TANTALUM PRODUCERS INTERNATIONAL STUDY CENTER

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The T.I.C. Nineteenth General Assembly

The Nineteenth General Assembly of the T.I.C. was convened on Tuesday May 24th 1983 in the Rasa Sayang Hotel in Penang, Malaysia. The meeting was chaired by Mr John Linden, President of the T.I.C.

As the first order of business, four companies were elected to membership, bringing the total current membership of the T.I.C. to sixty-seven. Further business included :

— The nomination of Mr Robert Franklin of STC to be the next President of T.I.C., for the year following the Twentieth General Assembly, and of Mr R.J. Tolley of Datuk Keramat Smelting to be a member of the Executive Committee. Mr Brian Reynolds resigned from the Executive Committee.

— Amending the T.I.C. Charter to change the fiscal year from the calendar year to the twelve month period ending June 30th, in order that accounts can be closed and budgets established in time for the annual business meeting in October.

— The decision of the Executive Committee to have a legal adviser present at all Executive Committee meetings and General Assemblies to provide guidance on matters which may involve possible conflict with anti-trust laws and regulations.

— Changing the basis of fees for membership from Belgian francs to U.S. dollars as most of the T.I.C. expenditure is in dollars and the fluctuating exchange rate makes fiscal management difficult. The annual fee was amended to $ 750.

— Presentation and discussion of statistics covering the production and shipments of tantalum source materials and the shipments of tantalum products by processing companies.

— Expression of appreciation by the Executive Committee and the assembled delegates to Mr Brian Reynolds for his efforts on behalf of the T.I.C. as President for one year and as a member of the Executive Committee for several years.

— The plans for the Twenty-First General Assembly, to be held in Stockholm, Sweden, from June 4th to 6th 1984. The theme of the meeting will be "The use of tantalum in hard metals", and it will be jointly sponsored by Sandvik, Seco Tools, Axel Johnson Ore and Metals and Ekman and Co. It is planned that the meeting will include a visit to the production and research centre of Sandvik in Stockholm and the production plant of Seco Tools in Fagersta.

— The Twentieth General Assembly will be held in Brussels on Wednesday November 2nd 1983 at 40 rue Washington. Details will be announced in the Bulletin, issue no. 35, in September.

After the completion of the business of the association, other participants, including guests and members of the press, joined the meeting for the presentation of a number of papers.

— The Presidential Address presented by Mr John Linden, President of the T.I.C., Managing Director of Greenbushes Tin Ltd. :
An analysis of the cost of producing tantalum source material in tin slags, as co-product of tin mines, and as the output of both primary tantalum mines and secondary production from alluvial deposits, tailing retreatment and amang operations. (Included in this issue of the Bulletin.)

— Dr J. Rodney Lay, Managing Director of Thailand Smelting and Refining Co. Ltd. :
A review of the history of Thaisarco and the production of high-quality tantalum-bearing tin slags at Thaisarco.

— Mr Yeap Soon Sit, S.A. Minerals Limited Partnership and Thailand Tantalum Industry Corporation Limited :
A review of the status of the project to build a tantalum chemical refining plant and a tin slag upgrading plant in Thailand.

— Dr Wilfried Rockenbauer, Hermann C. Starck Berlin :
The processing of various grades of tin slags into synthetic tantalite concentrates.

— Dr Günter Duderstadt, Gesellschaft für Elektrometallurgie :
Presentation of the vertical integration in the tantalum industry by the Metallurg Group.

— Mr Sa-Ngob Kaewpaitoon, Deputy Secretary General of the Department of Mineral Resources, Thai Ministry of Industry, on behalf of Mr Sivavong Changkasiri, Director General of the Department of Mineral Resources :
A discussion of tantalum in Thailand and the objectives of the Thai government in developing this national resource.

— Dr Abdullah Hasbi bin Haji Hassan, Director of the Southeast Asia Tin Research and Development Centre :
The status of tantalum as a resource in Malaysia. (Published in this issue of the Bulletin.)

T.I.C. NINETEENTH GENERAL ASSEMBLY

The Nineteenth General Assembly of the Tantalum Producers International Study Center was held in the Rasa Sayang Hotel in Penang, Malaysia, on Tuesday May 24th 1983, chaired by Mr John Linden, President of the T.I.C. 51 of the 63 member companies were represented in person or by proxy. 130 delegates and guests of member companies attended the seminar following the business of the association.

