	3	8	66,270	143,221
	Sweden	5	5	147,518	156,075
	Other countries	7	4	65,221	54,744
	Total	77	103	692,799	865,941
Ferro tungsten		222 *(a)*	103 *(b)*	728,509	267,332
Tungsten carbide					
from:	Sweden	24	55	82,049	238,621
	USA	40	30	180,131	155,717
	Canada	28	15	219,795	117,129
	Portugal	14	–	84,961	–
	Other countries	30	30	111,015	175,444
	Total	136 *(c)*	130 *(d)*	677,951	686,911

Table 7 *continued*

Exports (including re-exports)		*Quantity: tonnes* 1970	1971	*F.o.b. value: £* 1970	1971
Tungsten:	unwrought and wrought				
to:	Netherlands	20	22	151,318	143,130
	Western Germany	27	17	211,417	135,400
	France	7	9	93,610	101,097
	Austria	12	7	68,095	46,556
	Italy	6	6	79,905	63,768
	Australia	8	6	63,616	57,817
	USA	4	5	58,849	54,583
	Sweden	8	4	72,782	34,216
	Hungary	12	–	63,926	----
	Other countries	50	39	324,357	369,950
	Total	154	115	1,187,875	1,006,517
Ferro tungsten					
to:	Netherlands	247	1,082	253,703	466,812
	France	1,014	1,076	1,217,822	1,048,911
	Western Germany	499	734	576,827	482,230
	Austria	146	583	178,140	339,611
	Belgium	44	63	63,566	74,276
	Norway	48	49	83,304	82,300
	Sweden	105	5	167,465	15,808
	Italy	29	5	71,497	6,206
	Other countries	162	228	405,900	333,468
	Total	2,294 *(e)*	3,825 *(f)*	3,018,224	2,849,622
Tungsten carbide					
to:	Denmark	22	21	125,310	125,398
	Belgium	21	20	109,359	111,639
	Finland	19	20	87,495	85,757
	Poland	8	19	54,560	107,533
	Yugoslavia	12	16	71,000	99,387
	Australia	12	15	74,803	68,579
	Luxembourg	13	14	79,862	82,614
	Sweden	11	13	51,673	38,518
	Argentine Republic	9	9	51,549	50,893
	Other countries	107	70	467,701	335,618
	Total	234 *(g)*	217 *(h)*	1,173,212	1,105,936

(a) Containing 163 tonnes W
(b) Containing 79 tonnes W
(c) Estimated to contain 130 tonnes W
(d) Estimated to contain 124 tonnes W
(e) Containing 850 tonnes W
(f) Containing 806 tonnes W
(g) Estimated to contain 223 tonnes W
(h) Estimated to contain 207 tonnes W

Source: HM Customs and Excise

Table 8 United Kingdom: trade in tungsten concentrates in 1971

	Wolframite				*Scheelite*				*Other ores and concentrates*			
	tonnes				*tonnes*				*tonnes*			
	gross	*WO_3 content*	*% W (b)*	*value £ thous. (a)*	*gross*	*WO_3 content*	*% W (b)*	*value £ thous. (a)*	*gross*	*WO_3 content*	*% W (b)*	*value £ thous. (a)*
Imports from:												
Argentine Republic	41	25	49	49	20	13	50	26	–	–	–	–
Australia	97	69	57	158	101	74	58	173	–	–	–	–
Belgium	54	38	56	66	–	–	–	–	–	–	–	–
Bolivia	677	308	36	1,006	–	–	–	–	1,619	653	32	1,859
Brazil	–	–	–	–	0	0	–	1	–	–	–	–
Burma	20	14	55	36	–	–	–	–	–	–	–	–
Canada	–	–	–	–	109	72	52	132	–	–	–	–
China	30	21	57	52	–	–	–	–	–	–	–	–
Czechoslovakia	–	–	–	–	–	–	–	–	68	26	29	60
Japan	–	–	–	–	16	12	63	29	–	–	–	–
Kenya	62	40	52	86	–	–	–	–	–	–	–	–
Malaysia	151	104	54	234	–	–	–	–	–	–	–	–
Mexico	–	–	–	–	54	34	50	73	–	–	–	–
Netherlands	287	194	54	431	6	5	67	8	–	–	–	–
North Korea	–	–	–	–	5	4	60	9	–	–	–	–
Peru	101	71	55	142	–	–	–	–	488	203	33	704
Portugal	834	613	58	1,459	32	22	56	50	–	–	–	–
Republic of Korea	21	15	57	43	191	149	62	326	–	–	–	–
Republic of South Africa	3	2	67	4	–	–	–	–	–	–	–	–
Rwanda	199	136	54	270	–	–	–	–	–	–	–	–
Singapore	35	23	54	48	–	–	–	–	–	–	–	–
South West Africa	77	51	52	129	–	–	–	–	–	–	–	–
Spain	76	52	54	122	89	67	60	181	–	–	–	–
Thailand	701	475	54	956	27	19	56	44	–	–	–	–
Uganda	55	36	51	65	–	–	–	–	–	–	–	–

