

Twenty-seventh General Assembly and associated meeting

The meeting will take place in Rio de Janeiro and delegates will stay at the Sheraton Hotel.

MONDAY JUNE 1st 1987

Registration.

Cocktail Party 6 p.m.-8 p.m.

TUESDAY JUNE 2nd 1987

9.30 a.m. Twenty-seventh General Assembly

For delegates of member companies only.

10.30 a.m. Coffee break. Delegates of non-member companies join the meeting at this time.

11.00 a.m. Technical programme

Speakers will include :

Mr Simon Rodriguez, Director of the Ministry of Mines, Venezuela, who will discuss the minerals and mineralogy of Venezuela;

Dr Michael Hörmann, W.C. Heraeus, presenting a paper entitled 'The production of high thermal conductivity niobium for high frequency superconductors on a technical scale';

Mr Hans-Jürgen Heinrich, Gesellschaft für Elektrometallurgie (Metallurg group), reviewing developments in the technology of niobium;

A representative of Companhia Brasileira de Metalurgia e Mineração;

Mr Andrew Jones, T.I.C. Technical Officer, will interpret tantalum industry statistics, leading to a general discussion on current topics.

Lunch will be served from 1 p.m. to 2 p.m. The meeting will end at about 4 p.m.

In the evening all delegates and their ladies will be the guests of the host companies, Metallurg and CBMM, at a banquet dinner.

WEDNESDAY JUNE 3rd 1987

Delegates may choose to visit either the Araxá mine of CBMM or the mine and plant of Metallurg do Brasil at São João del Rei.

Invitations are being sent to the nominated delegates of member companies. Inquiries from non-member companies may be sent to the T.I.C. Secretary General.

'The Bulletin' — fifty issues old

This is issue no. 50 of the T.I.C.'s quarterly publication 'The Bulletin'.

First published in February 1975, 'The Bulletin' has provided worldwide coverage of the tantalum industry for the past 12 years, niobium for the past two years. A wide spectrum of subjects has been examined, including geology/exploration, production and processing of ore concentrates and the uses of niobium and tantalum metal and compounds. The economics and technologies of the industries have been included, as well as reports on the activities of particular T.I.C. member companies. 'The Bulletin' also carries T.I.C. production and shipment statistics and announcements and

reports of General Assemblies. Most of the 50 issues have been edited by Mr Graham Brown who relinquished the post in 1985.

Although 'The Bulletin' is primarily produced for the benefit of the T.I.C. member companies, it is also sent on request to an ever increasing number of individuals and organisations in over 20 countries with an interest in the niobium and tantalum businesses, such as those involved with finance, government, journalism and scientific research. Current circulation is over 800 copies a quarter, up by a factor of four from ten years ago.

Requests to be placed on the distribution list for 'The Bulletin' which is sent free of charge should be addressed to : T.I.C., Rue Washington 40, 1050 Brussels, Belgium.

**TWENTY-SEVENTH
GENERAL ASSEMBLY
TO BE HELD AT 9.30 a.m.
ON TUESDAY JUNE 2nd 1987
AT THE RIO-SHERATON HOTEL,
RIO DE JANEIRO**

AGENDA

1. Voting proxies.
2. Minutes of the Twenty-sixth General Assembly (held in Brussels on October 24th 1986).
3. Membership : applications, resignations.
4. Report of the Executive Committee.
5. Statistics collection.
6. Report of the Technical Officer.
7. Forthcoming General Assemblies :
Twenty-eighth, Brussels : date proposed October 20th 1987
Twenty-ninth : May/June 1988.
8. Other business.

President's letter

I am very pleased to address you all in this our fiftieth Bulletin. Following the publication of the recent amendments to our Charter in the Belgian Government Gazette, it marks the formal incorporation of the sister element of tantalum, niobium, into our activities, as well as the run-up to the first of our general assemblies to be held in Brazil, the home of the world's largest economic deposit of niobium ore.

I hope that all of you will make an effort to attend what should be a very worthwhile meeting: the circular with details will be sent to you shortly.

In 1981 at the symposium on niobium in San Francisco, I was very taken by the number of existing or potential non-metallic applications there were for the element. I was reminded of this again with regard to tin, at a meeting in Brussels last October. The effect could well be that the metallurgists amongst us will have to brush up their chemistry if such uses start to account for a significant part of total consumption. Are there any such uses in the offing for tantalum?

Yours sincerely,
R.J. Tolley
President

Niobium : high-purity uses expanding; new source development under way

Thirty years ago, niobium was largely regarded as a laboratory curiosity and had few industrial applications. Today, it is established as a widely-used additive to steels and non-ferrous alloys, as well as being applied in more diversified and specialised fields. Most of these are a long way from fulfilling their true potential, so widespread commercialisation of these 'exotic' applications has been anxiously anticipated by producers for some years.

Current consumption of niobium is around 20 000 tpy Nb_2O_5 worldwide, with an average annual growth of around 10 % over the last two decades. Shipments fell after 1980 for three successive years due to the recession in the steel industry, before recovering well in 1984. Non-ferrous demand for niobium has increased at a faster rate than the ferrous market over the last few years, but still only represents 13 % of total consumption. These newer applications take advantage of a variety of special properties; Cia. Brasileira de Metalurgia e Mineração (CBMM), the world's largest concentrate producer, maintain that 'niobium's growing acceptance is based on three important technical and commercial attributes: its versatility, its cost effectiveness and its assured availability'.

World demand for niobium (tonnes Nb_2O_5 contained)



Source : CBMM

There are three major producers of niobium concentrates (pyrochlore): CBMM, Mineração Catalão de Goiás and Cambior, Inc. (formerly Niobec, Inc.). The two Brazilian producers, CBMM and Catalão, convert all their concentrates into 'down-stream' products, mainly ferro-niobium, in line with their government's minerals policy. CBMM hold 70 % of the market and are the lowest-cost producer, their Araxá mine in the state of Minas Gerais containing vast ore reserves at a very high grade (3 % Nb_2O_5). Cambior's production from their underground mine in Quebec, Canada, is sold as pyrochlore to ferro-niobium producers in Europe, Japan and USA. Ferro-niobium is obtained from pyrochlore by aluminothermic reduction and then added to HSLA (High Strength, Low Alloy) steels in very small ('micro') concentrations to improve strength and toughness by grain refinement. HSLA steels have found applications in line pipe, construction and automobiles.

Niobium is also added in more conventional amounts to various stainless, heat-resisting and other special steels.

Current producers of niobium concentrates

| | Capacity (10^3 t Nb_2O_5) | Ore grade (% Nb_2O_5) | Reserves (10^6 t Nb_2O_5) |
|---|------------------------------------|-----------------------------|------------------------------------|
| Cia. Brasileira de Metalurgia e Mineração | 24.9 | 3.0 | 500 + |
| Mineração Catalão de Goiás | 2.3 | 1.5 | 50 |
| Cambior, Inc. | 3.2 | 0.7 | 11 |

High-purity, i.e. non-ferrous, applications can be conveniently placed in categories: additive to superalloys; optics and electronics, requiring very high purity oxide; metallic uses and niobium-based alloys; and cemented-carbide tools. The starting material for all these uses is refined oxide (99 % purity) produced by various routes: chemical processing of pyrochlore by CBMM; chlorination of ferro-niobium by Teledyne Wah Chang Albany; and as a by-product from tantalum oxide production by companies such as Hermann C. Starck Berlin, using hydrofluoric acid digestion followed by solvent extraction with MIBK. Demand for oxide increased by a factor of four from 1975 to 1979, causing prices to rise to \$15/lb Nb_2O_5 . CBMM entered the oxide market in 1980, and other producers increased processing capacity in expectation of the market expanding further. This expansion did not materialise; the market has been over-supplied ever since, current prices for niobium oxide of \$6-7/lb reflecting this.

Overall niobium use is expected to rise by around 5 % per year for the next five years at least, demand for high-purity oxide by even more. It is not unnatural, therefore that some companies are looking to enter the niobium business by locating and developing new sources of supply, and some of these efforts will be described later. But CBMM's low cost of production and large market share could well deter any prospective market entrant. Already producing oxides and vacuum-grade alloy additives at their Araxá mine site, CBMM have recently been awarded government approval to install a 40tpy electron-beam furnace by 1990, enabling production of niobium ingots.

