TANTALUM INTERNATIONAL STUDY CENTER

BULLETIN N° 46 APRIL 1986 SECOND QUARTER

Twenty-fifth General Assembly and associated meeting

The meeting will take place at the Kobe International Convention Center and the Portopia Hotel, which form part of the same complex on "Port Island" in Kobe, Japan. Three member companies will host the meeting : Mitsui Mining and Smelting, Showa Cabot Supermetals and Vacuum Metallurgical Company.

MONDAY MAY 19TH 1986

Registration.

Cocktail Party in the Kairaku Room of the Portopia Hotel, 6 p.m. - 8 p.m.

Dinner at leisure.

TUESDAY MAY 20TH 1986

9.30 a.m. Twenty-fifth General Assembly of the T.I.C. in the Conference Room of the Convention Center. Attendance is limited to delegates of member companies.

10.30 a.m. Coffee break : guest delegates from non-member companies join the meeting.

11 a.m. Presentation of papers

Mr Y. Takekuro, President,
Japan Society of Newer Metals, Tantalum Committee :
"History of tantalum industry in Japan and its problems"

Dr K. Tachikawa, Director,
Tsukuba Laboratories, National Research Institute for Metals :
"Recent progress in superconductors"

Mr N. Matsuda, Director,
Basic Industries Bureau, Non-ferrous Metals Division, Ministry of International Trade and Industry (MITI) :
"Japan's resources policy for non-ferrous metals"

Mr L.S. O'Rourke, Vice President,
Cabot Corporation :
"Perspectives on the development of the tantalum industry"

Dr H. Wada, Staff Manager of Engineering Section,
Showa Cabot Supermetals KK :
"Behaviour of oxygen in tantalum"

Mr T. Mori, Miike Plant Manager,
Mitsui Mining and Smelting Co., Ltd. :
"Tantalum/niobium industry at Mitsui Mining and Smelting Co., Ltd."

It is also hoped that a speaker from China will give a presentation, but this is still under negotiation.

From 12 noon to 1.30 p.m. there will be a buffet lunch : all delegates and guests are invited as the guests of the T.I.C.

4 p.m. Meeting adjourns.

In the evening the host companies invite all the participants and their ladies to a banquet dinner, in the Kairaku Room of the Portopia Hotel.

WEDNESDAY MAY 21ST 1986

A choice of two plant tours will be offered : the capacitor plant of NEC Kansai at Ohtsu or the Sintered Alloy Division of Sumitomo Electric Industries at Itami. NEC Kansai is the Electronic Component and Semiconductor Division of NEC, a world leader in communications and computers. They are the largest tantalum capacitor manufacturer in Japan. The Sintered Alloy Division of Sumitomo Electric Industries manufactures a range of powder metallurgical products, including cemented carbide cutting tools which contain tantalum and niobium carbide.

Information concerning the meeting may be obtained from The Secretary, T.I.C., Rue Washington 40, 1050 Brussels, Belgium.

TWENTY-FIFTH GENERAL ASSEMBLY TO BE HELD AT 9.30 A.M. ON TUESDAY MAY 20TH 1986 IN THE KOBE CONVENTION CENTER, KOBE, JAPAN

AGENDA

1. **Voting proxies.**
2. **Minutes of the Twenty-fourth General Assembly (held in Brussels on October 22nd 1985).**
3. **Modifications to the Charter.**
4. **Membership :**
   applications,
   resignations.
5. **Report of the Executive Committee.**
6. **Statistics.**
7. **Niobium interests.**
8. **Forthcoming General Assemblies :**
   Twenty-sixth : Brussels, October 20th-21st 1986,
   Twenty-seventh : Brazil, May/June 1987.
9. **Other business.**

Telecopier

A telecopier, model Panafax UF/400, has been installed in the building where the T.I.C. has its offices : the number is 02/649.32.69, identification code INAC B TELEFAX.

There is no operator near the machine, so the telephone will not normally be answered except by the machine itself. Would all T.I.C. member companies please supply us with their telefax number.

President's letter

The Twenty-fifth General Assembly will be held in Kobe, Japan, May 19th through May 21st, and will include visits to Sumitomo Electric Industries, Sintered Alloy Division, Itami Works, and NEC Kansai Ltd, Ohtsu Plant. It is my pleasure to welcome you to Japan in the most pleasant season. I hope that you will all add this General Assembly to your schedule.

Kobe, as the largest international trading port of Japan, has been making a tremendous contribution to Japan's industry, economy and culture. Kobe and its immediate surroundings offer a very special environment : the sea, rolling hills and mountains, the distinctly international — almost exotic — flavour, the wide range of international cuisine, and residents from 74 nations. The port city of Kobe, with all of this, is an open and friendly city.

The International Convention Center, where our General Assembly will be held, and the hotel where we will be staying, are conveniently located in the central part of Port Island.

The speakers for our Twenty-fifth General Assembly are :

Mr Y. Takekuro,
President, Japan Society of Newer Metals, Tantalum Committee

Dr K. Tachikawa,
Director, Tsukuba Laboratories National Research Institute for Metals

Mr N. Matsuda,
Director, Basic Industries Bureau Non-ferrous Metals Division, Ministry of International Trade and Industry (MITI)

Mr L.S. O'Rourke,
Vice President, Cabot Corporation

Dr H. Wada,
Manager, Showa Cabot Supermetals KK

Mr T. Mori,
Miike Plant Manager, Mitsui Mining and Smelting Co Ltd.

Chinese speaker
(under negotiation).

I hope that each of you will be able to attend. Should you be unable to do so, and you are your company's voting delegate to the T.I.C., please give your proxy to another delegate so that all of our member companies will be represented during the business sessions.

T.I.C. is continuing to grow in membership. We are now chartering, not only for tantalum, but for niobium. I hope this assembly can contribute to our further growth in the future, and wish to ask the co-operation of each of you for such growth.

The literature on this General Assembly is being sent from the T.I.C. office in Brussels.

I look forward to seeing each of you in Kobe, Japan.

Sincerely yours,
Chikara Hayashi,
President

The tantalum market in 1986

For the tantalum industry, 1985 was a recession year; this year — 1986 — is predicted to be a period of expansion — at least for a section of the industry. Capacitor manufacturing, the single largest consumer of the metal, has been forecast to experience growth in 1986. The boom anticipated last year in personal computers, a major market for tantalum capacitors, did not materialise. US sales (in constant dollars) actually decreased by 3.8 per cent over 1984 : during this year, however, sales are likely to exceed those in 1984. US sales of all electronic equipment are forecast to increase by 6.3 per cent over 1985. This was according to Mr Carroll Killen, former T.I.C. President, speaking to the Twenty-fourth General Assembly last October. Mr Killen went on to say that equipment manufacturers had reduced their inventories of tantalum capacitors considerably during 1985 but were expected to increase them again slightly in 1986. US shipments plummeted to 886 million units (estimated) in 1985, down 24 per cent from the previous year. But a pick-up will occur, and shipments will achieve 1282 million units in 1986. This increase of 45 per cent over last year's shipments will not be entirely due to higher equipment sales or inventory build-up : consumption of tantalum chips, currently around 6-7 per cent of US shipments, is expected to experience substantial growth. Surface Mounted Technology (SMT) is the reason for this optimism. This is a rapidly-advancing technique for attaching electronic chip components to a circuit board, involving temperatures of 260 °C to 320 °C which conventional aluminium capacitors cannot tolerate, but tantalums can. And so tantalum chip capacitors have the opportunity to displace some aluminiums from their traditional markets.

In Japan, tantalum chips already account for 25 per cent of total tantalum capacitor sales (in 1985). This is expected to increase to 30 per cent this year, according to one leading manufacturer. Overall shipments in Japan will achieve 2190 million units in 1986 — 10 per cent up on last year. Individual chip capacitors do not use a large amount of material : less than 15 per cent of the average quantities of tantalum used by metal-cased and molded capacitors. So in Japan, the increased demand for these components, mentioned previously, may not account for more than 5000 lb of tantalum over the entire year. Because of higher charge powders and smaller diameter wire being developed in the future, tantalum requirements will not increase proportionally with capacitor production.

The metal-cutting tool industry will consume the same quantity of tantalum for cemented carbide in 1986 as last year, say leading producers. This is still 10 per cent down on 1984 shipments, when substitution for TaC due to high prices and technological advances was being reported. Since then these movements have slowed down, the main reason being stable prices which have reduced the drive for substitution. The influence of coated tools, which resulted in less TaC being used in the substrate, has also levelled out. More important for consumption are recycling processes : zinc and chemical. These currently displace around 30 per cent of virgin TaC requirements and new zinc process capacities are being planned. Overall consumption, in the US especially, is dependent on automobile production : smaller vehicles are being built which means less metal being cut. The drive for smaller-sized vehicles was brought about by high fuel prices. Because oil prices have collapsed, it is conceivable that this trend towards smaller vehicles will be slowed down or even reversed, resulting in increased tool use. However, long-term prospects for growth in TaC consumption are not encouraging.

An application for tantalum which is well-established — and growing — is as an alloy additive to superalloys, normally nickel-based and directionally-solidified for turbine blades in aircraft jet engines. Growth in both directional solidification as a processing technique and in aircraft manufacture should result in greater tantalum consumption in 1986 over 1985. Previously scrap has been used as an additive, but tighter analytical specifications for superalloys will mean that more virgin material will be used in the future. It is expected that superalloy consumption will exhibit stronger growth than any other application for tantalum.

