TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

BULLETIN N° 66 JUNE 1991 SECOND QUARTER

April meeting in Brussels

The T.I.C. was pleased to see thirty-five delegates of member companies and guests at the informal meeting in Brussels on April 23rd 1991. Participants heard a report on the Executive Committee's discussions of April 22nd, and an account of the work being carried out by the Technical Adviser, and also took part in a general exchange of ideas on the present and future activities of the association.

The President, Mr Peter Adams of Thaisarco, was able to report a sound financial position for the current year so that the membership fee for the year from July 1st 1991 would be maintained at the same level as in 1990-91. Members numbered 66, with several applications in prospect. Arrangements for the General Assembly in October 1991 were progressing well, and Mr Adams gave a preliminary outline of the plans for the meeting to be held from November 16th to 19th 1992 in Phuket, Thailand, including a tour of the Thaisarco tin smelter.

Mr Rod Tolley, Technical Adviser, told the group that the new statistics collecting firm, Boeye Geddes Van Gulck, had made a very promising start and he hoped that data would continue to be reported promptly by members and by the collectors. As a step towards the promotion of tantalum and niobium which was an aim of the T.I.C., he was assembling material for display on the association's stand at EMC'91, the First European Metals Conference, to be held from September 15th to 20th 1991 in Brussels.

GENERAL ASSEMBLY IN PHILADELPHIA, OCTOBER 1991

The general programme of events had been settled, including registration and a welcome reception on October 23rd, the Thirty-second General Assembly, technical presentations and a banquet on October 24th, and a field trip on the 25th to Cabot Corporation at Boyertown or to an alternative venue for those in the same industry sector as Cabot. Joint hosts and sponsors would be Cabot Corporation and Showa Cabot Supermetals. The conference and social events would be at the Sheraton Society Hill, and delegates would stay at this hotel, too.

The technical programme would take processing as its main theme, with emphasis on tantalum and niobium products and their end-uses. New materials would be discussed, and well established products, such as capacitor powder, would be reviewed. The Executive Committee was vigorously at work putting together a varied and interesting series of presentations.

Invitations will be sent to the voting delegates of member companies in early August. Several inquiries from non-member companies have already been received : others interested in attending should contact the Secretary General, T.I.C., 40 rue Washington, 1050 Brussels, Belgium, for further details.

President's letter

We have just wound up our second well-attended informal gathering in Brussels : an opportunity for T.I.C. members to meet, contribute their ideas for the conduct of our association, and to discuss future activities. Plans for the General Assembly in Philadelphia in October are well advanced, and papers to be presented will be finalised shortly; emphasis will be on the downstream and on perspectives from users of the industries' products. Variety in the presentations and programme should ensure a most interesting Thirty-second Assembly.

Peter Adams
President
April 23rd 1991

A newcomer's view of the tantalum industry

A presentation to the T.I.C. meeting in Perth, November 1990, by Mr Anthony J. Grey, Chairman of Pancontinental Mining Limited.

INTRODUCTION

The production and sale of tantalum is a boutique industry, small and high class. Annual free world demand by processors of tantalum feedstock is about 2.8 million pounds of contained Ta_2O_5 resulting in a turnover in the vicinity of US $ 100 million a year at current prices. This is not a large business by world standards. However, as the main mass constituent of capacitors, tantalum is linked to the fortunes of the burgeoning high tech electronics industry. As such it plays a vital role in the advancement of civilisation.

DEMAND

	%
Oxide and K-salt	4
Alloy additive	6
Carbides	31
Capacitor powder & anodes	41
Mill products	15
Metal & scrap	3

Fig. 1 : Tantalum demand 1989
Source : 1989 T.I.C. statistics :
total shipments 2.05 M lb, equivalent Ta_2O_5 2.77 M lb

Figure 1 shows the division of world-wide tantalum demand. The largest component is demand in the form of powders and anodes for capacitors, 41 %, followed by carbides at 31 %. The balance of 28 % is accounted for mainly by :

- Mill products 15 %,
- Alloy additives 6 %.

The total tantalum metal of 2.05 million pounds requires 2.77 million pounds of tantalum pentoxide equivalent contained in concentrates of various types.

ELECTRONIC CAPACITOR DEMAND

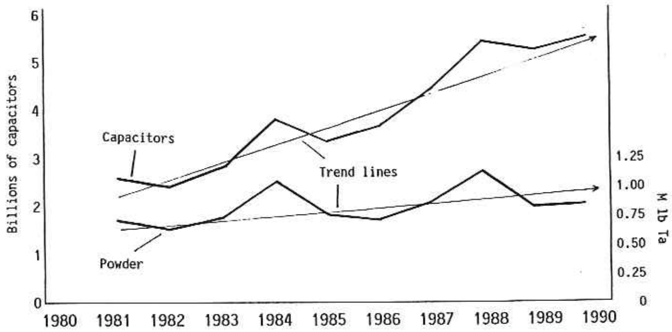

Fig. 2 : Tantalum powder and capacitor shipments
Source : T.I.C. statistics - processor shipments