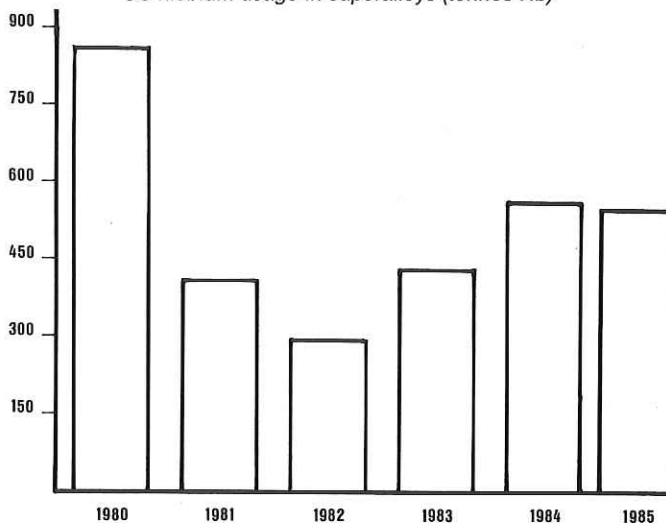
The size of the high-purity market worldwide is estimated at around 2000 tpy Nb_2O_5 , with superalloys accounting for over 70 %. Niobium in metallic and alloyed forms takes 9 %, optics and electronics 12 % and cemented carbides 7 %. Over 70 % of high-purity niobium oxide goes to the US market. Future prospects for these high-purity, non-steel uses are for the most part encouraging.

SUPERALLOYS

The term 'superalloys' describes those nickel, cobalt and iron-nickel based alloys used for gas turbine components, primarily for aircraft jet engines but also for marine and power turbines. Superalloy usage has spread to high-temperature applications outside the gas turbine field such as pollution control systems. But jet engines are still the major market for niobium-containing superalloys.

Niobium enjoys extensive use as a superalloy additive with US consumption closely reflecting the fortunes of the superalloy market: recessions occurred in the industry during the mid-1970's and early 1980's.

US niobium usage in superalloys (tonnes Nb)



Source : US Bureau of Mines

Contents of up to 5 % have been used for many years. Niobium strengthens the alloy by forming stable carbides and concentrating in precipitates; its low density favours its use over other refractory-metal additives such as tantalum and tungsten. However, its use tends to

be confined to intermediate-temperature alloys as niobium provides little of the solid-solution strengthening needed at very high temperatures.

During the 1950's, a nickel-based alloy IN713, containing 2.0 % niobium, was developed, commercialised and is still widely used today for turbine blades, as is Mar-M200 (1.0 % niobium), adopted by Pratt & Whitney for their blading during the 1970's. The period 1970-74 saw a doubling of niobium use in superalloys because of the widespread introduction of component casting which favoured compositions including niobium.

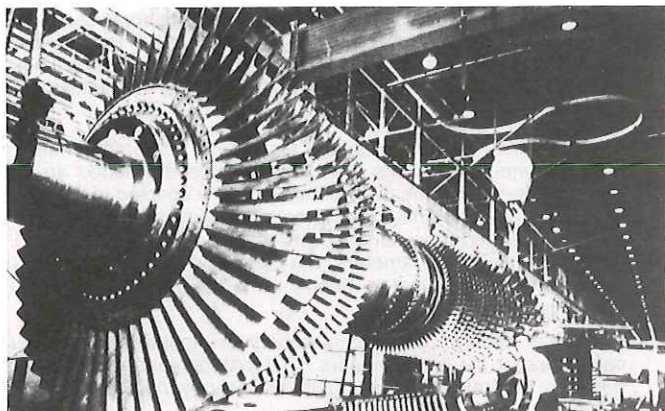
Price run-ups for cobalt during the late 1970's caused jet engine makers to replace the widely-used 'Waspaloy', containing 13.5 % cobalt, with IN718, an FeNi-based alloy containing 5.3 % niobium. As a result, consumption of high-purity niobium increased dramatically. Today, IN718 dominates as the preferred material for a wide range of 'cool-end' turbine components, especially in the USA. The continuing trend in the jet engine industry is toward substituting forged components for cast ones, favouring usage of IN718.

Another widely-used alloy is IN625, containing 3.5 % niobium, for corrosion-resistant applications. This alloy, together with IN718, accounts for the major proportion of niobium usage in superalloys.

The major market for niobium-containing superalloys, therefore, lies in the turbine market for aerospace, marine and power applications; but pollution control equipment for coal-fired power plants is a potential major user of an alloy such as IN625. One purchase of such a system could contain quantities of this alloy equivalent to more than nine tonnes of niobium.

A current trend is toward adding niobium to superalloy melts in the form of high-purity oxide; normally, niobium is added in the form of vacuum-grade master alloys such as nickel-niobium or ferro-niobium, produced by the aluminothermic reduction of oxide.

Turbine utilising superalloy blades



METALLIC USES AND ALLOYS

Uses for niobium in the metallic and alloyed states fall broadly into two categories: 'conventional' applications utilising niobium's refractory and corrosion-resistant properties; and superconducting applications, an area of increasing interest over the last few years.

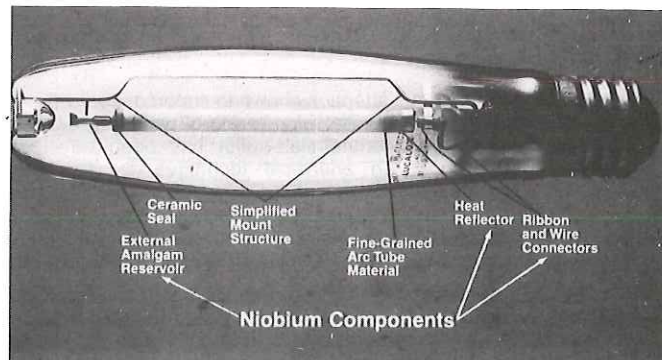
Metal is normally obtained from oxide by aluminothermic reaction and then purified by electron-beam melting under high vacuum, normally two or three melts being performed to reduce impurities to a level acceptable for most applications. Alloys of niobium are produced by vacuum-arc melting.

Niobium is rarely used in the unalloyed state as its large grain size makes forming operations difficult, and so for many applications, 1 % zirconium is added as a grain refiner. The corrosion-resistant properties of this alloy enable its use as a nuclear fuel element cladding material in reactors in power-generating plants and nuclear-powered submarines and space satellites. Niobium's low thermal neutron capture cross-section is also an advantage in the nuclear field. Another widespread application of niobium-1 % zirconium is for support members in high-intensity, sodium-vapour lamps.

Equipment for the manufacture of highly-corrosive chemicals is sometimes fabricated from alloys such as KBI 40 and 41, developed by the Cabot Corporation and containing about 40 % niobium. These tantalum-based alloys offer a substantial cost advantage over alloys with a higher tantalum content without drastically reducing either strength or corrosion resistance.

Several niobium alloys have attained a niche in the aerospace field: C-103, containing 10 % hafnium and 1 % titanium, has been applied in many aspects of the space programme; and FS-85, containing 28 % tantalum, 10 % tungsten and 1 % zirconium, was the construc-

Niobium components in sodium-vapour lamp

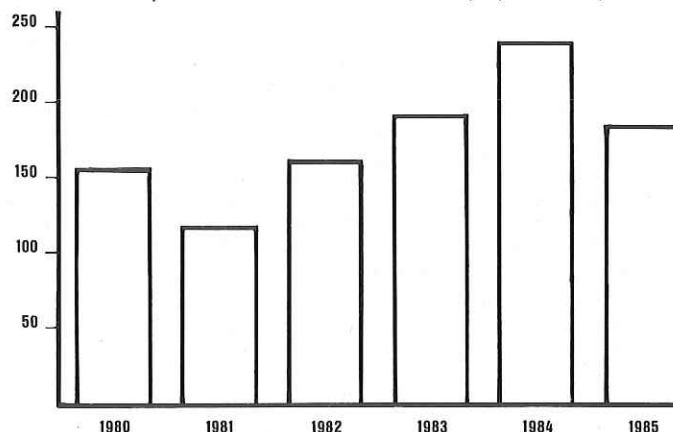


tion material of the Orbital Maneuvering System engines on the Space Shuttle. Another alloy, WC-3015 with 28 % hafnium, 4 % tantalum and 2 % zirconium, is reportedly being considered by the US Military as a potential turbine component material.