Tantalum is a prime candidate for use in armour-penetrating projectiles and preliminary estimates indicate that requirements could be for millions of pounds. This was put forward by Mr Conrad Brown, Vice President and General Manager of Fansteel Metals in a speech to the Metal Bulletin Ferro-Alloys Conference in November 1985. Reportedly, tantalum is under investigation by the Military because of its high-temperature strength, coupled with good ductility and high density. These properties enable self-forging by the projectile to occur on impact. Self-forging has apparently been successful in defeating armour targets over long distances.

So when will raw material producers participate in this optimistic future which processors and capacitor manufacturers are predicting ? The signs are that it will not be in 1986. Shipments reported by T.I.C. members totalled 674 776 lb Ta_2O_5 in 1985, 51 per cent down on the corresponding figure for 1984. The Metal Bulletin tantalite price is at its lowest level since April 1983, currently at $ 20-26 per lb Ta_2O_5 and even being quoted as "nominal" for much of the last quarter of 1985. Producers cite the high level of processors' inventories as being responsible for low shipments. One leading producer, Mr John Linden of Greenbushes Ltd, estimated that inventories of normal raw materials stood at 2.6 m lb Ta_2O_5 at the end of 1985, but went on to forecast that these would fall below "normal" levels by the end of 1986. Low-grade slag inventories stood at 6.6 m lb Ta_2O_5 at the end of 1985 and would only fall below "normal" levels in 1989 : it is these slag inventories which are causing the present depression in the raw material sector of the industry. In 1985 there was a short-fall between Ta_2O_5 production and demand (T.I.C. data : 1.4 m lb against 2.8 m lb). The forward production estimates for 1986, made this year by the T.I.C., are significantly less than those made during the final quarter of last year. The two different sets of estimates are contrasted below (in lb Ta_2O_5) :

MB price	*4th quarter 1985 estimate*	*1st quarter 1986 estimate*	*% Decrease*
$ 30	1 698 660	1 518 660	10.6
$ 40	2 043 460	1 866 460	8.7
$ 50	2 614 860	2 408 860	7.9

This reflects shrinking production capacity world-wide, probably due to the crisis in the tin market. (Tantalum is produced as a by- or co-product with tin, except for deposits in Canada and Mozambique.) Small comfort can be gained from the state of other specialty and non-ferrous metals markets, principally molybdenum, nickel and tungsten, which are experiencing similar problems of large inventories with the resulting depressed prices.

Turning back to tantalum processing, a general mood of optimism prevails in the industry. The signs are there : new processing capacity is being constructed this year in Japan and Thailand. It is also demonstrated by the decision taken last year by Cabot Corporation to divest themselves of all their metals assets : cobalt and nickel alloys, beryllium-copper and aluminium master alloys, with the notable exception of their tantalum and niobium processing plant at Reading, Pennsylvania. According to Cabot, it is one of the few areas of the metals businesses with clear-cut growth and profitability.

Andrew Jones
Technical Officer

Graham Brown

Graham Brown, Editor of the T.I.C. Bulletin for many years, stepped down during 1985 and passed along the responsibility of providing the quarterly editions to Mr Andrew Jones. Mr Brown participated, as a representative of the Billiton Trading Company, in the organizational efforts of the T.I.C. When the organization was finally formulated and the Bulletin was instituted, he accepted the role of Editor and has carried on ever since.

In addition to his T.I.C. activities, Mr Brown has been associated with the tantalum and niobium business for almost forty years. His experience ranges from being a formulator of policy and objectives for the U.S. National Stockpile as a commodity advisor in the Office of the Secretary of Defense during the late 1940's to being a tantalum consultant to producers, processors and consumers during the 1970's.

The T.I.C. expresses sincere appreciation to Mr Brown for his innumerable contributions to the success of our organization; the Quarterly Bulletins have been one of the mainstays and strength of the T.I.C. and we are deeply grateful to Mr Brown for a truly outstanding job.

Conrad Brown
Fansteel/Metals

Abstracts

The following papers will be presented at Kobe :

HISTORY OF TANTALUM INDUSTRY IN JAPAN AND ITS PROBLEMS

Mr Yoichiro Takekuro, President, Japan Society of Newer Metals, Tantalum Committee

The course of tantalum in Japan :

- The history of tantalum industry in Japan.
- From the experimental and feasibility studies to the refinery manufacturer, and to the start of production by processing manufacturer.
- MITI's guidance for fostering domestic products and withdrawal by tantalum manufacturer.
- From the time of oligopoly to the present time.

Future problems :

- Lessons learned from the sudden rise of tantalum prices.
- Recognition of international products.
- Trade friction.
- Formation of international prices.
- Policy for raw materials.

RECENT PROGRESS IN SUPERCONDUCTORS

Dr K. Tachikawa, Director, Tsukuba Laboratories, National Research Institute for Metals

Superconducting materials are being applied to various new technological fields such as energy, information, medical diagnosis, transportation, natural resources and fundamental sciences. Up to date Nb-Ti alloys, Nb_3Sn and V_3Ga compounds have been developed as superconducting materials for practical use. Now, fabrication processes for advanced superconductors such as Nb_3Al, Nb_3Ge and $PbMo_6S_8$ together with developments of superconductors suitable for AC applications are in progress. The development of new fabrication techniques and metallurgical approaches would be indispensable for the development of those advanced superconducting materials.

JAPAN'S RESOURCES POLICY FOR NON-FERROUS METALS

Mr Norikazu Matsuda, Director, Basic Industries Bureau, Non-ferrous Metals Division, Ministry of International Trade and Industry

Way of thinking for the policy and its measures (Policy against domestic mining and reserves, etc.).

PERSPECTIVES ON THE DEVELOPMENT OF THE TANTALUM INDUSTRY

Mr L.S. O'Rourke, Vice President, Cabot Corporation

A brief history of the industry is reviewed in terms of demand for end product, raw material pricing, and volume. A short-term forecast is given. Following this broad framework a pattern is presented of a number of events significant in the development and maturing of the industry to date. Comments are made on these events, which are derived from impressions of a number of long-term industry leaders from whom input was received. Included are those impressions generally considered by the contributors to have had greatest impact on the current industry structure.

BEHAVIOR OF OXYGEN IN TANTALUM

Dr Hiroaki Wada, Staff Manager — Research and Development, Showa Cabot Supermetals KK

Effects of impurities on the electrical, thermal and mechanical properties of tantalum capacitor powder differ depending on what the impurities are. Some impurities improve the properties, while others, such as oxygen, degrade them.

Tantalum powder readily absorbs a considerable amount of oxygen from the environment as there is a strong affinity between tantalum and oxygen (enthalpy of formation of Ta_2O_5 : -499 kcal/mole). Consequently, it is difficult to make oxygen free tantalum powder. Therefore, it is essential to understand the behavior of oxygen in tantalum.

In his presentation, Dr Wada will discuss the behavior of oxygen in tantalum matrix and oxide, and also the deoxidization of the tantalum powder.

Host companies

The following three companies will host the Twenty-fifth General Assembly to be held in Kobe, Japan, during May 19th-21st 1986.

MITSUI MINING AND SMELTING

This exceptionally diversified producer of metals and minerals can trace its history as far back as 1874 when the Mitsui clan acquired the Kamioka lead-zinc mine. In 1911, the Mitsui Mining Co. was founded. After expansion into ore smelting, and also into copper and chemicals, the present day company was established when the Metals Division was separated from the parent company in 1950 to form Kamioka Mining and Smelting. This name was changed two years later to the present one : Mitsui Mining and Smelting.

The niobium and tantalum operations are located at Miike Rare Metal Plant, part of New Metals Division (set up in 1978). Mitsui Mining and Smelting are an integrated processor of niobium and tantalum, their activities covering ore smelting through to the final products : oxides for ceramic and optical applications, carbides for cutting tools and niobium metal for superconductors. Sputter targets of tantalum oxide are also manufactured. Monthly outputs are of the order of 7500 kg of niobium oxide, 3500 kg of tantalum carbide, 7500 kg of tantalum oxide and 2000 kg of composite carbide.

Mitsui Mining and Smelting are a leading producer of a range of non-ferrous metals; they are currently the world's largest zinc producer. Other products include chemicals, paints, construction materials and refractories.

SHOWA CABOT SUPERMETALS

Showa Cabot Supermetals are the sole domestic manufacturer of tantalum powder in Japan for capacitors. In addition, they import and sell products from Cabot Specialty Metals, namely tantalum wire, tantalum and niobium mill products, aluminium master-alloys, titanium alloy tubing and hardfacing equipment and materials.

They were established in 1972 as Showa-KBI : a joint venture between Showa Denko and Kawecki Berylco Industries. In 1979 Cabot International Capital Corporation took over the position of KBI and in 1984 the name of the company was changed to the present one.

The existing plant capacity at Fukushima Prefecture is 100 tonnes of powder per year. Construction of a new powder plant is presently under way and is scheduled for completion in November 1986. This new facility, being built alongside the old one which it will eventually replace, will have sufficient space to accommodate a capacity of 200 tonnes of powder per year. But the present plan is for an initial capacity of 100 tonnes in the new plant to run alongside the existing capacity for a period of time after November 1986.

VACUUM METALLURGICAL CO. (VMC)

VMC were originally established in 1962 as the Vacuum Metallurgy Division of the Ulvac Corporation to develop and market new products and processes resulting from the combination of "state-of-the-art" metallurgical and vacuum technologies. In 1966 they became a company in their own right.