Figure 2 shows the dynamic growth in demand for capacitors since 1980. This reflects the rapid expansion of the electronics industry carried on the back of robust economic activity in the industrialised

T.I.C. statistics

TANTALUM

PRIMARY PRODUCTION

(quoted in lb Ta_2O_5 contained)

	1st quarter 1991
Tin slag (2 % Ta_2O_5 and over)	198 417
Tantalite (all grades), other	187 961
Total	386 378

Note : 17 companies were asked to report, all 17 replied. The companies which reported included the following, whose reports are essential before the data may be released :

Datuk Keramat Smelting, Greenbushes, Malaysia Smelting, Mamoré Mineração e Metalurgia, Metallurg group, Pan West Tantalum (Wodgina Mine production), Tantalum Mining Corporation of Canada, Thailand Smelting and Refining

QUARTERLY PRODUCTION ESTIMATES

(quoted in lb Ta_2O_5 contained)

LMB quotation :	*US $ 30*	*US $ 40*	*US $ 50*
2nd quarter 1991	273 800	365 100	392 500
3rd quarter 1991	273 800	370 100	392 500
4th quarter 1991	279 800	370 100	398 500
1st quarter 1992	259 800	350 100	378 500
2nd quarter 1992	259 800	350 100	378 500

Note :

The quarterly production estimates are based on information available, and do not necessarily reflect total world production.

PROCESSORS' RECEIPTS

(quoted in lb Ta contained)

	1st quarter 1991
Primary raw materials (e.g. tantalite, columbite, struverite, tin slag, synthetic concentrates)	239 210
Secondary materials (e.g. Ta_2O_5, K_2TaF_7, scrap)	105 884
Total	345 094

Note : 14 companies were asked to report, 13 replied.

N.B. : Revised figures for fourth quarter 1990 :

	4th quarter 1990
Primary raw materials (e.g. tantalite, columbite, struverite, tin slag, synthetic concentrates)	586 015
Secondary materials (e.g. Ta_2O_5, K_2TaF_7, scrap)	126 143
Total	712 158

PROCESSORS' SHIPMENTS

(quoted in lb Ta contained)

Product category	*1st quarter 1991*
Ta_2O_5, K_2TaF_7	25 719
Alloy additive	43 536
Carbides	134 252
Powder/anodes	204 252
Mill products	83 416
Ingot, unworked metal, other, scrap	6 863
Total	498 038

equivalent to 672 351 lb Ta_2O_5.

Note :

14 companies were asked to report, and all 14 replied. For both receipts and shipments by processors, reports by the following companies are essential before the data may be released :

Cabot Corporation, Electronic Materials and Refractory Metals, W.C. Heraeus, Kennametal, Metallurg Group, Mitsui Mining and Smelting, NRC Inc., Showa Cabot Supermetals, Hermann C. Starck Berlin, Treibacher Chemische Werke, Vacuum Metallurgical Company, V Tech

NIOBIUM

PRIMARY PRODUCTION

(quoted in lb Nb_2O_5 contained)

	1st quarter 1991
Concentrates : columbite, pyrochlore	13 150 173
Occurring with tantalum : tin slag (over 2 % Ta_2O_5), tantalite, other	213 466
Total	13 363 639

Note :

18 companies were asked to report, 17 replied. The companies which reported included the following, whose reports are essential before the data may be released : Cambior, Mineração Catalao de Goiás, Niobium Products Co. (CBMM)

PROCESSORS' SHIPMENTS

(quoted in lb Nb contained)

	1st quarter 1991
Compounds and alloy additive : chemical and unwrought forms (e.g. $NbCl_5$, Nb_2O_5, NiNb, FeNb [excluding HSLA grades])	1 095 122
Metal and alloys : mill products, powder, ingot, scrap	129 128
HSLA grade FeNb	8 490 760
Total	9 715 010

N.B. : Revised figures for fourth quarter 1990 :

	4th quarter 1990
Compounds and alloy additive : chemical and unwrought forms (e.g. $NbCl_5$, Nb_2O_5, NiNb, FeNb [excluding HSLA grades])	1 142 796
Metal and alloys : mill products, powder, ingot, scrap	133 600
HSLA grade FeNb	6 317 902
Total	7 594 298

Note :

15 companies were asked to report for the first quarter 1991, all 15 replied. Reports by the following companies are essential before the data may be released : Cabot Corporation, Electronic Materials and Refractory Metals, Greenbushes, W.C. Heraeus, Kennametal, Metallurg Group, Mitsui Mining and Smelting, Niobium Products Co. (CBMM), NRC Inc., Hermann C. Starck Berlin, Teledyne Wah Chang Albany, Treibacher Chemische Werke, Vacuum Metallurgical Company

Capacitor statistics

U.S. TANTALUM CAPACITOR SALES

(thousands of units)

4th quarter 1990

Foil	124
Metal-cased	15 859
Moulded	55 408
Dipped	81 229
Chips	81 291
Wet slug	1 669
Total	235 580

(Data from EIA)

EUROPEAN TANTALUM CAPACITOR SHIPMENTS

(thousands of units)

4th quarter 1990 150 645

(Data from ECTSP)

JAPANESE TANTALUM CAPACITOR PRODUCTION AND EXPORTS

(thousands of units)

4th quarter 1990

Production	1 169 807
of which exports	268 868

(Data from JEIDA)

countries where GNP has risen by 33 % in the decade. The number of tantalum capacitors shipped rose by 140 %.