A new niobium-based alloy, Tribacor 532N containing 30 % titanium and 20 % tungsten, has been developed for environments which are both corrosive and abrasive. The surface is nitrided, but the material is ductile and can be readily machined. Initial market reception was said to be promising by Fansteel, Inc., the alloy's manufacturers.

One of the few applications requiring unalloyed niobium is cathodic protection (CP) of steel structures against corrosion in aggressive environments. Previously, CP was available only to large steel structures such as highway bridges. But platinum-clad niobium rods are now being employed as anodes in miniaturised CP systems for smaller structures: ships' hulls, power plant heat exchangers, buried pipelines and storage tanks. Although current requirements are small, the potential market for these devices is large, and so significant growth can be expected.

US shipments of niobium metal and alloys (tonnes Nb)



Source: Tantalum Producers Association

The worldwide market for niobium in metallic and alloyed forms is perhaps not much greater than 200 tpy niobium, the major consumer being the United States as can be deduced from the above data. Opportunities for future growth are mostly restricted, the aerospace alloys occupying limited niches in space and military applications, and corrosion alloys (Nb-1 % Zr, etc.) competing against lower-cost alternatives such as zirconium, titanium, stainless steels, etc. (Of widely-used corrosion-resistant metals, only tantalum is more expensive than niobium.) However, over the last few years another property of niobium — superconductivity — has resulted in an alloy of niobium-titanium being applied in many different and potentially high-growth fields. Future requirements for niobium in superconducting alloys, such as NbTi, could therefore be large: CBMM have estimated between 2000 and 6000 tonnes up to the end of this century. The actual figure will probably now be nearer the lower rather than the upper estimate.

At very low temperatures (close to absolute zero — minus 273 °C), metals exhibit superconductivity, i.e. zero electrical resistance, enabling the creation of very large current densities and magnetic fields without excessive power losses. The NbTi alloy becomes superconducting below 9K and is by far the most common alloy for superconducting applications. It can be cooled to below 9K (its critical temperature T_c) by immersion in liquid helium. Another material which has been used in the superconducting industry is intermetallic niobium-tin (Nb_3Sn) for high-performance applications. However, its fabrication is difficult because of its brittleness. Extensive research has been performed into manufacturing Nb_3Sn wire by solid-state diffusion, the so-called 'bronze

process'. This alloy has better superconducting properties than NbTi: a critical temperature of 18K. NbTi is produced by electron-beam melting, the resulting ingot being extruded into wire. Current processing yields from ingot to finished superconductor are approximately 50 %.

Despite the tremendous attention shown to superconductivity over the last few years and its potential wide range of uses, the fact remains that so far only one commercial outlet has been developed — magnetic resonance, an analytical technique for the study of molecular structure and dynamics. Elsewhere, superconductivity is being applied in research into particle physics. Potential applications in energy generation/transmission, transportation and industrial development remain speculative and a long way from fulfillment.

In 1985, CBMM estimated that about 40 tonnes of feedstock niobium were used for magnetic resonance, equivalent to 20 tonnes actually contained in the superconductor. Most of this was for medical diagnostics — magnetic resonance imaging (MRI) systems for body scanning. Another area of application is nuclear magnetic resonance (NMR) for non-destructive study and testing of materials such as food and industrial raw materials. Estimated future growth rates of MRI and NMR utilising NbTi superconductors range between 10 and 15 % per year, but the current rate seems to be much less.

In order to collide sub-atomic particles together (electrons, protons, etc.) at higher and higher energies, particle physicists need accelerators with superconducting magnets. Particle colliders consist of an underground tunnel, circular in shape and several miles in circumference, with particle accelerator cavities at various locations around a magnetic ring in the tunnel. The particle collisions are arranged to occur in special experimental areas, also at various locations round the ring.

The first of these installations to use NbTi superconductors in its cavities was completed in 1983, the 'Tevatron' at Fermilab in Chicago, USA, which contained 16 tonnes of niobium. Similar installations have followed in West Germany (HERA, Hamburg), Japan ('Tristan', KEK) and USA (RHIC, Brookhaven). The only NbTi required for these projects in the future will be for replacement parts; but NbTi requirements for two new installations now being planned (one almost certain to be built; the future of the other still not certain at this time) will be far greater than any so far for particle physics. The joint European nuclear research institute in Geneva (CERN) has planned to build the Large Electron-Positron ring (LEP), the tunnel for which has already been completed (17 miles in circumference). LEP's second stage, to be started in the 1990's, will contain 1000-1500 tonnes of NbTi, equivalent to 500-750 tonnes niobium contained. The future of the other large project being planned in the USA, the Superconducting Supercollider (SSC), is not yet so certain: Presidential approval was granted to SSC in February this year, but Congress has still to agree to the \$ 6000 million required. The SSC was designed by a consortium of three laboratories, will incorporate a 52-mile tunnel and contain about 1000 tonnes of NbTi alloy, equivalent to 500 tonnes of niobium.

A number of opportunities exists for superconductivity in the electrical industry. However, development programmes to investigate these started in the 1960's and 1970's have since been curtailed or abandoned. These programmes were in: magnetic fusion and power generation, transmission and storage.

If any full-scale fusion reactor is eventually built (an optimistic estimate is thirty years hence), it will almost certainly have to employ a superconducting confinement system for the control of the plasma. CBMM estimated that one reactor would contain 50 tonnes of niobium. Requirements so far for NbTi have been for research projects like the Large Coil Test Program at the Oak Ridge National Laboratory in the 1970's. Small-scale experimentation is under way at institutes such as the Joint European Torus at Culham, United Kingdom, and the Japanese Atomic Energy Research Institute. Worldwide niobium requirements for fusion research were estimated at 20 tonnes in 1985.

The other potential energy-related opportunities for superconductivity also remain firmly entrenched in the R & D stage. An outstanding example is energy storage. Projects exist at the Electric Power Research Institute in Palo Alto, California, and at the National Laboratory for High Energy Physics in Tsukuba, Japan. Efficiencies as high as 94 % have been demonstrated to be feasible, yet a full-scale plant seems unlikely to be built this century. However, the Bonneville power utility do operate a superconducting magnetic energy storage system in Tacoma, Washington — not for storage but to stabilise their grid. Research into superconducting transmission cables is proceeding at the Brookhaven National Laboratory.

Other applications have been investigated from time to time yet still offer little prospect of achieving commercial status. One of the more promising is the field of magnetic separation, to remove sulphur from coal, metals from kaolin, toxic metals from water supplies, etc.

The Strategic Defense Initiative ('Star Wars') may offer an interesting opportunity for superconductors: it has been proposed that SDI will incorporate a 'rail gun', a system for accelerating missile-killing projectiles off electrically-charged rails at huge speeds (maybe five

miles a second). To deliver the enormous electrical currents needed, superconducting systems may need to be employed. But it is not certain that SDI will ever be deployed.

OPTICS AND ELECTRONICS

These applications demand very high purity oxide (99.9 %) which is produced by further refining 'high-purity' oxide (99 %) into 'optical-grade' (for glass) or 'crystal-grade' (for electronics) niobium oxides.

Niobium oxide is added to glass for high-quality lenses used in cameras, photocopiers and ophthalmics. Contents of up to 70 % are used, but more normally seem to be in the range of 10-30 %. The major market is in Japan where consumption doubled from 1982 to 1984. Niobium oxide has the property of increasing refractive index without increasing the density of the lenses — hence it is being substituted for tantalum oxide in some instances — and also imparts good resistance to attack from chemical reagents.

Electro-optics is a field related to optics: growth is expected in the use of niobium oxide for high-quality wave guides to inter-connect a multiple cable of optical fibres.