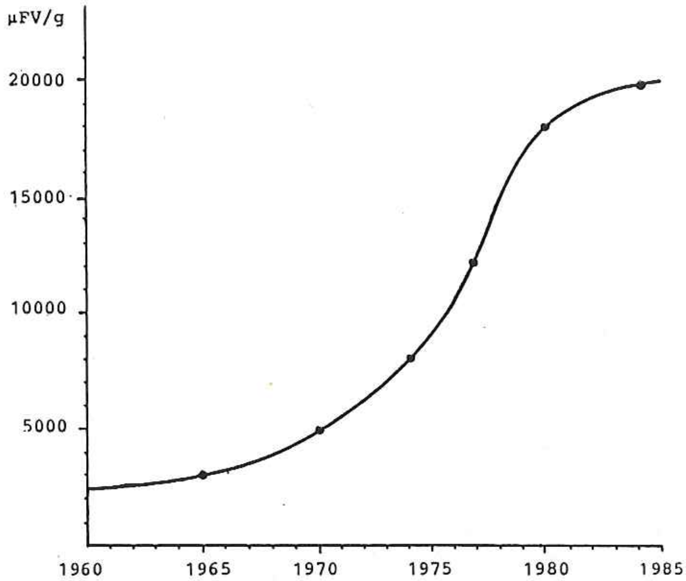
At their plant in Chiba Prefecture, and at their Kyushu subsidiary, VMC produce dry-plating (DRP) materials, refractory and reactive metals, ultra-fine metal powders, superconductive materials and special surface hardening. These products and processes have been applied in a wide variety of specialised industries: aerospace, nuclear, electronics, semiconductors, precision mechatronics, fine chemicals and bionics. Niobium and tantalum products manufactured by VMC include capacitor wire and foil, furnace hardware for the chemical and electronics industries and superconducting materials (NbTi, Nb_3Sn). VMC also sell capacitor powder from NRC Inc., USA, and superconducting systems from Intermagnetics General Corporation, USA, in the Japanese market.

New trends in the development of tantalum powders for capacitors

This paper, by Dr Reinhard Hähn and Mr Hans-Jürgen Heinrich, both of Gesellschaft für Elektrometallurgie, was presented at the Symposium on Materials for Electric and Electronic Devices on September 21st 1984 in Reutte, Austria. The original paper was in German and the T.I.C. is indebted to GfE for preparing an English translation.

The tantalum electrolytic capacitor has been one of the most important passive electronic components for many decades and still holds its own, in spite of keen competition from aluminium and ceramic multilayer capacitors, due to its outstanding electrical characteristics, such as unsurpassed reliability and a wide range of application from −50 to more than 100 °C.

The basic raw material for the manufacture of tantalum capacitors is powder which must have certain properties, that is, be able to flow well, have adequate electrical and chemical characteristics and finally must be economy-priced: this means, that per gram of tantalum powder the highest CV-product (quantity of electric charge) possible should be achieved. This problem is not easy to solve: some years ago the price development for tantalum raw material was so adverse that tantalum capacitors became too expensive for many applications and so they were replaced by lower-priced alternatives in electronic circuits. Tantalum processors had taken this situation into account and just at that time they developed new powders with higher specific capacitance.



Development of specific capacitance (µF.V/g) of tantalum powders

SODIUM-REDUCED TANTALUM POWDERS

Specific Charge (CV/g)	**5000-8000**	**8000-10 000**	**10 000-12 000**	**12 000-20 000**	
Proposed processing conditions					*Electric data referred to the following conditions*
Sintering temperature	1600-1850 °C	1600-1750 °C	1600-1700 °C	1500-1700 °C	Anode-weight : 0.3 g
Sintering time	15-30'	15-30'	15-30'	5-30'	Pressed density : 5.0 g/cm³
Pressed density	4.5-7.0 g/cm³	4.0-5.5 g/cm³	4.0-5.0 g/cm³	4.0-6.0 g/cm³	Sintering time : 30'
Maximum voltage	35 V (50 V)	35 V	25 V (35 V)	20 V	
Physical data					*Wet test*
Scott density	28-40	22-34	15-25	15-25	Electrolyte : 0.1 % H_3PO_4
					Temperature : 90 ± 2 °C
Average particle size (FSSS)	3.5-5.5	2.0-4.0	2.0-4.0	1.0-2.0	Formation voltage : 100 V
Sieve distribution					Time : 120 min.
+ 200 mesh	20-50 %	20-40 %	10-30 %	50 %	Formation current : 35 mA/g
− 200 + 325 mesh	10-30 %	10-30 %	10-30 %	20 %	
− 325 mesh	40-65 %	40-60 %	40-60 % (70 %)	30 %	
Electrical data					*Measuring conditions for CV, ESR, tan S*
BDV (V)	160-200	150-190	140-180	120-140	Electrolyte : 10 % H_3PO_4
					Temperature : 23 ± 2 °C
Specific Charge (µFV/g)	7000-8000	9000-10 000	11 000-12 000	14 000-18 000	D.C. Bias : 2.0 V
DCL (µA/g)	0.5-2	-5	-20	-30	A.C. Signal : 0.5 V
DCL (µA/µFV . 10^{-4})	2.5	5	16	16	Frequency : 120 Hz
Chemical analysis					*Measuring conditions for DCL :*
O	1800-2000	1900-2400	2000-2600	1900-2700	Electrolyte : 10 % H_3PO_4
H	10	10	10	10-150	Temperature : 23 ± 2 °C
N	40-70	20-50	40-100	30-120	Voltage : 70 V
C	30-70	30-70	40-100	40-70	Time : 2 min.
Nb	50	50	50	50	*Measuring conditions for BDV :*
Fe	20-60	30-50	30-70	30-60	
Na	30-60	60-200	60-200	20-180	Electrolyte : 0,1 % H_3PO_4
K	30-120	80-200	70-240	40-220	Temperature : 90 °C
Ca	5	5-20	5-40	5-60	Current : 35 mA/g
Si	20-50	20-50	20-60	10-50	
Ti	10	10	10	10	
W	25	25	25	25	
Mo	25	25	25-50	25-60	
P	10	10-50	10-180	10-180	

A distinction is made between tantalum powders according to their production process : the powders produced by the electron beam fusion process (EB) and those reduced by sodium.

Tantalum powder for capacitors

Group 1 : powders produced from electron beam fused tantalum metal (EB)
Range of capacitance : 1000 to 8000 CV/g
Main application in the high voltage range between 35 and 120 V

Group 2 : Sodium-reduced powders
Range of capacitance : 8000 to 20 000 CV/g
Main application in the lower voltage range up to 35 V

Powders up to 10 000 CV/g
— produced without doping agents
— high sintering temperatures recommended

Powders exceeding 10 000 CV/g
— produced with doping agents
— lower sintering temperatures recommended

In both cases, powder production is based on pure potassium tantalum fluoride, which is converted to tantalum metal and the corresponding fluorides by reduction with sodium. Due to the fact that the reaction is highly exothermic, but also in order to control the course of reaction and the product's characteristics, inert salts such as alkali chlorides or alkali fluorides are added. By leaching out these halides with water, crude tantalum powder is obtained, which is, after degassing in vacuum, molded into electrodes and subsequently refined in the electron beam furnace by carrying out several remelting processes. By means of hydrogenation, grinding, classification and dehydrogenation the co-called EB tantalum powder for capacitors is obtained. For tantalum powders produced from electron beam fused tantalum metal, first-class return materials, such as sheet-cuttings, are also used.

High-capacitive tantalum powders are obtained by carrying out the sodium reduction under strictly controlled conditions. Fine, crude tantalum powder is produced in situ, which is then thermally agglomerated, purified and surface stabilised. As sodium-reduced powders meet at least 70 per cent of current demand, these powders will be discussed with special emphasis.

SODIUM-REDUCED TANTALUM POWDERS

Average data of present-day commercial sodium-reduced powders are listed opposite. In order to be able to compare the specifications, all data are based on constant sintering, forming and measuring conditions.

The data reveal that the increases in specific charge and surface were mainly achieved by reducing particle size and bulk density and by decreasing sintering temperatures. Obviously, a slight deterioration in the leakage current behaviour as well as a reduction of the break-down voltage had to be accepted.

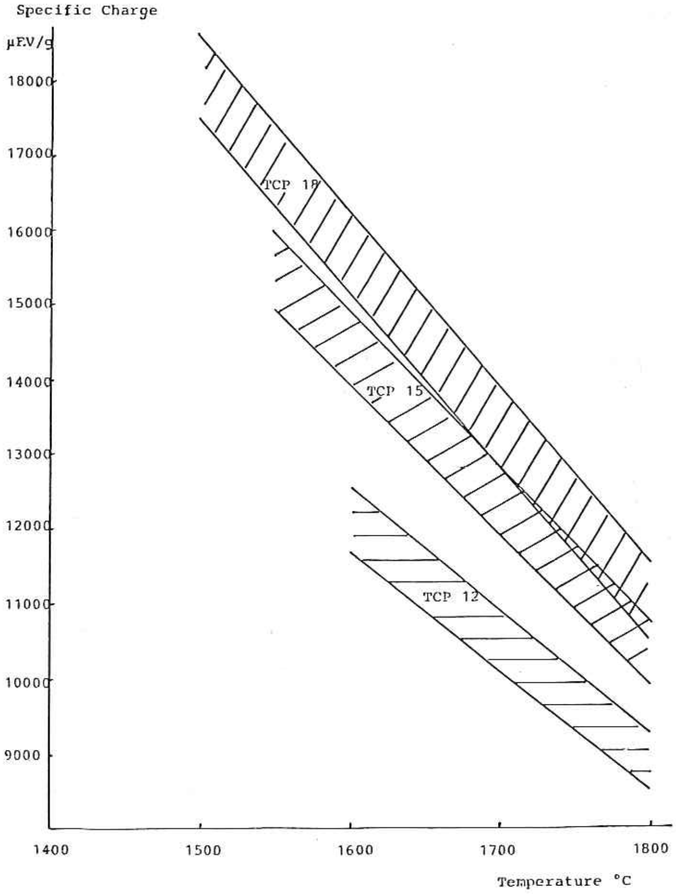
Tantalum powders up to 10 000 CV/g can be produced by optimising the reduction parameters. The formation of fine tantalum powder having a specific surface of 0.2 to 0.3 m²/g is primarily influenced by the grain size of the K_2TaF_7, the reduction temperature, the charge quantity and the use of inert diluting salts. The grain shape can also be influenced by these parameters to an extent : flaky material is preferred due to the favourable mass/surface ratio.