I should say a word or two about the scale used in this figure. The left hand vertical axis shows the number of capacitors in billions. The right hand vertical axis shows the number of pounds of Ta_2O_5 in millions.

We have put in a trend line which is drawn from a mathematical formula that smoothes the fluctuations in the statistics and in so doing illustrates the general direction in which they are heading.

The figure also demonstrates that tantalum powder demand has risen less rapidly than overall capacitor demand recently. Tantalum powder shipments rose by 40 %. For the first part of the decade the two were in lock-step. However from 1985 onward the growth curves decoupled with tantalum powders growing at a slower rate.

There are two basic reasons for this decoupling :
- Miniaturisation of capacitors in the electronics industry,
- More efficient tantalum utilisation.

The trend towards miniaturisation generally has been very strong in the last two decades and this is likely to continue, for miniaturisation is clearly linked with increased efficiency. Because of greater tantalum price sensitivity arising around the turn of the decade, a factor which I will be dwelling on at greater length later, users swung to the better quality end of the resource base. This permitted lower physical tantalum consumption per capacitor thereby offsetting, to some extent, the effect of high tantalum prices.

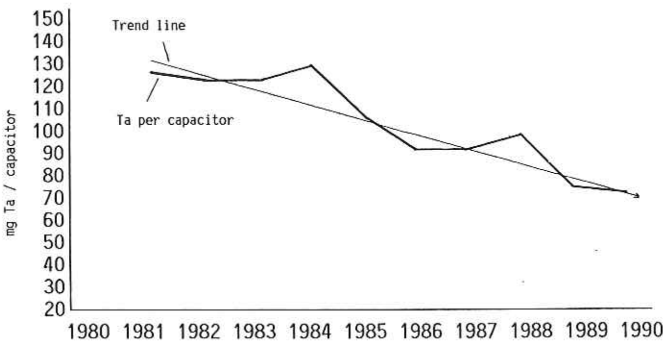

Fig. 3 : Apparent tantalum per capacitor
Source : T.I.C. statistics

Figure 3 illustrates the consequence of these features. As you can see the weight of tantalum per capacitor is reducing. This is not necessarily a threat to our industry. In a way it ensures the long term necessity for it. To the extent that tantalum has physical properties which allow the trend towards miniaturisation to continue to a greater degree than would be possible using other materials, it has a significant competitive advantage. Thus it is possible to say "the trend can be our friend".

CARBIDE DEMAND

The use of tantalum in carbides is the second largest source of demand. On an overall basis the demand for carbide compounds has stalled since technological advances in metal cutting and shaping have reduced the quantity of carbide raw materials required. However, within the carbide industry tantalum carbide demand is continuing to prosper because new applications are being found for its final products.

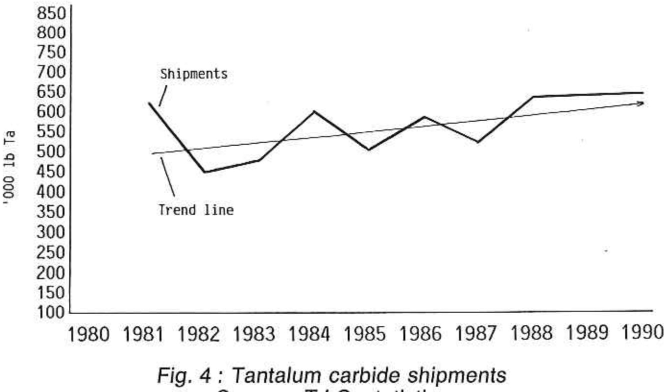

Fig. 4 : Tantalum carbide shipments
Source : T.I.C. statistics

Figure 4 shows a relatively healthy growth trend. In terms of the trend line, tantalum carbide shipments rose by 26 % over the last decade, a rise not too different from GDP growth in the industrialised countries.

PRICES

As we would expect, the electronic and industrial markets are vigorously competitive. Tantalum products face the discipline of substitution. Layered ceramic and aluminium capacitors can replace tantalum based capacitors. Other carbides, for example niobium, can substitute for certain tantalum carbide applications.