Crystal-grade niobium oxide is used as the starting material for lithium niobate (LN) single crystals. As many as 15 000 LN substrates (3 inch diameter by 0.020 inch) are produced monthly, these then being split into tiny sections for fabrication into surface acoustic wave (SAW) devices. The piezoelectric properties of LN enable these SAW devices to be used as filters to split audio and visual signals in television receivers. Advances in satellite and cable broadcasting will create new demand for SAW devices made from LN.

Piezoelectricity is the property of a material (such as LN) to convert mechanical energy into electricity and vice versa. Hence, in SAW devices two electrodes are attached to the LN crystal surface (these are normally thin, vacuum-deposited, aluminium lines). A radio-frequency (RF) a-c signal entering one electrode is converted into a surface acoustic wave by the LN. This wave travels across the LN crystal substrate to the other electrode where it is transformed back into a RF signal. Lithium niobate is favoured because of its high efficiency of energy conversion ('coupling factor'). This traversing of the LN crystal involves a time delay which is why delay lines also involve LN devices, although it is believed that by far the major market for LN is in television receivers.

An interesting new application for LN is in computer-integrated manufacturing where one US company has developed an identification system using the SAW principle. The spacing of the electrode lines controls the time delay; the configuration (shape and size) controls the frequency and power of the outgoing RF signal. By altering these two parameters, the company were able to produce a coding system sufficient to identify up to 250 million individual items instantaneously.

There has been an expanding market for niobium oxide in ceramic capacitors for the last few years: in Japan demand more than tripled between 1980 and 1984, stimulated largely by increased demand for ceramic monolithic capacitors.

CEMENTED CARBIDES

Niobium is added to cemented carbide tools for metal cutting in the form of mixed carbides with tantalum, titanium and tungsten, but normally in a binary phase with tantalum alone. These binary carbides tend to have TaC:NbC ratios of 90:10 or 80:20. Price run-ups for tantalum during 1979-81 caused substitution of this metal often favouring niobium; however, recycling of carbides increased at the same time, having the effect of reducing the requirements for virgin niobium carbide by about 25-30 %. Stable prices for tantalum in recent years have halted substitution drives. As it does not appear that niobium imparts any special or unique properties to cemented carbides, and it has been proved that it cannot work without tantalum, prospects for future growth in this field are dependant on two possibilities: a general pick-up in cemented carbide shipments; high prices for tantalum again causing substitution by niobium.

Niobium carbide is produced by the high-temperature carburisation of the oxide, often under vacuum. The resulting carbide powder is sintered with a binder phase such as cobalt or nickel to produce the cemented carbide insert.

SOURCE DEVELOPMENT

As outlined previously, there are essentially three producers of niobium raw material (pyrochlore concentrates) in the world. Columbite used to be produced in considerable quantities as a by-product from tin-mining in Nigeria, but current output is almost negligible due to the price reduction for niobium oxide in 1981 and the tin crisis in 1985. Production capacity of almost 30 000 tpy Nb_2O_5 outstrips demand of about 20 000 tpy, and this over-capacity is expected to continue for some time with growth in demand being more modest in the future, averaging 5 % per year. Besides the non-ferrous applications previously discussed, growth opportunities exist for niobium in such areas as tool steels and cast irons. Also, production of HSLA

steels is expected to increase in third-world countries such as Brazil, Indonesia, South Korea, Mexico and Taiwan in line with domestic demand for this product.

Therefore, it would appear that there is no immediate possibility of a niobium shortage — but this has not deterred a number of exploration and source development efforts being undertaken in Brazil and elsewhere.

A pyrochlore deposit known as 'Catalão 2', which extends off the one being mined by Mineração Catalão de Goiás, is being prospected by a company called Goiás Niobio, owned by Prometal. A pilot plant was planned for 1986. Grades are approximately 1.2 % Nb₂O₅.

The state-owned mining company, Cia. Vale do Rio Doce (CVRD), plans to begin producing titanium concentrates (anatase) by 1988 from a huge deposit at Tapira in the State of Minas Gerais. This deposit also contains niobium in a pyrochlore mineralisation at an average 0.9 % Nb₂O₅ in 113 million tonnes of ore. Bench-scale tests indicated that production of a 57 % Nb₂O₅ concentrate was feasible, and a pilot plant was being built in 1986 with a feed rate of 200 kg of ore per hour. However, the techno-economic feasibility of commercial production has yet to be established.

The Paranapanema group are currently producing about 100 tonnes a month of columbite concentrates as a by-product from the Pitinga tin deposit in the Amazon. A deposit at São Gabriel in the Amazon contains about 3000 million tonnes of ore at 2.8 % Nb₂O₅, but the complex nature of the mineralisation is beyond current processing technology.

Pyrochlore concentrates are being produced on a pilot basis from a deposit at Lueshe in Zaire by the Metallurg group. Grades are high at 2.9 % Nb₂O₅.

At Baotou in China, experts have been trying for some years to upgrade the iron ore from the deposit at Bayan Obo into concentrates suitable for smelting, the main problem being the inter-growth of various minerals, including those of niobium, with the ore. Now a German-Chinese research programme has succeeded in developing a process allowing the production of iron and niobium concentrates. Grades in the ore are low, however, at about 0.14 % Nb₂O₅. The Japanese government are said to be interested in the project with the aim of diversifying Japan's requirements for niobium. A pilot plant is being considered.

A final report on the Motzfeldt pyrochlore deposit in southwest Greenland has now been released by the Geological Survey of Greenland: grades in the ore are estimated at between 0.4 and 1.0 % Nb₂O₅ and reserves at 130 million tonnes. Companies to sustain the prospecting activities are now being sought.

Finally, West Coast Holdings are investigating the possibility of producing niobium from the Brockman deposit in Western Australia. This deposit, which contains a number of valuable minerals, may be capable of an output of 1500 tpy Nb₂O₅. Grades are 0.44 % Nb₂O₅. A feasibility study is currently investigating the most cost-effective end-product for a mining operation.

SUMMARY

Having achieved a stable supply base, the niobium industry is now looking forward to growth in demand for high-purity (99 %) oxide. These newer uses are described for the purpose of increasing public awareness of their true potential. There are, however, obviously still major gaps in our knowledge about these applications, especially the areas of optics and electronics requiring very high purity (99.9 %) oxide, so the T.I.C. will continue to monitor developments.

LITERATURE

- 'The nature of the niobium industry', Stuart.
- 'Projected niobium demand in applied superconductivity', Laverick and Stuart.
- 'The market of niobium', CBMM.
- 'The economics of niobium 1986', Roskill Information Services.
- 'The supply and demand for niobium', Lindsay.

Andrew Jones
Technical Officer

Niobium industry classification

The chart indicates which niobium materials the companies named have the installed capacity to produce — or expect to have installed within the foreseeable future. The information presented was obtained either by direct communication with the companies concerned or from published literature.