Production of tantalum powders having a capacitance yield of more than 10 000 CV/g can only be achieved by adding doping agents, the primary effect of which is to reduce the considerable surface losses occurring during thermal agglomeration and subsequent sintering of the molded compact. The doping agents act as "sintering brakes" and can only be added if they do not affect the other electrical characteristics of the capacitor. Additives of compounds containing nitrogen, oxygen, sulfur and phosphorus ranging from 50 to 500 ppm have proved particularly suitable.

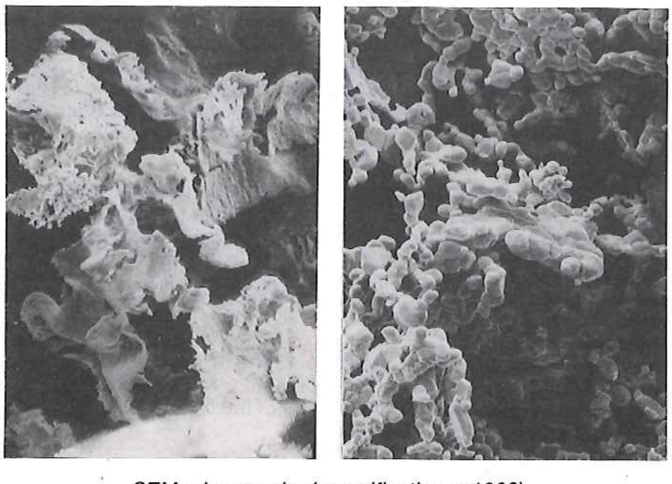
However, these doping agents can be applied during reduction of the K_2TaF_7 as well, where they have an inhibiting effect on grain growth, so that considerably larger powder surfaces as well as a reduction in the average grain size are achieved under reduction conditions which are otherwise unchanged. Consequently, these doping agents are added both to the K_2TaF_7 as well as to the reaction mixture. A further possibility of applying doping agents is offered via changing the dielectric constant of the tantalum oxide layer, which is a substance constant. For example, molybdenum compounds are added to the tantalum powder in order to make the capacitor, which is in itself polar, bipolar to a certain extent. Here, the dielectric is changed, that is, the amorphous Ta_2O_5 film. But the exact mechanisms of the doping with elements such as phosphorus, sulfur, etc. and their influence on the amorphous tantalum oxide film are not known up to now. It is only known that phosphate ions are incorporated into the Ta_2O_5 film.

APPLICATION OF HIGH-CAPACITIVE TANTALUM POWDERS

However, the application of high-capacitive, doped powders also leads to a series of problems, such as higher sintering sensitivity. The higher the specific capacitance of a powder is, the stronger the sintering sensitivity. At temperatures exceeding 1700 °C, there is no longer much difference between high-capacitive or low-capacitive powders. In order to achieve the necessary mechanical stability of the sintered body, as well as low residual current values and a low ohmic resistance, it is desirable to apply high sintering temperatures. But when sintering temperatures are increased, the surface and thus the capacitance decreases. The reason for this is the grain growth taking place in this temperature range with a corresponding surface loss. This can be distinctly recognised from pictures taken under a scanning electron microscope. Whilst the precursory powder (left picture) had a surface of 0.3 m²/g, the surface decreased to 0.03 m²/g (right picture) following sintering at 1400 °C for one hour. The specific charge decreased from 12 500 to 7000 CV/g during a sintering process at 1600 °C and 30 minutes. The usual task of a powder metallurgist, to produce a 100 per cent dense sintered body, is the opposite when producing tantalum anodes for capacitors.

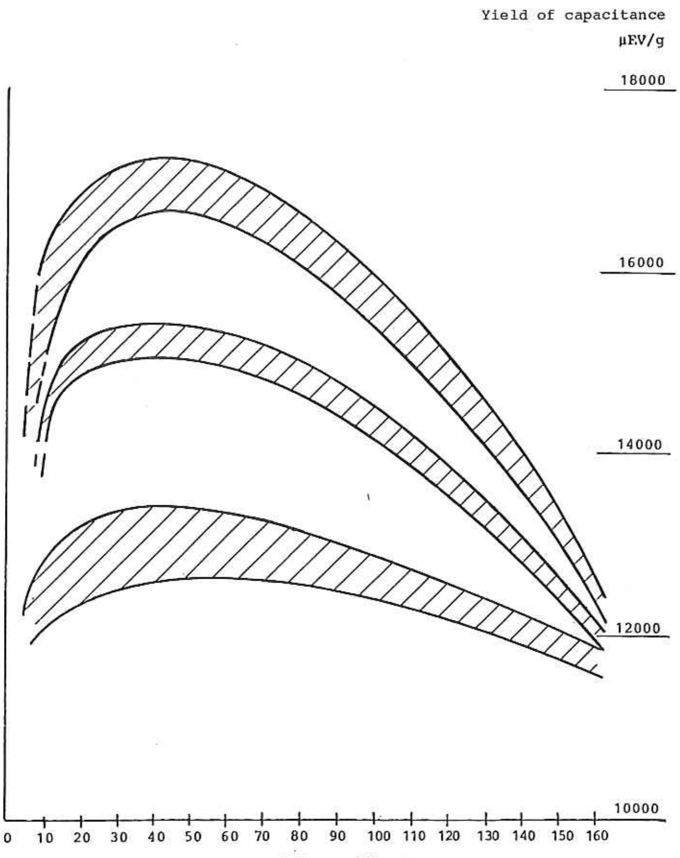


Dependence of the specific charge on the sintering temperature (sintering time 15 min.)



SEM micrographs (magnification x 1000).
Left : precursory tantalum powder, right : sintered at 1400 °C.

A further disadvantage when applying high-capacitive doped tantalum powders is the unusually strong dependence of the capacitance yield on the forming voltage. Theoretically, the product resulting from capacitance and voltage (μF.V) is a constant. High-capacitive powders can only produce this high capacitance yield within a relatively small voltage range. The advantages of these powders decrease drastically in the range of high and low voltages compared to powders having a lower capacitance. An explanation for this phenomenon is the so-called thorough forming of finest powder particles in the high voltage range, that is, the entire tantalum grain is oxidized and is thus no longer available as an active electrode surface. As far as the behaviour of these powders in the low voltage range is concerned, no satisfactory explanation has been found so far. There are indications that this phenomenon is connected with the oxygen content in the unfinished anode. The high capacitance yield decreases further due to the incomplete covering of the dielectric with manganese dioxide. The capacitor producers speak of the so-called "Fill-factor" which expresses the ratio between the capacitance yield in wet electrolytes (H_2SO_4) and in dry electrolytes (Mn-dioxide). The smaller the particle size of the powders, the narrower and more widely branched are the pores into which the manganese nitrate solution has to penetrate. In contrast to coarsely porous powders, not all pores of fine, high-capacitive powders are filled. For this reason, another five per cent of the surface and thus the capacitance of powders are lost.



Dependence of the capacitance yield (μF.V/g) on the forming voltage (V)

The data stated so far clearly show that the drastic change in tantalum powders for capacitors in such a short time requires a corresponding adaptation in the production of capacitors on the one hand, and a re-arrangement of the range of application on the other hand. High-capacitive powders are more difficult to process due to their poor flowability. Therefore, new pressing techniques have to be developed.

High-capacitive powders are more sensitive to sintering than low-capacitive powders. For this reason, new sintering techniques for these powders have to be developed. Also their electrical characteristics are not as good, and especially because of the leakage current and the voltage, their range of application is limited. The purity of these powders and anodes produced from these powders must be improved even further.

Due to the fact that high-capacitive powders are no longer pure tantalum powders, but powders doped with various elements, the effect of these elements on the durability of the capacitors over a long period of time has to be investigated.

After this critical review of disadvantages of high-capacitive tantalum powders, the positive characteristics must also be discussed. Today, eight to ten capacitors of type 10 μF/35 V are produced from one gram of powder, whereas ten years ago only three capacitors could be made. Due to this aspect, the price for tantalum capacitors was maintained within the general price trend. Exactly this economic aspect is one of the reasons for the increase in quantities of tantalum capacitors. Due to the higher specific capacitance yield, the amount of tantalum powder per unit could be reduced by more than 50 per cent for the same capacitor, which was also an important factor for the miniaturisation of these components.

Therefore, the tantalum capacitor will continue to represent an important electronic component, as long as its reliability is maintained within an economically justifiable scope.

However, in the long-term, limits will be set to the development of this capacitor by the progressive thick-layer and thin-layer technology. Therefore, it is unfortunate that intensive research is being carried out in the field of aluminium and ceramic capacitors, whilst far less attention is being paid to the development of tantalum capacitors. The progress achieved so far is mainly attributed to the tantalum powder producers.

These findings clearly mark the direction of future developments. It is imperative that the powder surfaces available in high capacitance powders are stabilised and maintained as an active capacitor surface during the manufacturing. This object can be achieved by a consistent further development in doping techniques and by changing the processing technology. A high sintering temperature, however, with short sintering periods would contribute to this. It is imperative that the influence of doping elements on the durability of capacitors is thoroughly investigated. The effect of doping elements requires a scientific explanation in order to influence directly the surface formation as well as the dielectric.