USA	185	132	57	360	246	160	51	307	28	22	64	51
Western Germany	211	146	55	299	113	74	52	173	–	–	–	–
Total	3,917	2,565	52	6,015	1,009	705	55	1,532	2,203	904	33	2,674
Exports (incl re-exports) to:												
Austria	–	–	–	–	–	–	–	–	18	14	61	14
Australia	3	2	67	4	–	–	–	–	–	–	–	–
Belgium	31	22	55	36	–	–	–	–	–	–	–	–
France	20	15	60	29	31	20	52	51	–	–	–	–
Japan	10	7	60	13	–	–	–	–	–	–	–	–
Netherlands	7	5	57	9	148	103	55	241	–	–	–	–
Poland	106	73	55	172	–	–	–	–	–	–	–	–
Rumania	–	–	–	–	5	4	60	7	–	–	–	–
Sweden	16	10	50	15	–	–	–	–	–	–	–	–
Western Germany	295	206	55	548	367	250	54	532	–	–	–	–
Total	488	340	55	826	551	377	54	831	18	14	61	14

Source: HM Customs and Excise

(a) Imports are valued c.i.f. and exports f.o.b.

(b) Estimated percentage of W in concentrates.

Demand trends

The difficulties inherent in considering demand trends for tungsten include the large number of end-uses, the general lack of information on the quantities consumed in various end-uses, the possibility that demand might change rapidly due to unforeseeable advances in technology and the threat of substitution should concentrates become too highly priced. It is doubtful, for instance, if the present scale of use of tungsten carbide for tyre studs, amounting to about one-third of the total tungsten carbide consumption in the United States, could have been forecast ten years ago.

Numerous trends affect the production of tungsten products. For example, until recently European ferro-tungsten makers were unable to use more than 25 per cent scheelite in the ferro-tungsten mix. Ferro-tungsten is now regularly made from an all-scheelite mix and from concentrates of widely varying quality, much of which would previously have been considered unusable.

Because tungsten and tungsten products are used largely for alloying with, or cutting, steel, the outlook for tungsten is bound up with that for steel and other metals. With long term economic growth, therefore, the trend in demand for tungsten should be a rising one. However, the scope for substitution (see page 35), for which there is likely to remain a clear tendency so long as uncertainties about supply and accompanying price fluctuations prevail, may limit the increase in demand.

Statistics

There are considerable difficulties in obtaining certain statistics, particularly those relating to end-use. Statistics of consumption and stocks of tungsten ores and concentrates do not include values because of the wide fluctuations in the tungsten ore price. However, values can be estimated using prices (for tungsten ore, metal, carbide powder and ferro-tungsten) quoted biweekly in the *Metal Bulletin*. There are no statistics of merchants' stocks of ores and concentrates. Such figures would be particularly useful in forecasting short-term movements in the level of imports, re-exports and speculative demand.

The main sources of statistics are as follows:

Overseas Trade Accounts of the United Kingdom, compiled by the Department of Trade and Industry, available from HM Stationery Office. These give the following information:

> Imports of tungsten ores and concentrates, tungsten and tungsten alloys (including waste and scrap), unwrought or wrought and articles thereof;
>
> Exports of tungsten carbide, tungsten ores and concentrates (re-exports), tungsten and tungsten alloys (including waste and scrap), unwrought or wrought and articles thereof.