| | Raw materials | Pyrochlore | Contained in tantalite, tin eler, etc. | Compounds | Carbide | Oxide (high-purity grade) | Oxide (optical grade) | Alloy additives | Alloy (high-purity grade) | Alloy (vacuum grade) | Alloy (conventional) and metal | Invest | Mill products | Superconducting alloys | High-purity titanium | Niobium-tin |
|--|---------------|------------|--|-----------|---------|---------------------------|-----------------------|-----------------|---------------------------|----------------------|--------------------------------|--------|---------------|------------------------|----------------------|-------------|
| Avamora Metal Industry..... | | | | | | | | | | | | | | | | |
| BEH Minerals..... | | | | | | | | | | | | | | | | |
| Cia. Brasileira de Metalurgia e Mineração (CBMM).... | | | | | | | | | | | | | | | | |
| Cabot Corporation..... | | | | | | | | | | | | | | | | |
| Cambior..... | | | | | | | | | | | | | | | | |
| Mineração Catalão de Goiás..... | | | | | | | | | | | | | | | | |
| Coframines..... | | | | | | | | | | | | | | | | |
| Continental Alloys..... | | | | | | | | | | | | | | | | |
| Datuk Keramat Smelting..... | | | | | | | | | | | | | | | | |
| Minera del Duero..... | | | | | | | | | | | | | | | | |
| Fansteel..... | | | | | | | | | | | | | | | | |
| Fundação de Tecnologia Industrial..... | | | | | | | | | | | | | | | | |
| Greenbushes..... | | | | | | | | | | | | | | | | |
| W.C. Heraeus..... | | | | | | | | | | | | | | | | |
| Intersteel..... | | | | | | | | | | | | | | | | |
| Japan Metals and Chemicals..... | | | | | | | | | | | | | | | | |
| Kanatini Tin Mines..... | | | | | | | | | | | | | | | | |
| Kennametal..... | | | | | | | | | | | | | | | | |
| Lian Metals..... | | | | | | | | | | | | | | | | |
| Malaysia Smelting..... | | | | | | | | | | | | | | | | |
| Hallinckrodt..... | | | | | | | | | | | | | | | | |
| Metallurg Group..... | | | | | | | | | | | | | | | | |
| Minas Gerais de Mozambique..... | | | | | | | | | | | | | | | | |
| Minex Corporation..... | | | | | | | | | | | | | | | | |
| Mitsui Mining & Smelting..... | | | | | | | | | | | | | | | | |
| Nurex..... | | | | | | | | | | | | | | | | |
| Nippon Denko..... | | | | | | | | | | | | | | | | |
| Nippon Kokan Steel..... | | | | | | | | | | | | | | | | |
| NRC..... | | | | | | | | | | | | | | | | |
| Paranapanema Group..... | | | | | | | | | | | | | | | | |
| Metallwerk Plansee..... | | | | | | | | | | | | | | | | |
| Reading Alloys..... | | | | | | | | | | | | | | | | |
| S.A. Minerals..... | | | | | | | | | | | | | | | | |
| Sominki..... | | | | | | | | | | | | | | | | |
| Hermann C. Starck Berlin..... | | | | | | | | | | | | | | | | |
| Taiyo Mining and Industrial..... | | | | | | | | | | | | | | | | |
| Teledyne Wah Chang Albany..... | | | | | | | | | | | | | | | | |
| Thailand Smelting and Refining..... | | | | | | | | | | | | | | | | |
| Treibacher Chemische Werke..... | | | | | | | | | | | | | | | | |
| Vacuum Metallurgical Co..... | | | | | | | | | | | | | | | | |

Cia. Brasileira de Metalurgia e Mineração (CBMM)

CBMM are a host of the Twenty-seventh General Assembly of the T.I.C., being held in Rio de Janeiro, June 1st-3rd 1987.

CBMM, a Brazilian corporation founded in 1956, is today the major supplier of niobium products to industrial markets in more than 40 countries around the world. It is owned 55 % by the Brazilian Moreira Salles group and 45 % by Molycorp, Inc. in the United States.

Araxá (population 55 000) is about 550 km northwest of Rio de Janeiro, in the state of Minas Gerais, an area of much social, commercial and industrial progress in Brazil. It is served by regular scheduled airline flights, and linked by road and rail to the great Atlantic ports.

It was at Araxá in 1954 that a Brazilian geologist discovered the pyrochlore mineral deposit now widely recognized as the world's largest niobium reserve. From this reserve CBMM conduct their mining, processing and production operations.

MINING AND CONCENTRATING

The discovery of pyrochlore in the Araxá carbonatite, followed by its mining and processing by CBMM since 1960, has proved to be a significant development in the history of metallurgy. It has assured ample supplies of niobium materials for improved steel and alloy

CBMM mine at Araxá

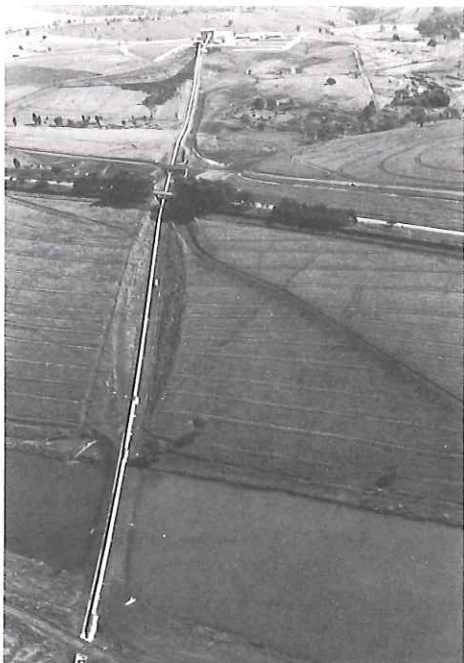


production — in any volume. At current levels of world usage of niobium, the Araxá pyrochlore deposit would guarantee supply for over 500 years. Ore reserves are estimated at 461 million tonnes.

The Araxá carbonatite formation is approximately 4.5 km in diameter and distinguished from other alkaline complexes by the uniquely high niobium mineralisation. Average ore grade is over 2.5 % Nb_2O_5 , and some isolated zones contain up to 5 % Nb_2O_5 .

Located 3.2 km from the mine pit to which it is linked by a 42-inch conveyor belt for the ore, the concentrator has a capacity for treating 3500 tonnes of ore per day. Rated annual production is 42 000 tonnes of pyrochlore concentrates, containing 60 % Nb_2O_5 (the equivalent of 55 million lb of contained Nb_2O_5). Expansion of this facility to double the present capacity has been foreseen: ore silos, a concentrator building, and a second ball mill are already in place; crushing facilities and utilities were built to support a much greater capacity.

Conveyor belt between mine and concentration plant



Bird's-eye view of plant facilities at Araxá

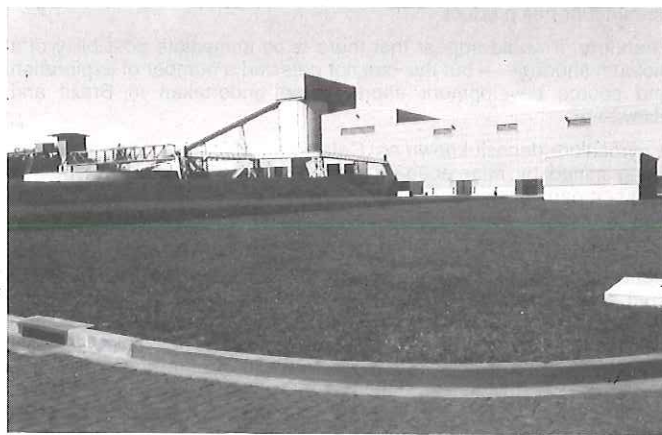


The initial steps in the concentration process are: crushing, ball-mill grinding and magnetic separation.

Normal run of mine ore at Araxá is almost completely desegregated and decomposed, and does not require heavy crushing. The crushing facilities consist of a 200-tonne concrete ore bin from which ore is drawn by an apron feeder and delivered to a vibrating screen having 50 mm openings. Screen oversize, comprising less than 10 % of the ore, goes to an impact crusher. Crushed ore joins screen undersize and is belt-conveyed to a 4500-tonne silo. From the silo, two apron feeders discharge to a belt conveyor which delivers the ore to the ball mill. An automatic weight balance monitors the amount of ore on this conveyor and controls the speed of the apron feeders.

Pyrochlore crystals in the Araxá ore are very small, seldom exceeding one millimeter in size. Optimum liberation is achieved after grinding to minus 150 mesh in the 1250 HP, overflow-type ball mill.

Concentration facility which came on-stream in December 1981, incorporating "know-how" developed over two decades



Flotation is highly sensitive to the presence of slimes which, in certain quantities, can inhibit the process. For this reason, three-stage desliming is used, with each stage followed by a re-desliming step. Three batteries of cyclones — 381 mm, 102 mm and 25 mm — accomplish the necessary separation. The ore also contains 10 to 25 % magnetite which is removed by low-intensity, double-drum magnetic separators.

Concentration of the niobium mineral is by selective froth flotation of the pyrochlore. Rougher flotation consists of a bank of eight 8.5 m³ cells; cleaner flotation consists of four stages, each in closed circuit with the previous stage. A separate circuit is used for flotation of the fine particles from the underflow of the 25 mm cyclones which is the last stage of desliming. Concentrate from this circuit joins the fourth cleaner concentrate of the regular flotation circuit to form the final concentrate.