KBI 41 Alloy

In response to the need for a low-cost, yet high-strength, tantalum alloy for corrosion-resistant applications, Cabot Corporation have developed KBI 41, a variation of their KBI 40 (60 % tantalum, 40 % niobium). The new alloy, patented by Cabot in July 1985, is the first commercial tantalum-base alloy to specify molybdenum : composition — 37.5 % niobium, 2.5 % tungsten, 2.0 % molybdenum, balance tantalum. The alloy additives, molybdenum and tungsten, provide substitutional strengthening without dramatically reducing KBI 40's corrosion resistance as can be deduced from the data :

UNIFORM RATE OF CORROSION TEST RESULTS FOR TANTALUM, KBI ALLOY 40 AND KBI ALLOY 41

(Rates of corrosion expressed as mm per year)

*Test Environment**	*Tantalum*	*KBI 40*	*KBI 41*
30 % HCl at 130 °C	nil	4	4
30 % HCl at 150 °C	< 1	15	17
28 % HCl & 50 ppm $FeCl_3$ at boil (110 °C)	0.1	0.1	0.1
60 % H_2SO_4 at boil (141 °C)	0.2	2	1
70 % H_2SO_4 at boil (170 °C)	0.5	8	5
80 % H_2SO_4 at boil (210 °C)	2	45	39
70 % HNO_3 at boil (120 °C)	nil	nil	nil
Bromine at 100 °C	nil	nil	nil
35 % acetic acid at 177 °C	nil	0.3	0.2

* All results measured following a 96 hour test period.

RESISTANCE TO HYDROGEN EMBRITTLEMENT OF TANTALUM, KBI ALLOY 40 AND KBI ALLOY 41

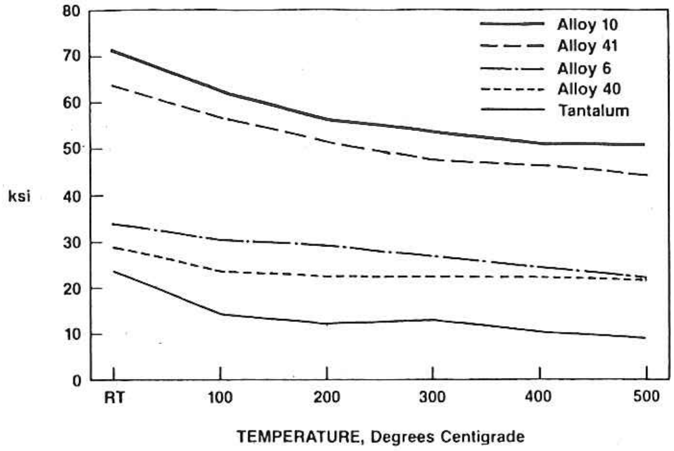
*Test Environment**	*Tantalum*	*KBI 40*	*KBI 41*
30 % HCl at 130 °C	5	80	5
30 % HCl at 150 °C	—	400	5
20 % HCl & 50 ppm $FeCl_3$ at boiling (110 °C)	<5	15	<5
60 % H_2SO_4 at boiling (141 °C)	<5	5	<5
70 % H_2SO_4 at boiling (170 °C)	<5	15	<5
80 % H_2SO_4 at boiling (210 °C)	<5	40	10
70 % HNO_3 at boil (120 °C)	<5	v5	<5
Bromine at 100 °C	<5	v5	<5
35 % acetic acid at 177 °C	<5	25	5

* All results are expressed in parts per million (ppm) hydrogen following a 96 hour test period.

KBI 41 actually has an improved resistance to hydrogen embrittlement over KBI 40 leading, claim Cabot, to a prolonged service life under many conditions.

The possible applications for this alloy coincide with those existing already for tantalum, namely in equipment for the manufacture of highly corrosive chemicals, principally acids. It is envisaged by Cabot that KBI 41 will be used as patch repairs for glass-lined tanks : tantalum has a corrosion resistance very similar to that of glass. The alloy Ta-10 % W is being widely used for this purpose at present. But the new alloy's lower cost and only slightly inferior strength could result in its adoption.

Yield strengths of tantalum and its alloys as a function of temperature :



(Alloy 10 : Ta-10 % W, Alloy 6 : Ta-2 1/2 % W)

Applications will also be found in the manufacture of welded tube bundles for heat exchangers, say Cabot. Tube sections can be made thinner using the stronger alloy than tube sections made from other refractory alloys. As a result, less material is needed to obtain the same strength in tubing.

Cabot Corporation are currently marketing this alloy which, although it has a lower tantalum content than conventional alloys, could help to maintain tantalum's presence in a market where it is classed as a relatively high-cost material.

Projected niobium demands in applied superconductivity 1986 — 2000 AD

This paper was presented at the Twenty-fourth General Assembly in Brussels on October 22nd 1985 by Professor Anthony J. DeArdo, Basic Metals Processing Research Institute, University of Pittsburgh. The authors are Dr Charles Laverick and Dr Harry Stuart, both of Niobium Products Co.

INTRODUCTION

The principal categories of use for superconductors are identified and the amount of niobium needed for each application is estimated for the period from 1986 to 2000 AD. Niobium-titanium alloys are used in most current applications and it is this material supply which is considered here. Niobium-tin compounds are also used but their brittle nature has hampered their adoption.

The promise of Magnetic Resonance Imaging (MRI) diagnostics is bringing great changes to what was a small commercial market overshadowed by needs in government development activities and high energy physics and fusion research. Several large corporations supplying medical equipment have entered the magnetic imaging market and have assured their superconducting magnet supplies by purchasing the smaller magnet companies which have supplied the limited market of the past.

Most magnet conductors are composites of copper and large numbers of fine strands of niobium-titanium. The composition of the NbTi is normally specified by weight and the copper-to-superconductor ratio by volume. Typical favorable compositions are 47-50 wt% Nb. Composite compositions vary from Cu/NbTi : 1/1 for small coils to over 20/1 for the very large coils envisaged for fusion and MHD. Thus the contained niobium can vary from over 15 % to less than 1 % by weight of the finished conductor or magnet. This variation sometimes accounts for apparent discrepancies in demand estimates; the basic definitions should be carefully examined in comparing estimates.

The processing yield is approximately 50 %. These losses occur when the initial ingot is manufactured, and in the stages of rod manufacture and wire drawing necessary to produce the final composite of metal (usually copper) and superconductor.

In 1979, the cost of niobium oxide increased dramatically and that of superconductor doubled which caused concern among its consumers. At that time, the oxide was obtained as a by-product of tantalum production. The concern was eliminated in 1980 when CBMM began to produce high-grade niobium oxide from pyrochlore at the site of its Araxa mine in Brazil for world-wide consumption at almost half the previous price. The nominal plant capacity is 2400 t/yr of niobium oxide (69.9 wt% Nb).

MAGNETIC RESONANCE

Magnetic resonance (MR) is probably the most powerful analytical tool known for the study of the structure and dynamics of molecules and has been a principal tool of chemists and biochemists for almost forty years. In recent years the availability of high field superconducting magnets at favorable prices, together with advances in computers, has led to the expanded use of spectroscopic techniques. A further development has been X-ray computed tomography (CT) in medical diagnostics. This has become a stepping stone to the application of MR in medicine, since much of the electronics and imaging techniques have been transferable. This new technique has already become the most important commercial application for applied superconductivity to date. Three distinct branches can now be distinguished in this area of magnetic resonance; they are :

1. Nuclear Magnetic Resonance (NMR)
2. Magnetic Resonance Imaging (MRI)
3. Magnetic Resonance Spectroscopy (MRS)

Nuclear magnetic resonance (NMR)

NMR is designated separately to distinguish it from MRI and MRS which are imaging techniques in medical diagnostics. Most major NMR equipment manufacturers now offer a range of systems to meet a wide range of applications. In a 1980 brochure, Bruker listed some of these for their high power NMR spectrometer. They pointed out that the equipment allowed fast, non-destructive studies of materials in all states of aggregation, without mechanical or electrical contact with the sample. Areas of application include industrial quality and product control, quality and product control of food and natural products, investigation and control of raw materials and a wide range of medical and biological measurements.

Magnetic resonance imaging (MRI)

Some MRI systems have already been approved in several countries, including the US, for clinical testing and pre-market approval. Since clinical trials began four years ago, almost 200 hospitals around the world have already installed MRI units.

MRI offers some unique benefits not provided by X-ray computed tomography (CT). It offers unprecedented soft-tissue contrast, user selective imaging planes and non-invasiveness. Other advantages include elimination of bone artefacts, cardiac and respiratory gating, high field imaging and spectroscopy, high resolution imaging and flow studies. It is a superior diagnostic technique for the central nervous system, in particular, the brain, and has demonstrated equality with other techniques for other anatomic regions. Using surface coils applied close to the region of interest, enhanced images can be obtained from the spinal column, eye, ear, breast, neck and extrem ties.

In the United States, MRI systems are classified as investigational devices under the Medical Device Amendments to the Food, Drug and Cosmetics Act and the FDA must approve pre-market use for each model and manufacturer before they can be offered commercially. Several firms have received such approval.

Companies which have committed themselves to MRI include :

Siemens commissioned a new Magnetic Resonance R & D Center (MAGNETOM) in January 1984 in Erlangen, West Germany, and a supplementary facility in New Jersey, USA. The FDA has granted pre-market approval for Magnetom MR systems operating at 0.35 T and 0.5 T for both head and body use and clinical trials to support further approvals for 1.0 T and 1.5 T systems are currently under way. The company has also concluded an agreement with Bruker Medizintechnik GmbH to market Bruker in-vivo MR spectrometers for imaging and spectroscopy of in-vitro samples and small animals. Self-shielded systems are also undergoing clinical test.