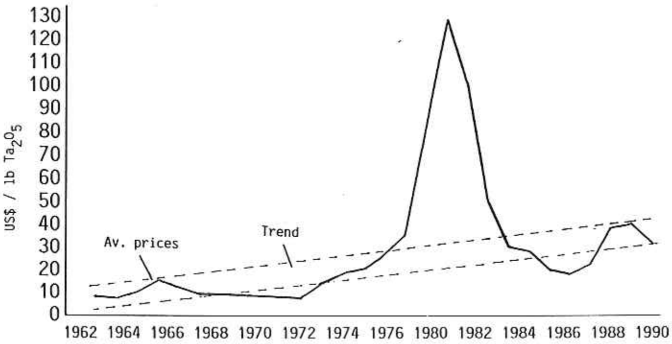

Fig. 5 : Average annual prices of Ta_2O_5 in concentrates 1963-1990
Source : 1963-1983 : US Bureau of Mines
1983-1990 : Metal Bulletin quote

As Figure 5 demonstrates, over the past three decades, with the exception of the five years from 1978 to 1982, prices of Ta_2O_5 fluctuated within a range that was relatively stable.

For this figure we did not draw the trend as a mathematical smoothing line because the short term aberration would create a misleading distortion. Instead we drew a free hand line that demonstrates intuitively the basic direction.

There was a wild aberration in the price during the period of 1978 to 1982 with a sharp mountain peak occurring in 1980. As could easily be imagined, these runaway prices caused perturbations throughout the consuming side of the industry. Processors were forced to pass a large part of these price increases on to the end users causing a reaction away from the utilisation of tantalum. Market penetration of tantalum was pushed back by inter-material substitution.

When prices for a commodity escalate in this fashion, the adverse consequences on future consumption patterns are caused not only by the absolute price but also by concern as to how much further the price will rise in the future. Fears of the unknown are reflected in anxieties about reliable access to supply at any economic price. These uncertainties propel the market to develop alternatives to cope with the reduced reliability with which the producing side of the industry is perceived. Damage, once done, is very difficult to repair, and constitutes a task that can only be accomplished over a long period of time.

PRICE EFFECTS ON DEMAND

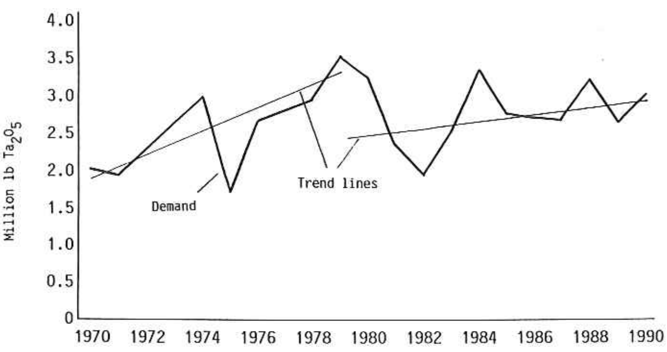

Fig. 6 : Free world demand for Ta_2O_5 1970-1990
Source : 1970-1985 O'Rourke (1986) & Linden (1985)
1986-1990 T.I.C. statistics

Figure 6 shows the net free world demand pattern over the last twenty years : as you can see there is a major break in the trend line occurring at the time of the price aberration. The price hike was followed by three years of plummeting demand. By 1982 the slump was over and demand adjusted to a growth pattern but at a more subdued pace and from a lower base.

During the period of high demand and runaway prices, processors were forced to move to higher grade tantalite concentrates in order to maximise their production from existing plant capacity. They did not have time to expand their production facilities.

Scarcity of raw materials drove the price up and caused several effects :

- Rising costs of tantalum feedstock had to be passed on to consumers;
- Processors developed scrap recycling capacity to reduce the impact of rising tantalite prices;
- Processors began accumulating feedstock inventories for security of supply that later on overhung the market when demand returned to normal;
- Processors developed better quality tantalum powders to maintain competitiveness;
- Inter-material substitution occurred, with layered ceramic and aluminium capacitors leading the charge. Normal tantalum carbide mixtures were replaced by other carbides and the use of tantalum-poor substrates coated with normal grades of tantalum carbide increased.

While some positive features can be discerned in this reaction, the overall effect of the price escalation destabilised the industry and benefited competitive materials. Many consumers turned away from tantalum products and most of these have not come back.

The trend line in Figure 6 shows that :

a. Up to one million pounds per annum of Ta_2O_5 demand was lost in 1980. Much of that is permanently gone;
b. Growth rates in Ta_2O_5 demand dropped from about 90 % per decade in the 1970's to about 25 % per decade in the 1980's.

Changes in general economic growth do not explain the decreased growth rates.

The detailed market survey conducted in 1982 by the Tantalum Producers International Study Center attributed half of the fall in demand during 1980 and 1981 to the then global economic recession and draw-downs on manufacturers' inventories.

The other 50 % fall in demand was attributed to :

1. Use of higher-charge capacitor powders thus reducing the weight of tantalum per capacitor;
2. Substitution of alternative products for tantalum generally;
3. Increased recycling to substitute for "virgin" tantalum products.

These demand-reducing processes were accelerated by price volatility.

In the 1970's the aggregated real GDP of industrialised countries rose by 32 % and the free world demand for Ta_2O_5 rose by 92 %. On the other hand in the decade of the 80's the aggregated real GDP of industrialised countries rose by 33 % while the free world demand for Ta_2O_5 rose by 23 %.