Float cells and batteries of cyclones achieve the concentration of the niobium mineral



Araxá flotation concentrates contain levels of phosphorus, sulphur and lead which must be reduced considerably for the production of high-quality ferro-niobium. For this purpose, the concentrates are treated in a calcining and leach plant. In this process, flotation filter cake is mixed with calcium chloride and lime, calcined in a rotary kiln at temperatures above 800 °C, cooled and leached at 50 % solids with

Leaching plant for the chemical and calcining treatment of concentrates



5 % hydrochloric acid. The leach plant has capacity to treat 150 tonnes per day of concentrates, allowing an annual production of approximately 50 000 tonnes of leached material.

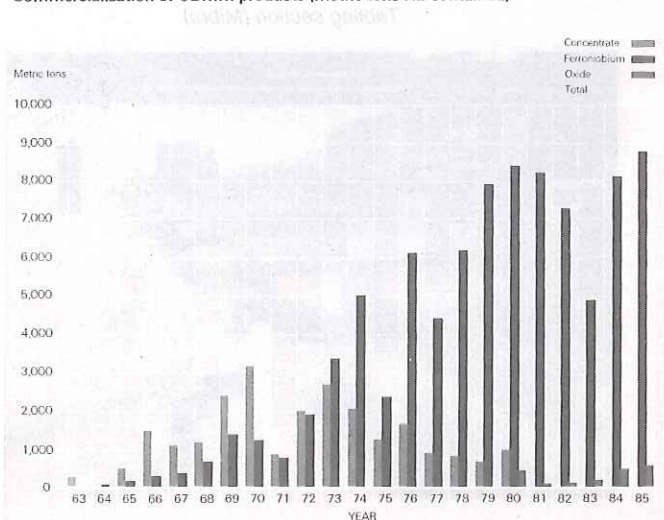
CBMM PRODUCTS

Araxá pyrochlore is processed and converted by CBMM into five distinct products : standard-grade ferro-niobium, vacuum-grade ferro-niobium and nickel-niobium, high-purity niobium oxide and optical-grade niobium oxide.

Standard-grade ferro-niobium is used as an alloying element in steelmaking, mainly in HSLA steels for oil and gas pipelines, structural steel, offshore drilling platforms, rebar, rails and automotive applications. Vacuum-grade master-alloys are used in the production of superalloys and high-alloy steels, most importantly for turbine engines. Niobium oxide is the primary material for making vacuum-grade alloys, also for producing pure niobium metal and its refractory and superconducting alloys. Exceptionally pure oxide is needed for niobium's emerging optical and electronic uses.

Recently, it has been announced that CBMM have won government approval to build a 40 tpy electron-beam furnace to produce niobium metal ingots by 1990. At present, ingots from Fundação de Tecnologia Industrial, produced as part of this organisation's integrated program of research into refractory metals, are marketed by CBMM.

Commercialization of CBMM products (metric tons Nb contained)



Ferro-niobium, CBMM's major product in terms of both tonnage and dollar sales, is produced from pyrochlore concentrates by the aluminothermic reduction process. CBMM's batch operation is probably the largest aluminothermic reaction facility in the world in terms of reactor size, quantity of aluminium powder used and tonnes of ferro-niobium produced by each reaction. A single reaction charge consists of : 18 000 kg pyrochlore concentrates; 4000 kg iron oxide; 6000 kg aluminium powder; 750 kg fluorspar; and 500 kg lime. This produces an 11 tonne "button" of 66 % Nb ferro-niobium. CBMM has capacity to fire six charges a day producing 66 tonnes of ferro-niobium, with a recovery of 96 to 97 %.

FeNb button being removed from sand-pit for further cooling



After years of research and process development at the Araxá laboratories and pilot facilities, CBMM began commercial operation of a plant for production of high-purity niobium pentoxide in January 1980. Until then, all the niobium oxide used throughout the world had come from the chemical processing of columbite-tantalite ores. The introduction of high-purity oxide from pyrochlore has assured abundant and continuing supply to serve world demand out of the vast Araxá resource. Further development in 1981 has led to production of optical-grade oxide for application in optical and electronic materials.

Approximately 30 % of CBMM's production is sold through their international subsidiary, Niobium Products Company Ltd., through offices in Pittsburgh and Düsseldorf. CBMM ferro-niobium is also distributed by the following firms : Molycorp, Inc. and Shieldalloy Corporation in the USA and Canada; Klöckner & Co and Gesellschaft für Elektrometallurgie mbH in Europe; London and Scandinavian Metallurgical Co. Ltd. in the United Kingdom; AB Ferrolegeringar in Scandinavia; Nissho Iwai Corporation in Japan.

SUPPORT ACTIVITIES

The solid reputation which CBMM products enjoy in steel industries worldwide was won and is maintained by high quality standards and vigorous control at each step — from mining through beneficiation and leaching to metallurgical reduction or chemical processing, and then to grading and packing. In the Araxá laboratories, X-ray fluorescence and atomic absorption spectroscopy, simultaneous carbon/sulphur analysis, flame spectrophotometry, recording gas analysis and computer read-out and recording are daily tools for quality assurance to consumers.

CBMM through its mining subsidiaries is actively engaged in prospection and mineral research to keep abreast of new opportunities in the vast Brazilian territory. Currently three main programs are in progress :

- a thorough study of carbonatites through magnetic and radiometric verifications in these structures;
- prospection for alloy metals;
- other new potentials with special attention to fluorite occurrences.

ENVIRONMENT AND HUMAN RESOURCES

Extracting a single mineral from an ore, concentrating it and leaching it, takes water — lots of it. Conserving it and cleansing it of process pollutants is an obligation toward the ecology. At CBMM major effort has gone into providing a totally enclosed effluent system. Five earth-fill dams control the flow of effluents to and from the tailings ponds, so that all process water is recycled. Make-up water is pumped 2 km from a fresh water reservoir. Tailings from the concentrator go to large ponds for sedimentation. Magnetite mineral withdrawn by magnetic separators in the flotation circuit is stored in a separate pond for future possible use. Leach plant effluents are chemically purified before ponding.

CBMM believe that their personnel are the basic foundation for their achievement and progress, so the company invests substantially in staff development and continuously recruits and trains new people for research, mining, processing and marketing. Top technical management participates in a rotation of responsibilities to keep them abreast of new developments in mining, metallurgy and plant management. Worldwide contacts and consultation by CBMM metallurgists with user industries and research groups aim at development of new concepts and processes for the application of niobium products.

NIOBIUM DEVELOPMENT

Since 1970, CBMM have worked beyond the mere production and supply of niobium materials, implementing and funding the worldwide "Niobium Applications Development Program", in concert with universities, research institutions, technical societies and steel companies. Field consultation by technical experts at CBMM subsidiaries in Europe, North and South America and the Orient has been instrumental in recent metallurgical and chemical achievements : improved linepipe steels, weldable rebar, more formable HSLA automotive sheet and greater purity oxide. The program is co-ordinated from CBMM's headquarters in Brazil. Some projects have finite-term funding; others serve continuing long-term objectives.

CBMM, with other niobium producers, organised the international symposium "Niobium '81" in San Francisco, California, covering the mining, extraction, production, metallurgy and applications of niobium. They have hosted other international conferences since then, the T.I.C. Twenty-seventh General Assembly being the latest.

The Niobium Information Centre (CITEN), based in São Paulo, is supported by CBMM and is charged with the collection and dissemination of technical information relevant to niobium. As well as maintaining an extensive library and computerised access to scientific data-bases, CITEN distributes various CBMM publications such as "Niobium Abstracts" and "Niobium Technical Reports".