The General Assembly conducted the business of the T.I.C. Upon completion, the meeting was joined by invited guests, government representatives and trade press journalists.

Presentations were made covering various aspects of tantalum production and processing including addresses covering the general tantalum situation in Thailand and Malaysia.

Mr Tom Barron of Ayers, Whitmore and Company gave a summary of an updated industry outlook from a study sponsored by the T.I.C.

On Monday evening, participants were the guests of the T.I.C. at a Cocktail Party, and on Tuesday they attended a Banquet as guests of the three host companies. The entertainment for the evening featured the culture of Malaysia as represented by music and local dances.

On Wednesday morning, the participants visited the smelting facilities of Datuk Keramat Smelting, on the island of Penang. On Thursday some delegates visited the tin mines at Ipoh, a visit arranged by Malaysia Mining Corporation. Tours for the ladies to points of interest in Penang were conducted on both Tuesday and Wednesday.

The Twentieth General Assembly will be held in Brussels on Wednesday November 2nd 1983 in the conference room of the International Associations Centre, 40 rue Washington, where the T.I.C. now has its office.

— Mr Tom Barron, Ayers, Whitmore and Company :
A resume of the conclusions reached in a review of the 1982 tantalum market, including an updated industry outlook.

(All these presentations will be published in the Bulletin, two being included in this issue.)

After the completion of the presentations, the President asked the following delegates to comment on their outlook for tantalum during the remainder of 1983 and during 1984 :

— Mr H. Lahusen, Hermann C. Starck Berlin, Goslar, West Germany,
— Mr H. Tashiro, Showa-KBI, Japan,
— Mr D. Nocella, NRC, U.S.A.,
— Mr C. Killen, Sprague Electric Co., U.S.A.,
— Mr R. Franklin, STC, England.

The three member companies which were joint hosts of the meeting, Datuk Keramat Smelting, Malaysia Smelting and Thailand Smelting and Refining, entertained all delegates, guests and ladies at an excellent banquet in the Pelangi Ballroom of the Rasa Sayang Hotel. During dinner, entertainment was provided by a band of Malaysian musicians and a troupe of Malaysian dancers who performed traditional Malaysian folkdances, including the customs of a wedding ceremony.

Mr R.J. Tolley welcomed the delegates and guests on behalf of the host companies. Mr John Linden replied on behalf of the T.I.C. The assembled group was then addressed by the guest of honour, Datuk Mohamed bin Yeop Abdul Raof, President of the City Council of Penang.

President's address

This paper, "TANTALUM - COST OF PRODUCTION", was presented by Mr John Linden, President of the T.I.C., as his introductory address to the Nineteenth General Assembly.

Cost of production has nothing to do with the price of the commodity in question. Nothing I say will refer to price, as price is determined by market forces independent of the cost of production. In the long term, however, cost of production will have a relationship to price, but no effort is made to analyse this relationship.

The absolute cost of production of any metal varies tremendously with a whole set of interdependent variables and it is not my intention to address these issues today. It is my intention to put in perspective the cash costs of extracting tantalum from its various occurrences and to present a relative cost of production for tantalum from different source materials.

Before commencing with this task, however, I think it useful to examine the order of magnitude of cost of production in relation to other metals. Why is tantalum quoted in "dollars per pound" while copper is "cents per pound" and gold is "dollars per ounce" ? The answer lies in crustal abundance and Table 1 shows the relative concentration of copper, tin, niobium, tantalum and gold in the earth's crust :

Element	*Content*	*Ratio*
Cu	50 ppm	21.7
Sn	18 ppm	7.8
Nb	20 ppm	8.7
Ta	2.3 ppm	1
Au	0.005 ppm	460

The table shows that tin and niobium are seven to nine times more abundant than tantalum, while copper is 50 times more abundant and gold occurs in 1/500th of the concentration. Again there is no inference that these ratios should be reflected in the price of the commodity or even that these ratios hold true for the cost of production. The relative abundance does, however, indicate that to extract tantalum will be significantly more costly than tin or niobium.

The cost of production of tantalum has been analysed by source of the raw material in the following categories :

- tin slags — more than 10 %
- tin slags — less than 10 %
- tin mines — co-production
- tantalite — secondary alluvial deposits
- tantalite — primary hard rock deposits

The cost of production, as used, is the cash cost of production. Depreciation charges, interest charges, deferred costs and other non-cash items have not been included in the calculated cost of production as, in the main, these costs depend on individual company policy. Similarly, no account is taken of currency exchange rate effects. Estimation of costs is based on what the costs would be in US dollars in a western country rather than what the actual costs are in the country in question.