As the graph illustrates, the tantalum industry has had a roller coaster ride over the past twenty years. There was a precipitous drop in demand in 1974 which was presumably attributable to the international recession following upon the first oil shock. Then the great build up occurred which culminated in runaway prices. The excessive price increase propelled a G-force dive in demand which hit bottom in 1982 when the roller coaster started back up. In more recent times however the oscillations are becoming smaller — a trend which is encouraging.

Fundamentally most of the damage to demand can be attributed to the events of that fateful five year period, 1978 to 1982. It meted out a harsh lesson from which all members of the industry both on the producer side and the consumer side should take instruction.

SUPPLY

Supply of tantalum products is in two stages :

- Producers of raw material feedstock : Ta_2O_5
- Processors who convert raw materials to products : tantalum.

Both segments of supply are dominated by relatively few organisations.

	%
Wodgina	8 to 12
Greenbushes	8 to 12
Tanco	8 to 12
Syncons	30 to 40
Thaisarco	8 to 12
China	8 to 12
Brazil	5 to 10
Africa	2 to 5
Others	1 to 2

Fig. 7 : Tantalum producers 1990
Source : Pancon estimates
Total production 2.5 M lb Ta_2O_5

Figure 7 shows the Ta_2O_5 producers as they are in 1990. Since figures are not officially published for the supply side, we have given ranges that encompass our "guestimates". We could not draw the pie chart, of course, without precise figures so we composed it on the basis of our best guess. The absolute statistics are not so important as we are seeking merely to demonstrate the approximate proportions. Synthetic concentrates (Syncons) produced by H.C. Starck and GfE from old and new low grade tin slags account for 20 % to 30 % of production. In addition, high grade tin slags produced by Thaisarco of Thailand account for a further 10 % to 20 %.

Three primary tantalite mines, Wodgina and Greenbushes in Western Australia and Tanco in Canada supply 20 % to 30 % of Ta_2O_5 in high grade concentrates. Overall six producers control about 85 % of the world's Ta_2O_5 production.

Similarly, three firms, H.C. Starck, Cabot and GfE, control about 85 % of the world's tantalum processing.

Since there are relatively few players it should be possible to achieve a broad consensus of views of how the industry can achieve a healthy long term growth based upon reliable supply at economic prices. In order to achieve this consensus, there is no need to risk falling foul of relevant legislation outlawing anti-competitive activity.

Figure 7 also demonstrates how dependent the world is on secondary sources of Ta_2O_5. Around half of the world's supply comes from the re-processing of tin slags, an activity that is dependent for its raw material supply upon events totally outside the control of the tantalum industry. The outlook for the world tin industry is dubious at best and the future availability of tantalum bearing tin is even more so.

The regulated tin market collapsed in 1985 and the International Tin Council ceased its tin price maintenance activities. This occurred k-prone period of time. The supply side of the industry too late to prevent the development of Brazil's large tin reserves, especially the Pitinga project. Brazil's tin slags are tantalum-poor and the main by-product from their industry is columbium, not tantalum. Tin production from South East Asia is declining, probably irreversibly as Brazil's tin production continues to grow vigorously.

It is not healthy for an industry to rely so heavily on sources of raw material, the availability of half of which is determined by events completely outside its control. While perhaps it can be said that there are presently large supplies of Ta_2O_5 available in existing tin slag stockpiles, that is not a long term solution to the issue of reliability of supply. It is essential that the primary production component of supply be increased. For that to occur it is necessary for an economic price structure to be present that gives incentive to the primary producers to develop and produce from their existing reserves and to conduct the necessary exploration to replace them when depleted. There is no doubt that there is sufficient exploration potential for tantalite ores throughout the world to accomplish this task but it will not be undertaken unless there is adequate economic incentive.

Pancontinental entered the tantalum business because we saw this need to increase the role that primary producers play in the supply of tantalum. Our exploration team identified the Pilbara region of Western Australia as being highly prospective for tantalum since it contains some of the most extensive pegmatite occurrences in the country. Accordingly we farmed into prospective areas and were fortunate in discovering significant tantalum reserves. Wodgina which is the base of our present operations and in which we have a 50 % interest and are the operator, has approximately one million pounds contained Ta_2O_5 in ore at a grade of around three pounds per tonne. In addition our joint venture has about 4.5 million pounds in the measured, indicated and inferred categories at different locations in the vicinity. The principal one of these is Mt. Cassiterite where we have discovered a resource of indicated and inferred material consisting of 3.5 million pounds contained Ta_2O_5. The grades, while economic because of the near surface presence of the ore, are about half those at Wodgina.

Currently Wodgina is producing at a rate in excess of 200 000 pounds per year. Since we expect to produce tantalum from more than one deposit in the future, we have named our enterprise Pan West Tantalum. The production and resource base is sufficient to allow us to conclude that Pan West is, and will be, a major producer of tantalum for a very long time.

We consider it our role to provide to the industry a long term secure source of supply based upon grades and costs that are competitive.