Cia. de Estanho Minas Brasil

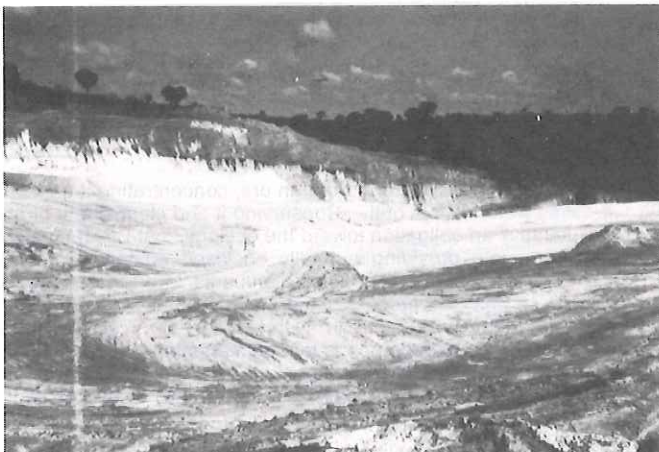
Cia. de Estanho Minas Brasil are a host of the Twenty-seventh General Assembly of the T.I.C., being held in Rio de Janeiro, June 1st-3rd 1987.

Cia. de Estanho Minas Brasil are a member of the Metallurg group, a major producer and supplier of ferrous and non-ferrous metals, alloys and chemicals, among these commodities tantalum and niobium products playing an important role. Production is concentrated at five plants in Brazil, West Germany, UK and USA.

Metallurg's Brazilian operations consist of: the Mibra mines in São João del Rei, Minas Gerais State, recovering mainly tantalite and cassiterite, but also smelting the tin concentrates; and the nearby Fluminense plant, incorporating another tin smelter and production of tantalum and niobium oxides. The São João del Rei region is about 300 km northwest of Rio de Janeiro.

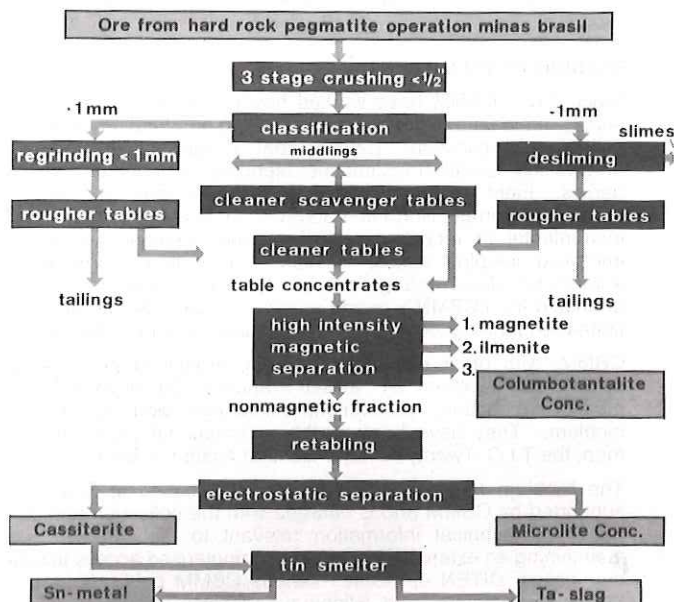
Mibra maintain several open-pit operations for recovery of microlite, tantalite and cassiterite from hard rock and weathered pegmatite. Two types of pegmatite can be identified: one with and one without spodumene. Both types are mineralised with tantalite, cassiterite and minor associated minerals. About 600 tonnes of ore per day can be mined by open-pit methods. Drilling and blasting are necessary for the hard pegmatite, but for semi-decomposed and soft pegmatite, bulldozer operation is sufficient; gravel pumps are used in the alluvial-colluvial deposits. Ore transportation between the mine and the ore-dressing plant is by motor scrapers and trucks.

Open-cast mining at Mibra



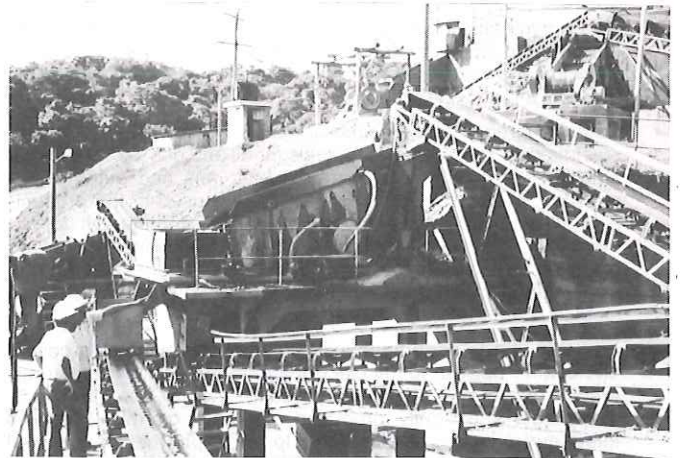
Mining is centred on three deposits, all located within a distance of two to three miles of each other: Fumal, Minas Brasil and Volta Grande.

Schematic flow-sheet of Mibra's operations

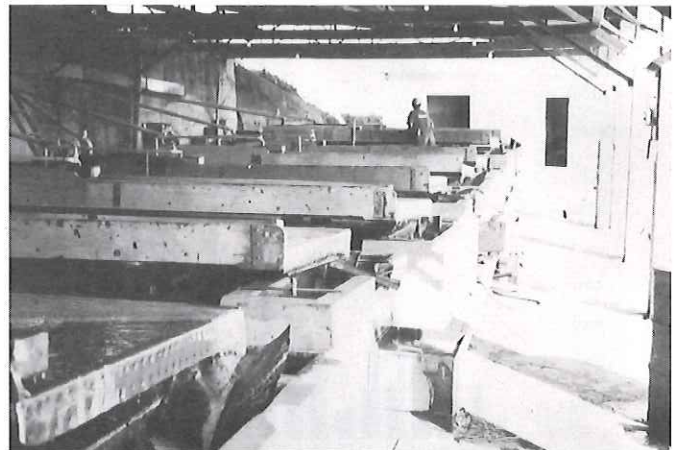


Tin metal and tantalite concentrates are recovered from the mined ore by a series of mineral dressing steps. The tin smelter produces a high-grade slag, 30-45 % Ta_2O_5 and 3-7 % Nb_2O_5 .

Ore classification and crushing (Mibra)



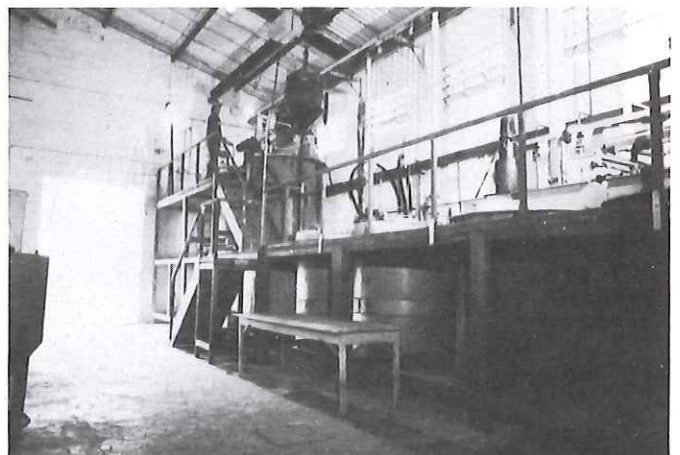
Tabling section (Mibra)



The annual capacity of the total mine operation is 75 000-100 000 lb Ta_2O_5 . The Mibra smelter can produce 700 tonnes of tin per year. An additional smelter is located at the Fluminense plant which has a capacity of 1500 tonnes of tin metal per year, produced from Mibra cassiterite concentrates.

The Fluminense plant can also produce tantalum and niobium oxides by liquid-liquid solvent extraction. Stated capacity is 60 tonnes of ore concentrate feed per year, the oxides produced going to the Brazilian cemented carbide industry.

Digester units at Fluminense plant



T.I.C. statistics

Price Waterhouse report the following statistics :

QUARTERLY PRODUCTION ESTIMATES

(quoted in lb Ta₂O₅ contained)

| MB quotation : | US \$30 | US \$40 | US\$50 |
|------------------|---------|---------|---------|
| 1st quarter 1987 | 238 200 | 310 150 | 439 250 |
| 2nd quarter 1987 | 248 200 | 325 150 | 454 250 |
| 3rd quarter 1987 | 248 200 | 335 150 | 454 250 |
| 4th quarter 1987 | 248 200 | 335 150 | 484 250 |
| 1st quarter 1988 | 276 200 | 363 150 | 512 250 |

Note : The estimates were based on information available and do not necessarily reflect total world production.