Picker began MR development in 1974 and by 1980 they had the world's first routine whole body scanner operating at London's Hammersmith Hospital. Since that time, performance and resolution have improved dramatically. They have received approval for several imaging systems and claim that MR is already the procedure of choice for many routine and special studies. Their systems include resistive units operating at 0.15 T, superconducting systems to 2.0 T, and mobile systems at 0.5 T as well as spectroscopy systems.

General Electric made a major corporate commitment to MRI in 1983 with the purchase of a manufacturer of NMR instruments and the establishment of a superconducting magnet manufacturing facility. They also began to establish a wire manufacturing facility which has now been abandoned. They have yet to obtain FDA approval.

Diasonics have developed a universal cryostat in conjunction with *Oxford Instruments* to allow the magnet to function at 0.5 T, or as high as 2.0 T, to accommodate upgrades of field strength when necessary. They acquired American Magnetics, a manufacturer of superconducting magnets, in 1983 to enhance their capability in this field and are also expanding their research into magnetic resonance spectroscopy (MRS).

Fonar Corporation manufacture permanent magnet, resistive, superconducting and mobile units. Their cost analysis for the 0.3 T superconducting system gives a total of $ 2.35 million and an annualized equipment cost of $ 671 000. Total annual costs for this system, at 15 % interest, are $ 1 096 000. At $ 500 per scan, the Fonar superconductive magnet breaks even at 2192 scans annually.

Thomson CGR have developed the Magniscan 5000, a whole body, 0.5 T superconducting system and is gathering clinical data to submit its application to the FDA by mid-1985.

Philips Medical Systems have announced that the first images of a human head had been produced with a research NMR unit located at the company's laboratories in Hamburg, West Germany. They claim this as a major breakthrough, but not everyone is in agreement with this claim.

Intermagnetics General Corporation are developing a prototype high field, high homogeneity magnet for imaging and spectroscopic applications. Production of mobile superconducting systems is also in progress and several orders for these units have been received.

In Japan, *Toshiba* was the first company officially licensed by the Ministry of Health and Welfare to produce MRI scanners. *Shimazu, Mitsubishi,* and *Sanyo Electric Company* have products undergoing clinical test.

In 1983, Wall Street analysts forecasted a world-wide market for MRI scanners exceeding the $ 1000 million plateau by 1987. At approximate system prices of $ 1.6-$ 1.7 million, this translates to around 600 units. Thomson CGR estimates 500 systems in 1987, valued at $ 600 million. The Daily Industrial newspaper of Japan noted on June 19th 1984 that the Japanese MRI market will be around $ 110-$ 130 million per year in the near future. CBMM Orient office estimates Japanese demand for these systems to be 200 units per year in 1987.

Siemens have estimated world demand to be as follows :

Year	*No. of units*
1985	300
1986	450
1987	600
1988	800
1989	1000

The most recent medium and high field coils contain around 150 to 200 lb of NbTi per magnet corresponding to around 1000 to 1500 lb of conductor with the 4/1:Cu/NbTi volume ratio now being used. Wastage must be included in calculating the amount of source material needed.

Magnetic resonance — scenario for demand

It is clear that magnetic resonance is destined to play a prominent part in industrial control and medical diagnostics. As a wide range of medical technologists and physicians become familiar with the new techniques, a growing and self-generating society will evolve around imaging, spectroscopy and industrial control and analysis. The experience with CAT scanners have been that they have a lifetime of five years and this may also be the case with many whole body proton imaging systems. However, the magnets ought to last much longer, and it may be that customers updating their systems may sell them to institutions willing to upgrade the electronics and use the units for another five years before replacing them with more modern units.

Two scenarios are considered :

Scenario 1 — Demand for NMR and commercial magnets grows at 10 % per year from a base of 43 tonnes in 1985. Some 200 MRI units are installed in 1985 and subsequent installations increase at a rate of 10 % per year to 2000 AD. Some 70 % of five year old units are replaced by modern units from 1989. Ten year old units are scrapped and replaced from 1994.

Scenario 2 — Demand for NMR and commercial magnets grows at 15 % per year from 43 tonnes in 1985. The estimates by Siemens are used for the demand for MRI units up to 1989, and after this date demand grows at 15 % per year to 2000 AD. Also, 70 % of five year old units are replaced from 1989 and ten year old units are scrapped and replaced from 1994.

The consequences of these assumptions can be seen in the following tables and contrasted with future market trends; they illustrate the impact of various rates of growth on both annual and cumulative niobium and superconductor demand. They show a possible cumulative need for feedstock niobium for these purposes varying from about 1300 to 4000 tonnes to the turn of the century and a demand rate of somewhere between 160 and 630 tonnes per year of high purity feedstock niobium.

PARTICLE PHYSICS

Experiments at ever higher energies are needed in particle physics. The most recent accelerator designs involve contra-rotating, high energy particle beams focussed to interlace so that some of the particles in each beam collide with each other with maximum energy transfer. The collisions are arranged to occur in specially constructed experimental areas where suitable particle detectors are installed. The main ring guide magnets of the highest energy proton colliders will be superconducting in view of the successful operation of the Fermilab Tevatron.

The estimated demand for contained niobium in superconducting magnets for high energy physics ranges from 80 tonnes to a high of 340 tonnes, discounting orders for machines in construction. The high estimate is dependent on the possibility that a large machine being proposed in the United States will be built.

	Contained niobium (tonnes)
HERA — Hamburg, W. Germany, 1984-1991 electron-proton collider, 820 GeV protons on 30 GeV electrons.	16
TRISTAN — KEK, Japan, 1983-1986, 300 GeV protons on electrons.	12
UNK — Serpukhov, USSR, 1984-1990, 3 TeV protons.	45
Tevatron-Fermilab, USA, COMPLETED 1983, enhancements are under way.	
SSC — Superconducting Super Collider (proposed), 40 GeV on 40 GeV protons, site undetermined. See text for estimated amounts of Nb.	
RHIC — Relativistic Heavy Ion Collider, Brookhaven. Proposal to maximize use of cancelled CBA installation (This is a nuclear physics proposal).	

Large high energy machine projects involving superconducting magnets

Conductor purchases are small in the early stages of design and increase to a maximum as the magnet construction period reaches its mid-phase, tapering off near the end of construction and installation. Many magnets are purchased or built throughout the life of a large installation.

HERA is an electron-proton colliding beam machine with contra-rotating beams of 820 GeV protons and 30 GeV electrons (or positrons). Construction was planned to begin in 1984 and operation was scheduled to begin in 1991. The estimated quantity of contained niobium in the magnet is 16 tonnes.

TRISTAN is also an electron-proton colliding beam machine with 300 GeV protons, and requires 12 tonnes of contained niobium. In 1980, it was scheduled for operation in 1986.

UNK is a 3 TeV proton synchrotron based on a scale-up of the Fermilab machine. Construction was expected to begin in 1984 and the machine is scheduled for completion in 1991.

Design studies for the proposed Superconducting Super Collider (SSC) are now in their second year. With two 20 TeV proton beams colliding at 40 TeV center-of-mass energy, this is the largest and highest energy particle accelerator so far proposed. The high field ring needs the most superconductor, about 460 tonnes of alloy, corresponding to 230 tonnes of contained niobium and 460 tonnes of feedstock niobium. In 1984, it was assumed that the machine could be operational in nine years from the establishment of a design center. This is probably an optimistic figure. At present it is hoped that construction can start in late 1987.

ENERGY RELATED APPLICATIONS

Applied superconductivity is of potential benefit to the electrical industry and shows great promise. Over the last twenty years, it has been a component of several development programs, most of which have now been curtailed or abandoned. The principal items and the estimated amounts of niobium needed to 2000 AD are shown in the table comparing 1981 and current estimates.

		1986 to 2000 AD	
		Current draft	
	1981 estimate	*High demand*	*Low demand*
Generators	11	4	2
Magnetic fusion	230	50	20
MHD power	65	16	8
Transmission	70	2	<1
Mag. energy storage	16	4	2
Current limiters	4	2	1

Niobium in the electrical energy industry — comparison of current 1984 and 1981 estimates (in tonnes)

A reduction in enthusiasm for existing development programs was noted in 1981 and reflected in the estimates of that time. This reduction has continued and the current estimates are even lower. The low estimate assumes that the programs will continue at a lower pace and that commercialization will be deferred.

In the 1960's, the electric utility industry was in a state of continued rapid growth. Projections of future electrical demand and corresponding need for a greatly expanded energy system were optimistic. The energy crises of the 1970's led to a series of initiatives to develop alternative energy supplies, improve efficiencies throughout the electrical energy system and practice conservation measures; development programs in superconducting electrotechnology were funded as part of this effort. It was recognized that most of these technologies would not become commercial before the turn of the century, but that development should continue as a matter of national need.

When the 1981 estimates were made, annual growth rates of electrical energy demand were slowing in the advanced countries. This process has continued as energy prices have continued to increase and the developed world has experienced economic difficulties. In the United States, it is being questioned whether or not the utility companies are obsolete and asserted that the National System faces radical change. These changes could include less centralization and the reduction or elimination of programs to develop the very high capacity power farms and transmission systems planned some years ago. The situation is similar in Europe and Japan. This explains the curtailment of the development efforts and the corresponding reduction in demand estimates for these purposes.

Superconducting generators

In 1981, the principal activity in superconducting generator development was that for utility power station use. In the US, a prototype 300 MVA machine was under development by Westinghouse Electric Corporation under contract to the Electric Power Research Institute. This contract has since been cancelled and development has been abandoned. The USSR also had plans for a machine of similar rating, to be tested in the 1985-86 period and to be followed by a 1200 MVA machine some time after 1990. Several Western European and Japanese companies had similar plans, but on a much smaller scale.