Statistical Summary of the Mineral Industry, [Annual], Institute of Geological Sciences.

Quarterly Bulletin of UNCTAD Committee on Tungsten shows UK consumption of tungsten ore and concentrates, and consumers' stocks. The information is supplied by the Department of Trade and Industry.

Annual Statistics published by the British Steel Corporation on behalf of the Iron and Steel Statistics Bureau.

Substitutes

Tungsten ferro-alloys

High-speed steels can be made with molybdenum, in combination with chromium and vanadium, in whole or partial substitution for tungsten. M1 steel containing 8 per cent molybdenum and 1.5 per cent W has gained wide acceptance in the USA. In steels with a tungsten content lower than that of high-speed steels various combinations of chromium, silicon, nickel, molybdenum, vanadium and cobalt have been successfully employed.

While consumption of molybdenum in steel-making has grown rapidly in the United Kingdom, that of tungsten has tended to decline, and the proportion of total tungsten consumption attributable to the steel industry has gradually decreased. The increase in the consumption of molybdenum relative to that of tungsten in steel manufacture in the period 1961-1971 is shown by the following figures:

Tonnes – metal content

	1961	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*
Tungsten	1,080	730	710	1,020	1,050	740	510	500	830	500	480
Molybdenum	3,090	2,430	2,900	3,500	4,000	3,780	3,430	3,840	3,810	4,210	3,700
Tungsten consumption as a percentage of combined tungsten and molybdenum consumption	26	23	20	22	21	16	13	11	18	11	11

It will be noted that between 1961 and 1971 consumption of tungsten in steel manufacture fell by 600 tonnes and consumption of molybdenum rose by 610 tonnes. While consumption of both metals depends on the level of steel production, it is notable that tungsten lost ground to molybdenum in seven of the ten years. It is likely that during the 1964-65 shortage of molybdenum, caused largely by the sudden rapid growth of world demand for steel (over 80 per cent of world molybdenum consumption is in steel production), tungsten steels were used for purposes for which molybdenum steel have since substituted. However, the relatively high growth rate for molybdenum steels results largely from their use in growth industries such as car manufacture.

Pigments

Tungsten in the form of paratungstic acid is used in the manufacture of toners (insoluble inorganic pigments). For some colours and some purposes paramolybdic acid is an acceptable substitute for all or part of the paratungstic acid although tungsten pigments are more brilliant and light fast. However, cheaper pigments are used wherever possible in place of those containing tungsten or molybdenum.

Tungsten carbide

For most purposes there appears to be no suitable substitute for tungsten carbide, although in some applications it can be replaced by titanium carbide. Titanium carbide is more brittle but can partly substitute for tungsten carbide in cutting tools with the added advantage that tendencies to 'cratering' are reduced. One such product has the composition, tungsten carbide 82, titanium carbide 8 and cobalt (binder) 10 per cent. The degree to which titanium carbide might compete with tungsten carbide in the future is at present difficult to assess.

Although other carbides, notably those of tantalum and niobium, are useful in special applications, both by themselves and in combination with tungsten carbide, their use is limited because they are too expensive or have an inadequate range of properties. Price comparisons between tungsten and its competitors are of only partial relevance when reasons for substitution are considered. In the case of molybdenum the effect of price difference is multiplied by the fact that twice as much tungsten must be used in tool steel to achieve similar high temperature hardness properties.

On 3 October 1972, the price of molybdenum concentrates was £1.52 per kg molybdenum in 85 per cent MoS_2 concentrate f.o.b. Climax Mine, USA. On the same date the equivalent c.i.f. price of tungsten-in-concentrate per kg contained tungsten was £1.83, taking the middle price per tonne unit (£14.10 to £15.20) contained WO_3. Molybdenum and tungsten powders were quoted at £3.45 to £3.60 and £2.99 per kg respectively, while free market cobalt was £2.26 per kg.