PRODUCTION AND SHIPMENTS

(quoted in lb Ta₂O₅ contained)

4th quarter 1986

| Material grade | Production | Shipments |
|---|------------|-----------|
| Tin slag (over 2 % Ta ₂ O ₅) | 113 425 | 38 894 |
| Tantalite (all grades) | 31 287 | 120 898 |
| Other materials | 0 | 0 |
| Total | 144 712 | 159 792 |

Note : The response from the companies asked to report was 15/17 and included these producers :

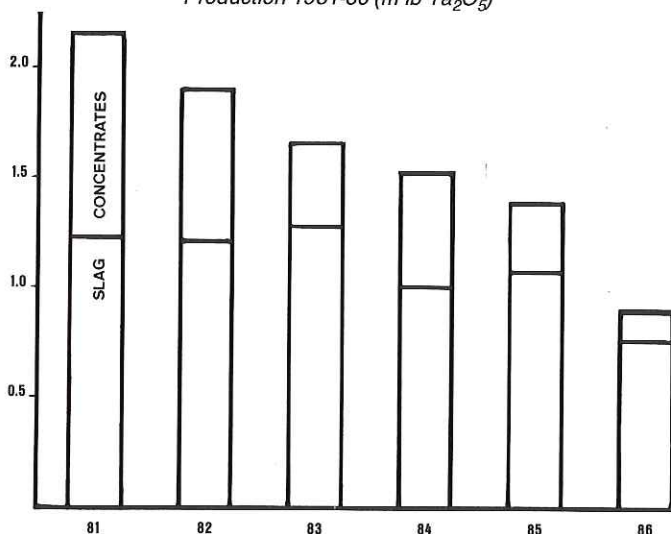
Datuk Keramat Smelting
Greenbushes
Malaysia Smelting
Metallurg Group
Tantalum Mining Corporation of Canada
Thailand Smelting and Refining

Total for 1986

| Material grade | Production | Shipments |
|---|------------|-----------|
| Tin slag (over 2 % Ta ₂ O ₅) | 760 494 | 399 105 |
| Tantalite (all grades) | 135 396 | 294 020 |
| Other materials | 0 | 0 |
| Total | 895 890 | 693 125 |

T.I.C. production data for the years 1981-86 are demonstrated graphically below (the lower part represents tantalum contained in tin slag, the upper part that in concentrates).

Production 1981-86 (m lb Ta₂O₅)



The decline which has occupied since 1981 in tantalum raw material output continued throughout 1986, the low requirements by processors for tantalite concentrates being reflected in the MB price quote of \$17-22/lb Ta₂O₅. The fall in prices for tin reduced smelter output so that tantalum produced in tin slag fell below one million lb Ta₂O₅ in 1986. This situation is expected to continue as long as tin prices remain at current levels. Production of tantalite concentrates is also often dependant on tin mining, so it too was affected by the lower world output of tin.

PROCESSORS' SHIPMENTS

4th quarter 1986

| Product category | lb Ta contained | lb Ta ₂ O ₅ equivalent |
|--|-----------------|--|
| Tantalum oxide/K ₂ TaF ₇ | 25 261 | 34 102 |
| Alloy additive | 64 750 | 87 413 |
| Carbide | 159 658 | 215 538 |
| Powder/anodes | 182 422 | 246 270 |
| Mill products | 87 404 | 117 995 |
| Scrap, ingot, unworked metal and other | 9 579 | 12 932 |
| Total | 529 074 | 714 250 |

Notes :

1. The response from the companies asked to report was 16/18 and included these processors :

Cabot Specialty Metals - Electronics
Fansteel
W.C. Heraeus
Kennametal
Metallurg Group
Mitsui Mining and Smelting
NRC
Showa Cabot Supermetals
Hermann C. Starck Berlin
Treibacher Chemische Werke
Vacuum Metallurgical Company

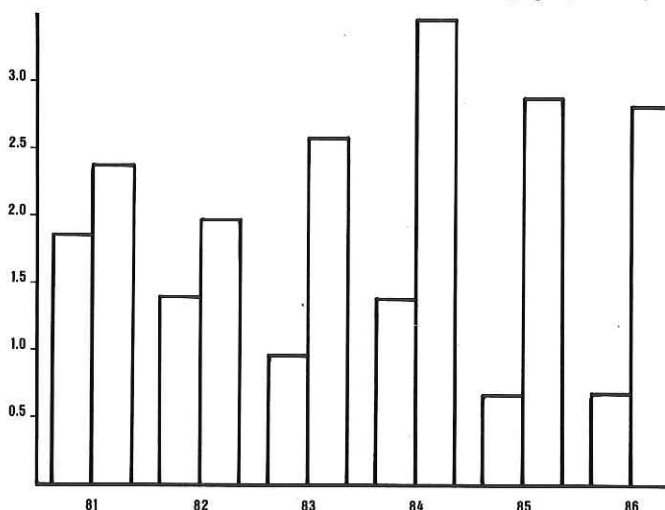
2. Reports were made in lb tantalum contained.

Total for 1986

| Product category | lb Ta contained | lb Ta ₂ O ₅ equivalent |
|--|-----------------|--|
| Tantalum oxide/K ₂ TaF ₇ | 130 215 | 175 790 |
| Alloy additive | 197 411 | 266 505 |
| Carbide | 578 986 | 781 631 |
| Powder/anodes | 710 215 | 958 790 |
| Mill products | 312 419 | 421 766 |
| Scrap, ingot, unworked metal and other | 150 823 | 203 611 |
| Total | 2 080 069 | 2 808 093 |

Raw material shipments (left-hand column) and processor demand (right-hand column) are contrasted below for the years 1981-86.

Producer shipments vs processor demand (m lb Ta₂O₅ equivalent)



Recycling of metallic and carbide scrap accounted for 10-20 % of processor demand.

Inventories were once again reduced by processors during 1986, and raw material shipments were low. But the market for concentrates and slags showed signs of improvement at year-end.

Shipments of tantalum metallic and compound products remained more or less stable throughout the year, the total only slightly down on 1985. The two major markets still lay in electronic capacitors and cemented carbides, though the alloy additive market was the fastest growing in 1986 : almost 200 000 lb tantalum were shipped for this purpose, 20 % up on the previous year. An increasing trend towards using single crystals for superalloy turbine components was responsible.

Capacitor statistics

EUROPEAN TANTALUM CAPACITOR SHIPMENTS

(thousands of units)

| | |
|-------------------------|---------|
| 4th quarter 1985 | 127 053 |
| Total for 1986 | 529 082 |

(Data from ECTSP — shipments from European manufacturers to European-located consumers only.)

JAPANESE TANTALUM CAPACITOR PRODUCTION AND EXPORTS

(thousands of units)

| | <i>Production</i> | <i>Of this, exports</i> |
|-------------------------|-------------------|-------------------------|
| 4th quarter 1986 | 615 932 | 135 545 |
| Total for 1986 | 2 297 417 | 524 438 |

(Data from JEIDA)

U.S. TANTALUM CAPACITOR SALES

(thousands of units)

4th quarter 1986

| | <i>U.S. Shipments</i> | <i>Exports</i> | <i>Total</i> |
|-----------------|-----------------------|----------------|----------------|
| Foil | 274 | 12 | 286 |
| Metal cased | 25 969 | 7 630 | 33 599 |
| Non-metal cased | 130 638 | 28 782 | 159 420 |
| Chips | 22 460 | 2 029 | 24 489 |
| Wet slug | 2 327 | 275 | 2 602 |
| Total | 181 668 | 38 728 | 220 396 |

Total for 1986

| | <i>U.S. Shipments</i> | <i>Exports</i> | <i>Total</i> |
|-----------------|-----------------------|----------------|----------------|
| Foil | 1 200 | 61 | 1 261 |
| Metal cased | 122 323 | 37 668 | 159 991 |
| Non-metal cased | 522 851 | 114 788 | 637 639 |
| Chips | 70 342 | 8 144 | 78 486 |
| Wet slug | 9 241 | 1 015 | 10 256 |
| Total | 725 957 | 161 676 | 887 633 |

(Data from EIA)