The picture foreseen in 1981 now seems too optimistic and slowing of development and demonstration also slows commercialization; the current estimates take these factors into account.

Assuming a composite conductor with Cu/SC:1.5/1 ratio, the weights of composite and of niobium required for various machine sizes are given below.

Machine rating MVA	300	600	1200
Conductor weight kg	1100	1800	2900
Niobium weight kg	180	300	450

Relationship between generator rating and the weights of conductor and contained niobium

Magnetic fusion power plants

Magnetic fusion is one of a number of controlled fusion power approaches and the most favored. The dates of its possible demonstration and commercialization have been the subject of much debate and variation over the past decade. In the US it is now thought that commercialization of a fusion economy may not be needed, if at all, before 2030 AD. Thus the time scale to construction and operation of demonstration plants based on large scale magnetic containment concepts may be extended.

The possibilities for fusion will be better understood in the next ten years. Fusion programs are not yet at the stage of demonstrating scientific feasibility and no choice has yet been made between the various concepts. The front runner is the Tokamak. Very large superconducting magnets are considered essential to the success of this $ 10 000 million development effort. A commercial Tokamak reactor might require 50 t of niobium in the reinforced, cryostabilized conductor. It is still hoped that engineering test reactors incorporating magnetic containment systems will be in operation by 1990, although they may not incorporate superconducting magnets, and that construction of 500 MWe demonstration systems could be under way in the 1990's.

Magnetohydrodynamic power generation (MHD)

Magnetohydrodynamic convertors may boost power station efficiencies 10 % or more. US development policies for MHD have oscillated over the years from encouragement to indifference. Stimulated by the US-USSR collaboration, 1975-80 policies were supportive, but the US program was cancelled once more, only to be reinstated recently, at a marginal funding level. A superconducting magnet for the Component Design and Test Facility (CDIF) of the earlier program was built but not installed.

At the time of the US-USSR collaboration, it was expected that two or three other model MHD systems using superconducting magnets would have been operating within a few years and that the 800-1000 MWe combined MHD and steam power plant then under design in the USSR would be approaching operation by 1990. The current estimate for MHD is a low of nine tonnes and a high of sixteen tonnes from 1985 to 2000 AD. A base load MHD system with reinforced, cryostable conductor might have a magnet weight of 2300 tonnes of which 324 tonnes would be composite and only eight tonnes would be niobium.

Underground electric power transmission

This is a possible technology for conveying electrical power through the crowded utility corridors of large cities. Underground, high capacity, superconducting AC transmission lines are technologically feasible, as has been demonstrated in Brookhaven National Laboratory. If they were ever to be built, such transmission lines might require around 170 kg of niobium for each kilometer of cable and one 120 km-long, three-phase test link might contain about 21 tonnes of niobium.

The low demand estimate of less than one tonne assumes that small amounts of superconductor would be needed for test purposes. The high estimate of two tonnes reflects the possibility that a five-year plan proposed by Brookhaven would be implemented. This plan proposes that several cables be built commercially and tested at Brookhaven so as to develop industrial capability and that a two-mile long test line should then be constructed at the electric utility company during the 1990's using this expertise.

Superconducting magnetic energy storage (SMES)

The 1981 estimates for utility storage over the period 1986-2000 AD have been reduced from sixteen tonnes to a high of four tonnes and a low of two tonnes. This assumed that modest development studies will continue. The conductor for diurnal load levelling in electric utility systems would be heavily stabilized with copper and reinforced with stainless steel to support the operating stresses. Thus, the superconductor would be a very small fraction of the conductor weight.

Magnetic energy storage has been considered for three principal applications; these are :

- Diurnal load levelling.
- Electric utility system stabilization.
- Pulsed storage in magnetic fusion energy systems.

In each of the above cases, theoretical studies have been funded. The technological feasibility has been established in many instances, but questions of reliability, economics and need have yet to be established.

With diurnal load levelling, minimum unit sizes of 1 GWh (gigawatt-hour) capacity are judged to be economic for population centers of one to two million people and form a goal for current programs. Such devices could be constructed after the turn of the century.

The test program in which a Los Alamos storage system was placed in the Bonneville Power Administration's power line as a system stabilizer was discontinued by Bonneville because the cryogenics needed too much on site attention. No further tests are planned at present.

The magnet fusion energy program supported efforts to demonstrate the feasibility of pulsed energy storage coils for use in Tokamak reactors. A relatively small demonstration coil was designed and operated in Argonne National Laboratory with success, but it is not known at this time if a follow up program is planned.

Current limiters

Fault current limiters for electric utility power systems are a relatively new concept utilizing variable inductors with superconducting windings. Pioneered by IRD, such units would be engineered by NEI (Northern Engineering Industries), England. A 5 MVA test unit has been constructed. The race track coils are 4 m long by 1.2 m wide, with a conductor cross-section four inches square. Interest in this application is growing and a tender is being prepared with 50 % EEC (European Economic Commission) support for a 100 MVA unit; these negotiations are at an early stage. These limiters require several tonnes of composite and significant amounts of niobium. Five tonnes of contained niobium was estimated for this purpose in 1981. This figure is retained as a high range estimate and one tonne as a low range figure until more information becomes available.

TRANSPORTATION

High speed trains

The only project to develop high speed trains with superconducting magnetic suspension systems, still actively funded, is in Japan. A decision as to whether or not to proceed with the construction of such a system has yet to be made. Developments in recent years suggest that such a decision may be deferred as Japan National Rail has adequate capacity for the foreseeable future. The weight of NbTi per suspension coil was 12.5 kg in early models, implying a weight of

100 kg per carriage, 1.6 tonnes per 16 car train and hence 0.8 tonnes of contained niobium. It is assumed that a trial system might involve five such trains and that such a demonstration system would operate to the turn of the century.

Ship propulsion

Superconducting electric drives for ship propulsion were pioneered by IRD, England, but the UK program has since been terminated; it could be reinstated in three or four years. The US navy began similar work later and a low power unit was successfully tested in 1980 on a small research vessel. Large machines for ship propulsion need around 30 tonnes of composite per ship, corresponding to one tonne of contained niobium. An estimate of nine tonnes has been used in this report as a high demand.

INDUSTRIAL DEVELOPMENT

Superconducting computers

Superconducting computers show great promise for applications requiring the highest packing density in very large memories. In recent years, solid state devices have been improved so as to be economically and technologically competitive. IBM has abandoned its superconducting computer effort in favor of solid state for commercial applications while Japan has not. However, superconducting devices still hold promise for applications in space.

Magnetic separation

Magnetic separation is a proven technology. Superconducting magnets offer technological advantages in certain applications, but the industry is conservative and not easily convinced of the overall advantages of high technology when the total economic picture is considered. Consequently, it is still too early to say whether or not a commercial market for this application will develop. However, IRD is making a large demonstration unit for the CEGB (Central Electricity Generating Board), to be used for the removal of sulphur from coal. General Atomic has a contract to develop a pulsed system to separate ferritics from kaolin clays in a high speed slurry.

SUMMARY

The high-purity niobium required for superconducting applications from 1985 to 2000 AD is estimated to be between 2000 and 6000 tonnes. Principal categories of use and the estimated amounts of niobium needed are given below. (Current processing techniques require double the amount of contained niobium to produce the final product; hence the initial quantity of niobium metal needed to provide the amounts of contained niobium in the finished products is double that shown.)

	High	*Low*
ESTABLISHED COMMERCIAL USES		
Medical diagnostics	2100	600
Nuclear magnetic resonance	400	200
HIGH ENERGY PHYSICS (HEP)	340	80
ENERGY RELATED DEVELOPMENT		
Generators	4	2
Magnetic fusion	50	20
MHD power	16	8
Transmission	2	<1
Magnetic energy storage	4	2
Current limiters	2	1
TRANSPORTATION		
High speed trains	4	1
Ship propulsion	9	1
INDUSTRIAL DEVELOPMENT		
Computers	1	1
Magnetic separation	2	<1

Niobium in superconducting electrotechnologies — probable demand from 1986 to 2000 AD (in tonnes)

Nuclear magnetic resonance in industrial analysis and control and in medical diagnostics represents the first major commercial application of superconducting electrotechnology. Military needs and those for space are included in the estimates for commercial magnets.

As in the past, US particle physics could continue to be a principal user if the proposed Superconducting Super Collider project is approved. The contending designs have been reduced to two and that using the most niobium is taken for the high estimate in this report. The low estimate given here assumes that no such machines will be built this century.

Some years ago, energy related development programs were expected to result in widespread and significant use of superconductors but many of these have been curtailed, leading to the reduced estimates given here. Similar considerations apply to programs for transportation and for industrial development outside the energy industry.

The favored superconductor for most uses is niobium-titanium because of its ductility, but the possibilities for niobium-tin should not be overlooked. Its potentially lower price and superior electrical and temperature characteristics may outweigh its poorer mechanical properties in many future applications.