Figure 8 shows the realities which the industry must face concerning its source of supply and how the make up is changing.

The chart demonstrates that there are three distinct phases over the last fifteen years. The first is the period 1975 to mid 1979 (the year of the great price hike) where primary production and total production trends were in lock-step. In the second phase which ended in 1988, both sources of supply declined as excessive inventories built up after the price rises were worked off. An unhealthy situation occurred in 1983 and again in 1985 to 1988 where consumers were forced increasingly to rely on secondary sources from the tin slag processing

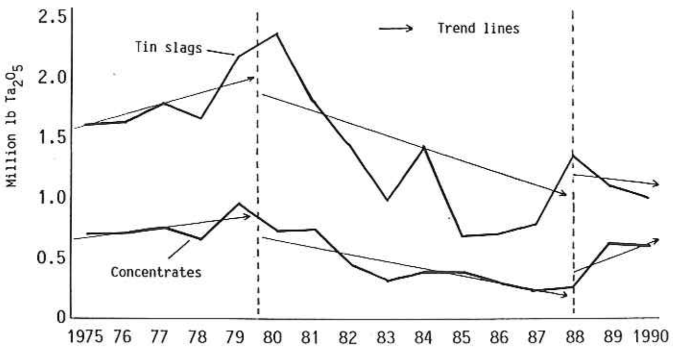

Fig. 8 : Shipments of primary concentrates & tin slags
Source : T.I.C. statistics

because primary production was not available in sufficient quantity at prevailing prices. Generally however throughout this period primary production began to play a larger role relatively as a supplier. This function is seen by the converging of the two trend lines on the graph. In the third phase, primary production turned up for the first time in nine years stimulated by a more encouraging price structure while secondary sources turned down. The two trend lines are now on a converging path but the world is not yet able to count heavily enough on primary production.

Concentrate production has been steadily rising from a low in 1987 and, if prices can be maintained at economically motivating levels, this trend can continue and compensate for the expected decline in availability and supply of tin slags.

CONCLUSION

The severe lessons of history cannot be ignored. There is an Old Russian proverb which says : "Dwell on the past and you will lose an eye; ignore the past and you will lose both of them". Mistakes were made on both sides of the industry which have resulted in more turbulence than was necessary. Consumers need reliability of supply at reasonable prices. Producers require adequate prices to allow them to earn a reasonable rate of return on their investments which are characterised by very high risk. These returns must support a sufficient amount of exploration which by its nature can only be expected to result in success over a long and risk-prone period of time. The supply side of the industry cannot provide the consumers with the required amount of reliability unless a much higher proportion of it is represented by primary production. For the industry to mature to this level of equilibrium it will be necessary for consumers and producers to discuss their problems with each other in a constructive manner, obviously avoiding anti-trust pitfalls.

Hopefully this conference will provide a conducive venue for such an exchange of views.

Niobium : The key to commercial superconductivity

Presented by Mr William K. McDonald, President, Teledyne SC, to the T.I.C. meeting in Perth, November 1990.

INTRODUCTION

Niobium has been generally considered to be useful as an alloy additive to iron and nickel alloys. Other applications have been specialized and interesting, but the refined element has not been a basis for any significant industry, until now, and that is superconductivity.

The industry of superconductivity is struggling to get established and become a major entity in the world of business. One of the technologies has been centered around niobium-based superconductivity, and prospects for major applications are on the threshold of emergence.

PROLOGUE

I will review the current and prospective applications later, but first a description of the special characteristics for superconductors will be interesting.

When dealing with superconductivity, it is desirable to develop wires which can carry very large densities of current. By comparison, where your household circuit might be limited by a 20 amp fuse, the same size superconducting wire would be limited by a 20 000 amp fuse. A cable with 1 000 household wires of copper would be required to carry the equivalent maximum current. A very special difference is that the superconductor transports large currents without generation of heat from electrical resistance. This analogy is an obvious simplification for the purpose of comparison, but it helps visualize the characteristic of high current density in Nb-based superconductors.

The benefit of high current density without resistance is utilized in the manufacture of very strong electromagnets with a manageable volume of material. Typical superconductor magnets operate at 5 Tesla. The giant electromagnets used in junk metal yards, as depicted in James Bond movies, are only 2 Tesla. Special, small superconductor magnets are regularly manufactured which operate at 10 Tesla to 12 Tesla, and technology is moving toward 15 Tesla magnets. Those great junkyard magnets are small by comparison with the magnetic field strengths of superconductor magnets, 2 Tesla compared to 15 Tesla. These very high field strengths are so strong that structural material must be skillfully selected and designed to be able to resist the crushing forces generated by the magnetic field.

The most cited difficulty, or limitation, for low temperature superconductors such as Nb is the need to cool the conductor below the transition stage. Useful superconductors have a high resistance to electrical current flow at normal temperatures, but zero resistance below the critical transition temperatures. As temperature is reduced further below the critical temperature (T_c), the current density of the superconductor increases. That means it is desirable to make the superconductor as cold as possible, and reasonable, for a given application. The useful temperature for most Nb-based superconductors is the temperature at which helium liquifies, 4.2 degrees Kelvin (−269 degrees Celsius).