Research is likely to enhance the possibilities for partial substitution of tungsten by other metals in periods of prolonged high prices, or if medium-term difficulties of availability are feared. The most serious threats to the markets for tungsten carbide arise from ceramics and electro-chemical machining, though the former have only limited application at present due to their greater brittleness.

Other refractory metals, for example molybdenum, cobalt and nickel, are also deficiency commodities of which all United Kingdom primary requirements have to be imported. Molybdenum concentrates are imported mainly from Canada and the Netherlands, those from the Netherlands comprising principally roasted concentrates from the Rotterdam roaster of American Metals Climax. Imports of molybdenum concentrates, including roasted concentrates, during recent years have been as follows:

	1965	1966	1967	1968	1969	1970	1971
Quantity (tonnes)	8,177	9,507	9,407	8,402	12,918	11,716	7,824
Value (£ millions)	6.9	7.2	7.0	7.3	11.8	11.0	7.3

The main factors leading to the use of alternative materials are the uncertainty of tungsten supplies, fluctuating prices and concern about reserves in the longer term. Thus although, in many applications of tool steels, molybdenum is technically superior as it is claimed to confer improved toughness, it is probable that decisions to use molybdenum instead of tungsten rest mainly on economic considerations, that is price and availability. On the basis of both these criteria molybdenum must be regarded as having the advantage for its price has remained stable over long periods owing to the strong influence exerted by large, vertically-integrated producers, and it is mined largely within the developed countries. Further, since a period of shortage lasting from 1963 to 1965, supplies have been adequate to fulfil requirements, and will almost certainly remain so for some years. Tungsten consumers are therefore likely to switch to molybdenum whenever practicable as long as the tungsten market remains uncertain.

In general, however, the alloys and compounds in which tungsten is currently used are the best compromise between maximum performance and lowest cost. Thus although diamond tipped tools or ceramics might be more efficient in many applications, the net cost would be greater. Provided, therefore, that demand can be satisfied at reasonable prices, there is unlikely to be massive substitution in existing end-uses unless cheap, efficient ceramic materials become available.

Because of its high strength, low vapour pressure and high melting point there is unlikely to be any substitution for tungsten in electric lamp filaments. Neither tantalum nor molybdenum, both of which have been used for this purpose, are as efficient.

Industry

Associations concerned with the end-products of the tungsten consuming industries include the following:

The British Hard Metals Association

The British Mining and Quarrying Tool Association

The British Hacksaw Makers Association

The Twist Drill Association

The British Non-Ferrous Metals Federation

The Milling, Cutter and Reamer Association

The British Independent Steel Producers Association

The Welded Tool Manufacturers Association

The High Speed Steel Tool Bit Association

The associations likely to be concerned with tungsten mineral production in the United Kingdom are The United Kingdom Metal Mining Association, The Cornish Mining Association and The Cornish Chamber of Mines.

World Wide Energy (UK) Ltd is a subsidiary of World Wide Energy Co Ltd of Calgary, Alberta. South Crofty Mines Ltd is a subsidiary of the St Piran Mines Ltd, and Hydraulic Tin Ltd, which recovers tungsten concentrates from dump material, is a subsidiary of the Continental Ore Corporation. International Mine Services Ltd is a subsidiary of the Hirshorn Group.

In some companies, tungsten processing is undertaken as a relatively minor activity aimed at fulfilling their requirements for tungsten parts eg two firms (Lamp Metals Ltd, a subsidiary of GEC and Thorn Electric, and Mullard Ltd, a subsidiary of Philips Electronic and Associated Industries Ltd) manufacture metal mainly for in-house use in electrical and electronic goods. Tungsten carbide and hard metal are produced by London and Scandinavian Metallurgical Company Ltd, Murex Ltd, Wickman Wimet Ltd, Production Tool Alloy Co Ltd and Firth Brown Tools Ltd. The last company is a large consumer of high speed steel bars, sections, sheets and forgings.

Two firms, London and Scandinavian Metallurgical Co Ltd (a member of the Metallurg Companies, an international group of producers) and Murex Ltd (part of the British Oxygen group), produce tungsten in many forms, eg metal powder, ferro-tungsten, tungsten carbide and tungsten salts. The former is also an important reclaimer of tungsten scrap.