MR DEMAND SCENARIO 1: 10% GROWTH FROM 1985 ESTIMATES (IN TONNES)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NMR-INDUSTRY	10% GROWTH		FROM	1985												
Conductor wt/yr	43	47	52	57	63	69	76	84	92	101	111	122	134	147	162	178
NbTi/yr@30%wt	13	14	16	17	19	21	23	25	28	30	33	37	40	44	49	53
Total NbTi wt	13	27	43	60	79	100	123	148	176	206	239	276	316	360	409	462
Nb/yr@15%wt	6	7	8	9	9	10	11	13	14	15	17	18	20	22	24	27
Total Nb wt	6	13	21	30	39	49	60	73	87	102	119	137	157	179	203	230
MRI DIAGNOSTICS																
					*10% GROWTH FROM			1985								
Systems/yr	200	220	242	266	293	322	354	389	428	471	518	570	627	690	759	835
70%replace@5yr	to smaller hospitals.				105	140	154	169	186	205	225	248	272	300	330	363
Total install/yr	200	220	242	266	398	462	508	558	614	676	743	818	899	990	1089	1198
NbTi/yr	18	20	22	24	26	29	32	35	39	42	47	51	56	62	68	75
Nb/yr	9	10	11	12	13	14	16	18	19	21	23	26	28	31	34	38
Scrap 10 yr sys	- replaced with extra production systems.									150	200	220	242	266	293	322
Make up NbTi/yr										14	18	20	22	24	26	29
Nb makeup/yr										7	9	10	11	12	13	14
(NbTi+makeup)/yr	18	20	22	24	26	29	32	35	39	56	65	71	78	86	94	104
(Nb+makeup)/yr	9	10	11	12	13	14	16	18	19	28	32	36	39	.43	47	52
Total Installed	200	420	662	928	1326	1788	2296	2854	3468	4144	4887	5705	6604	7594	8683	9881
Total NbTi wt	18	38	60	84	110	139	171	206	245	301	366	437	515	601	695	799
Total Nb wt	9	19	30	42	55	69	85	103	122	150	182	218	257	300	347	399
NMR + MRI + MRS																
NbTi/yr	31	34	38	41	45	50	55	60	67	86	98	108	118	130	143	157
Nb/yr	15	17	19	21	22	24	27	31	33	43	49	54	59	65	71	79
Total NbTi	31	65	103	144	189	239	294	354	421	507	605	713	831	961	1104	1261
Total Niobium	15	32	51	72	94	118	145	176	209	252	301	355	414	479	550	629
Feedstock Niobium	30	64	102	144	188	236	290	352	418	504	602	710	828	958	1100	1258

MR DEMAND SCENARIO 2: 15% GROWTH FROM 1985 NMR ESTIMATES, SIEMENS MRI ESTIMATES USED UP TO 1989 - 15% GROWTH AFTER 1989 (IN TONNES)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
NMR-INDUSTRY	15% GROWTH FROM 1985															
Conductor wt/yr	43	49	56	64	74	85	98	113	130	150	173	199	229	263	302	347
NbTi/yr@30%wt	13	15	17	19	22	26	29	34	39	45	52	60	69	79	91	104
Total NbTi wt	13	28	45	64	86	112	141	175	214	259	311	371	440	519	610	714
Nb/yr@15%wt	6	7	8	10	11	13	15	17	20	23	26	30	34	39	45	52
Total Nb wt	6	13	21	31	42	55	70	87	107	130	156	186	220	259	304	356
MRI DIAGNOSTICS																
					15% GROWTH FROM 1989											
Systems/yr	300	450	600	800	1000	1150	1323	1521	1749	2011	2313	2660	3059	3518	4046	4653
70%replace@5yr	to smaller hospitals.				105	210	315	420	560	700	805	926	1065	1224	1408	1619
Total install/yr	300	450	600	800	1105	1360	1638	1941	2309	2711	3118	3586	4124	4742	5454	6272
NbTi/yr	27	41	54	72	90	104	119	137	157	181	208	239	275	317	364	419
Nb/yr	14	20	27	36	45	52	60	68	79	90	104	120	138	158	182	209
Scrap 10 yr sys	- replaced with extra production systems.									150	300	450	600	800	1000	1150
Make up NbTi/yr										14	27	41	54	72	90	104
Nb makeup/yr										7	14	20	27	36	45	52
(NbTi+makeup)/yr	27	41	54	72	90	104	119	137	157	195	235	280	329	389	454	523
(Nb+makeup)/yr	14	20	27	36	45	52	60	68	79	97	118	140	165	194	227	261
Total Installed	300	750	1350	2150	3255	4615	6253	8194	10503	13214	16332	19918	24042	28784	34238	40510
Total NbTi wt	27	68	122	194	284	388	507	644	801	996	1231	1511	1840	2229	2683	3206
Total Nb wt	14	34	61	97	142	194	254	322	401	498	616	756	921	1115	1342	1603
NMR + MRI + MRS																
NbTi/yr	40	56	71	91	112	130	148	171	196	240	287	340	398	468	545	627
Nb/yr	20	27	35	46	56	65	75	85	99	120	144	170	199	233	272	313
Total NbTi	40	96	167	258	370	500	648	819	1015	1255	1542	1882	2280	2748	3293	3920
Total Niobium	20	47	82	128	184	249	324	409	508	628	772	942	1141	1374	1646	1959
Feedstock Niobium	40	94	164	256	368	498	648	818	1016	1256	1544	1884	2282	2748	3292	3918

T.I.C. Statistics

Price Waterhouse report the following collected statistics :

QUARTERLY PRODUCTION ESTIMATES

(quoted in lb Ta_2O_5 contained)

LMB quotation :	*US $ 30*	*US $ 40*	*US $ 50*
1st quarter 1986	369 765	451 715	569 815
2nd quarter 1986	377 965	459 915	588 015
3rd quarter 1986	382 965	469 915	608 015
4th quarter 1986	387 965	484 915	643 015
1st quarter 1987	387 965	494 915	643 015

Note : These estimates are based on information received to date, and do not necessarily reflect total world production.

PRODUCTION AND SHIPMENTS

(quoted in lb Ta_2O_5 contained)

4th quarter 1985

Category	*Material grade*	*Production*	*Shipments*
A/B	Tin slag	243 412	57 832
C/D	Tantalite under and over 25 % Ta_2O_5	65 638	46 982
F	Other materials	0	0
	Total	309 050	104 814

Notes :

1. In accordance with the rules of confidentiality, categories A and B, and C and D, have been combined, as shown, because certain individual returns accounted for more than 65 per cent of the total of the category concerned.
2. The response from the companies asked to report was 18/20; the statistics given above include reports from these producers :
   Datuk Keramat Smelting
   Greenbushes
   Malaysia Smelting
   Metallurg Group
   Tantalum Mining Corporation of Canada
   Thailand Smelting and Refining
3. Taking into account unrecoverable processing losses, it can be estimated that the above raw material shipments are equivalent to 77 640 lb tantalum (after processing).

TOTAL FOR 1985

	Production	*Shipments*
Tin slag	1 071 029	298 633
Concentrates	323 381	376 143
Total	1 394 410	674 776

Note : Taking into account unrecoverable processing losses, it can be estimated that the above raw material shipments are equivalent to 499 834 lb tantalum (after processing).

PROCESSORS' SHIPMENTS

(quoted in lb tantalum contained)

4th quarter 1985

Product category	*Shipments*
Tantalum oxide/K_2TaF_7	18 572
Alloy additive	41 173
Carbide	101 343
Powder/anodes	167 613
Mill products	67 138
Scrap, ingot, unworked metal and other	97 195
Total	493 034

Notes :

1. In accordance with the rules of confidentiality, the categories of "Scrap" and "Ingot, unworked metal and other" have been combined, because in each category one individual return exceeded 65 per cent of the total of the category concerned.
2. The response from the companies asked to report was 18/18; the statistics given above include reports from 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

TOTAL FOR 1985

Product category	*Shipments*
Tantalum oxide/K_2TaF_7	100 732
Alloy additive	165 149
Carbide	497 966
Powder/anodes	751 971
Mill products	294 274
Scrap, ingot, unworked metal, other	301 646
Total	2 111 738

Capacitor Statistics

EUROPEAN TANTALUM CAPACITOR SHIPMENTS

(thousands of units)

1st quarter 1985	155 251
2nd quarter 1985	147 919
3rd quarter 1985	122 590
4th quarter 1985	109 008
Total for year 1985	534 768

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

JAPANESE TANTALUM CAPACITOR PRODUCTION AND EXPORTS

(thousands of units)

	Production	*Of this, exports*
3rd quarter 1985	533 781	86 681
4th quarter 1985	521 085	95 990
Total for year	2 176 576	387 611

(Data from JEIDA)

U.S. TANTALUM CAPACITOR SHIPMENTS

(thousands of units)

3rd quarter 1985

	US Shipments	*Exports*	*Total*
Foil	310	8	318
Metal cased	32 480	8 497	40 977
Non-metal cased	116 740	24 649	141 389
Chips	11 285	1 667	12 952
Wet slug	2 450	169	2 619
Total	163 265	34 990	198 255

4th quarter 1985

	US Shipments	*Exports*	*Total*
Foil	267	8	275
Metal cased	31 513	8 473	39 986
Non-metal cased	114 699	22 181	136 880
Chips	13 450	2 126	15 576
Wet slug	2 265	244	2 509
Total	162 194	33 032	195 226

Total for year 1985

	US Shipments	*Exports*	*Total*
Foil	1 260	32	1 292
Metal cased	145 419	39 994	185 413
Non-metal cased	512 570	90 723	603 293
Chips	51 443	7 818	59 261
Wet slug	10 290	764	11 054
Total	720 982	139 331	860 313

(Data from EIA)

Japanese tantalum consumption

Units : kg (tantalum contained)

	1983	*1984*	*1985*
Powder	79 462	117 370	122 200
(capacitor, metallurgical)	(16 427)	(21 067)	(21 200)
Compounds	43 280	60 786	54 000
(TaC, Ta_2O_5)	(9 280)	(14 500)	(12 500)
Other	29 886	54 270	51 540
(mill products, etc)	(7 151)	(27 630)	(22 323)
Total	152 628	232 426	227 740
	(32 858)	(63 197)	(56 023)

Notes :

1. Figures in parentheses indicate imports included in respective totals.
2. Data from the Japanese New Metals Society.
3. Data for 1985 are estimated.

Address

Is your Bulletin correctly addressed ? If there are changes to be made, please let us know.

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