The good news for niobium is that the cryogenic technology for generating 4.2 °K is advancing rapidly. Development work is quietly underway to provide reliable and efficient devices, called crycoolers, which will readily generate the necessary temperatures for niobium superconductors. It is probable that improved crycoolers will greatly moderate the touted advantage of the new "high temperature" superconductors.

TECHNICALLY SPEAKING

Nb, alloyed with Ti, is highly malleable. The superconducting alloys contain 47 weight percent Ti, and are cold deformed to area reductions typically ranging from 2 million to 2.5 million to 1.

The metallurgical characteristics of the NbTi alloy have been exploited to raise the performance of the finished product. This exploitation develops through painstaking control of the alloy's metallurgical response to thermal and strain cycles. The alloy is a solid solution body centered cubic structure in equilibrium at room temperature. At slightly elevated temperatures, additional phases of different structure and alloy composition can be precipitated from the matrix alloy. The dominant, and preferred, phase is a titanium rich hexagonal structure called alpha. Alpha Ti does not superconduct, but provides the benefit of flux pinning for the superconductor during operation.

A characteristic of superconductors is the exclusion of magnetic flux, well known as the Meisner Effect. Flux exclusion produces the floating pellets shown frequently in pictures depicting the new superconductors, called the high temperature superconductors. Magnetic flux is only excluded when conditions are right. A group of parameters must each be below a maximum level for flux to be excluded, and these include temperature (T), electrical current density (J), and magnetic field strength (H), or flux penetration strength. When the temperature and current are low enough below the critical or "normal" values, flux will not penetrate the superconducting material until a critical field strength is reached (H_c). When H_c is reached, flux penetrates the material and transition from superconducting to normal material takes place. This is undesirable.

NbTi is a type of material which can be made to resist flux penetration by developing tiny regions of material which pin the flux. That means that by developing a resistive sub-structure in the superconducting matrix, the performance of the NbTi alloy can be improved dramatically. This improvement is accomplished by developing the alpha titanium precipitation network through a series of controlled strain/age cycles. The desired result is a volume of precipitates equal to 25 % of the total volume, with precipitate dimension of the order of 10-15 nanometers wide, spaced 10-15 nanometers apart, uniformly distributed throughout. By comparison, a human hair is about 75 000 nanometers in diameter.

The NbTi alloy provides a unique set of metallurgical characteristics which enables it to be formed into a superconducting filament as small as 6 microns in diameter (a hair is 75 microns), in continuous lengths of 40 000 kilometers and more, and be wound and twisted into braids and cable suitable for manufacture of giant electromagnetics for service in many new and exciting devices.

APPLICATIONS

The applications for superconductivity have been in the embryo stage for 15 years, but some births are now imminent.

Accelerators

A much discussed application is the Superconducting Super Collider (SSC). This device is a particle accelerator, 54 miles in circumference, which will accelerate protons (hadrons) to near the speed of light and collide them with each other. The collision energy will be about 20 trillion electron volts, an energy which has never been measured and dissected by quantum physicists. The structural components of hadrons, called quarks, will be released by collisions, then recombine. New wonders of our universe and its workings will be revealed. This great device is dependent on Nb for its life, and 3 million pounds of refined Nb will have been used when the SSC is complete, with current completion projections about 1999.

Another US accelerator, the Relativistic Heavy ion Collider (RHIC), is projected for completion in the mid 1990's. The RHIC is interesting in that it will accelerate nuclei of lead (for example), with all the electrons removed, and generate collisions. Again, new aspects of matter not yet revealed will be shown by the RHIC, and this device is possible only because of Nb in its form as a useful superconductor. RHIC will need about 30 000 lb of Nb to build the necessary superconductors.

As a footnote to particle accelerators, the first significant use of superconductors was for the Fermi Lab accelerator called the Energy Doubler. The Doubler used about 120 000 lb of refined niobium. Because of the Doubler, a fledgling industry of superconductor manufacturers was able to get a foothold, and these new accelerators are sure to add some needed reinforcement to a very important industry.

SMES

Nb superconductors are the basis for the very exciting concept of storing electrical energy as a direct current, without incurring the resistance losses of normal conductors. These devices are called Superconducting Magnetic Energy Storage (SMES). The electricity will be collected into SMES and made available for immediate use in any amount up to near total design capacity, with a 96 % return efficiency. That means that the energy required to cool SMES, and the energy lost at the switches will only be 4 %, compared to the best present storage of pumped water which has a 30 % loss.

SMES promises greatly improved efficiencies of operation for all types of energy generators, including dams, coal burners, nuclear, and intermittent types like wind, solar and tidal. SMES can be constructed almost anywhere, and there is no pollution except the steady magnetic field generated by the stored current flowing in the closed loop of superconductors.