Murex Ltd manufacture hard metal tools and dies and tungsten semi-manufactures. The British Oxygen group have recently acquired High Speed Steel Alloys, another producer of ferro-tungsten, tungsten carbide, tungsten powder and tungsten salts, and Edibrac Ltd, a hard metal producer. Anglo Metallurgical Ltd (Clay Cross) and G Bramall (Tungsten) Ltd are leading producers of tungsten melting base. A list of some of the companies manufacturing tungsten products, and/or trading in concentrates, is given in Table 9.

Table 9 United Kingdom Manufacturers of tungsten products and suppliers of tungsten concentrates

Manufacturers of tungsten products from concentrates

G Bramall (Tungsten) Ltd (a subsidiary of Imperial Chemical Industries Ltd)
British Oxygen Co Ltd (in the company's subsidiaries Murex Ltd, Blackwells Metallurgical Works, Edibrac Ltd and High Speed Steel Alloys Ltd)
Ferro Alloys and Metals Ltd (a subsidiary of Neepsend Steel and Tool Corp Ltd)
Lamp Metals Ltd (a subsidiary of GEC and Thorn Electric)
London and Scandinavian Metallurgical Co Ltd
Minworth Metals Ltd (a subsidiary of American Metals Climax)
Mullard Ltd (a subsidiary of Philips Electronic and Associated Industries Ltd)

Other manufacturers of tungsten carbide products (probably largely from powder, carbide or oxide)

Bush Beach (Hand Metal Tools) Ltd
Dymet Alloys Ltd
Eutectic Co Ltd
Futurmill Ltd
Higher Speed Metals Ltd
Hillcliff Hard Metals Ltd
Mallory Metallurgical Productions Ltd
Marwin Hard Metals Ltd
Nulay Ltd
Production Tool Alloy Co Ltd
Prolite Ltd
Qualcut Carbide Ltd
Tempered Tools Ltd
Tungsten Carbide Developments Ltd
Tungsten Electric Co Ltd

Some producers of tungsten and tungsten alloys for electrical uses

Elmet Alloys Ltd – contact materials and electrodes of tungsten-copper and tungsten-silver
Englehard Industries – resistance wire etc.
Lamp Metals Ltd – tungsten rod
Mallory Metallurgical Products Ltd (a subsidiary of Johnson-Matthey) – electrodes and contact materials of copper-tungsten and silver-tungsten
Mullard Ltd – tungsten wire, rod and electrodes
Murex Ltd – tungsten wire, sheet and rod
Tungsten Manufacturing Co Ltd – wire and rod

Suppliers and merchants dealing in tungsten concentrates include:

Ayrton and Partners Ltd
Beralt Tin and Wolfram Ltd
Brandhurst Co Ltd
Continental Ore Co Ltd

Derby and Co Ltd
Fergusson Wild and Co Ltd
Korea Tungsten Mining Co Ltd
London and Scandinavian Metallurgical Co Ltd
Oakland Metal Co Ltd

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Appendix

United Nations Conference on Trade and Development (UNCTAD) – Tungsten Committee

A UN ad hoc Committee on tungsten was established in 1963, within UNCTAD, after an exploratory intergovernmental meeting had been convened by the Secretary General to consider the problems arising out of the slump in the tungsten market and its effect on the primary exporting countries. Under its terms of reference it provides opportunities for international consultations concerning trade in tungsten, encourages the improvement of statistics on tungsten and follows developments in the tungsten market. The membership, representing producing and consuming interests, is as follows:

> Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, China, Cyprus, Federal Republic of Germany, Formosa, France, Gabon, Italy, Japan, Mexico, Netherlands, Peru, Poland, Portugal, Republic of Korea, Rumania, Rwanda, Spain, Sweden, Turkey, USSR, United Kingdom, USA.

The Committee is assisted by a small Working Group drawn from the member countries. The United States provides the Chairman both for the full Committee and the Working Group.

The Tungsten Committee produces a quarterly statistical summary of world production, consumption and trade in tungsten ores and concentrates based on reports from member countries.

Produced in England for Her Majesty's Stationery Office
by Product Support (Graphics) Limited, Derby

Dd 502687 K16 1/73