Even the magnetic field condition of SMES is considered to be a tenable problem. The problems associated with power lines are related to alternating currents and the resultant changing fields. Steady state peripheral fields have not been shown to be harmful to biological organisms, but pace makers and credit cards should avoid them.

Nb usage in SMES devices will start on a small scale, about 150 000 lb for the first small Engineering Test Model (ETM) of SMES. The proposed full scale SMES commercial units will be about 10 times larger in order to utilize some beneficial economies of scale. The need for SMES in the US today, once ETM demonstrates its usefulness, is for 20 full scale devices annually for 15 years in order to meet a 4 % annual growth. Ideally, no new energy generating devices would be needed in the US for 15 years because the existing excess capacity needed for peak loads would be efficiently utilized through direct storage.

SMES answers problems of energy generation pollution. Existing generating units will be able to operate at optimum efficiency and any excess energy will be stored. This is analogous to driving your car at 55 mph (88.5 kph) rather than ranging from stop through 100 mph (160.9 kph). Fossil fuel is used at optimum efficiencies so energy output per unit of generated pollution is improved. The analogy follows for nuclear power, hydro power, and all other types of generation. Since, ideally, new generators would not be required for 20 years, additional pollutants associated with new energy generation would be avoided. Problems of acid rain, nuclear waste, and the greenhouse effect are abated.

Once again, Nb makes the great benefits for SMES possible because of the application in superconductors. With rapid construction and the anticipated success of the ETM for SMES, first commercial units could begin as early as 1998. With each "full scale" commercial unit consuming about 1 $\frac{1}{2}$ million lb of Nb, 20 units needed annually in the US alone and maybe 5 to 10 units scheduled for construction worldwide, a 7 year construction schedule calls for about 1 to 2 million lb of Nb consumption annually for SMES superconductors. The need is imminent, and is a strong prospect to be underway by the late 1990's.

Mag Lev

Although the prospects for SMES are great, and imminent, the excitement does not end there. Another project of great importance to our social structure, as well as the highly visible pollution issue, is transportation by magnetically levitated trains (Mag Lev). In the US, Senator Moynihan is energetically sponsoring legislation directing the development and implementation of Mag Lev. These Mag Lev trains are being demonstrated in Japan and Europe today. The method is to lift a train a few inches off the ground and propel it along a guideway, using magnets. One of the technical approaches uses superconducting magnets to generate the high strength fields necessary for lift and propulsion.

Mag Lev trains are envisioned to replace air travel along the short distance corridors of high passenger miles. These corridors are 600 miles or less, and represent highly inefficient operation routes for commercial airlines. With an increasingly mobile population, airports are reaching a saturation level, and alternatives for relief are necessary. Mag Lev offers an attractive option to airplanes. The airlines are expected to recover the cost of Mag Lev implementation through operating efficiencies in 10 to 20 years. They will enjoy the increased revenues from the growth of passenger miles, reduction of pollution from jet aircraft (both noise and fuel) will be accomplished even though travel increases, congestion at airports will be controlled, and travellers will be better accommodated.

Nb usage for Mag Lev will be about 50 000 lb per train system per corridor, and the US projects the eventual need for about 100 corridors. Mag Lev is already a technically demonstrated system. Adoption in the US would take 7 years for initial implementation, and 20-30 years of continued construction. This application could use about 5 000 000 lb of refined Nb starting about 1997 through about 2015.

MRI

Physicians use imaging devices to view the insides of our bodies. Computerized Axial Tomography (CAT) scanners are familiar. These machines use X-Rays to see inside us, and X-Rays have associated health concerns. Another method has been developed to evaluate body tissue very effectively. It is called magnetic resonance imaging (MRI). MRI uses the magnetic aspect of some elements, particularly hydrogen, to evaluate the nature of associated tissue. The method is to use a strong magnet to align the magnetic poles of the appropriate atoms, then release the magnet and observe the rate at which the poles return to their original angle of spin. The changing pole angle emits a detectable signal which is evaluated by computer and formed into an image. The magnets used for MRI are predominantly superconducting. The MRI industry is the first major commercial application for refined Nb upon which an industry can be based.

The MRI industry utilizes about 100 000 lb of Nb annually, and growth is expected at about 10 % a year.

To summarise :

I. Niobium is the best basis for the superconductor industry.
II. Superconductors provide high current density with no resistance.
III. Niobium is malleable : it can accept more than a 2 000 000 to 1 area reduction. It forms an alloy with titanium, producing an alpha phase which pins magnetic flux. The result is a uniquely high current density for the generation of magnetic fields.
IV. These are applications which have been developed over the past 15 years :
   1. Accelerators
   2. SMES
   3. Mag Lev
   4. MRI or MRS

   and other likely uses lie in ship propulsion; ore separators; generators; MHO and fusion.

A superconductor industry based on refined niobium has excellent prospects for development. Proposed applications and projects would require millions of pounds of refined niobium each year for periods extending over several decades. We are on the threshold of emergence of applications for superconductors which border on science fiction. It is an exciting time both for the technology of superconductivity and for the utilization of refined niobium.

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