TIN SLAGS : MORE THAN 10 % Ta_2O_5

High grade tin slags are the largest single source of tantalum-containing raw materials and they have held this position since the tantalum industry was established. These slags are produced as by-products of tin-smelting but they incur some additional costs as a secondary electric arc furnace smelting operation is required to make grade.

	(1,000 lb. units Ta_2O_5) 1983	Capacity
S.E. Asia	600	800
Africa	110	180
Australia	30	80
Brazil	30	80
Other	10	60
	780	1200

COST $5 - $15 per lb Ta_2O_5

This table summarises the estimated production for 1982 and the available capacity by region. Actual production is dependent on grade and availability of tin concentrates. Current low levels of production reflect the 36 % reduction in tin concentrate production imposed by the International Tin Council's export quotas, affecting South-East Asia and Australia. African production is low compared to capacity as the capacity is based on the available resources of high-grade tin concentrates and not on the installed smelting capacity. Significant capital expenditure is required to increase African tin production before this capacity can be realised.

Cost of production is low and consists only of running an additional electric furnace to resmelt the tantalum containing slags from the primary tin smelting operation. The actual costs will vary from smelter to smelter and depend on such factors as the grade of concentrates, the number of re-smelts and the scale of production. These costs range from $5 to $15 per lb. Ta_2O_5 but do not include the payment for tantalum in concentrates, any government imposts, handling and storage, freight and finance, all of which together would add a further $5 to $10 per lb. Ta_2O_5.

TIN SLAGS : LESS THAN 10 % Ta_2O_5

The biggest source of production is right here in Penang with additional production in Singapore and Africa.

	(1,000 lb. units Ta_2O_5) 1983	Capacity
S.E. Asia	180	350
Africa	50	100
	230	450

COST < $5 per lb

These low grade slags are a true by-product from smelting tin concentrates and have an extremely low tantalum content. Some special handling and storage procedures add a nominal cost of production. Low grade slags in this form, however, cannot be considered as a tantalum raw material source as they need further upgrading prior to chemical processing.

The costs of upgrading the low grade slags apply equally to "old slags", there are the additional costs of locating, reclaiming and handling charges as well as any levies and government duties. The assumptions used in estimating the costs for production of synthetic concentrates are that the slags average 2.5 % Ta_2O_5, treatment occurs in Europe, recovery is 65 % and the production rate is 5,000 TPA.

Synthetic concentrate production cost

	$/Tonne	*$/lb. recovered*
Cost of slag production	100	2.80
C.I.F. Europe	65	1.80
First smelt (100 %)	600	17.00
Crushing & handling (20 %)	10	0.10
Re-smelt (20 %)	500	2.80
		24.50
Plus :		
Purchase price		$ 5-10
Duties, levies and charges		1- 5
Finance, depreciation, R. $ D		1- 4
Total		$ 31-44

The cost figures will vary greatly with the grade and recovery of the slag being treated and very greatly with the rate of production. The basis for estimating these costs has been to compare the cost of similar smelting operations elsewhere and to add the additional costs of special reagents and handling. Data from actual operations are not available and these estimates are not intended to reflect actual operational costs.

TIN MINES — CO-PRODUCTION

After tin smelters, the tin mines are the next largest source of tantalum raw materials. Production is in the form of tantalites, columbites and struverites recovered with cassiterite and separated prior to smelting. Estimated 1983 production is 300,000 lbs. but the potential capacity is double that amount :

	(1,000 lb. units Ta_2O_5) 1983	Capacity
Asia	50	100
Africa	100	200
Australia	80	150
S. America	50	100
Other	20	50
	300	600

Africa and Australia dominate production and capacity with individual companies like Zairetain and Greenbushes playing dominant roles. The Metallurg operations in Brazil dominate the South American figures. Tin production from these operations ranges from 100 to 1,000 tonnes with typical Ta_2O_5 production ranging from 10,000 to 200,000 lbs. from individual mines. Past and present production comes predominantly from decomposed surface or open cut operations but a number of these mines have depleted the decomposed ore and are turning to the hard rock source for continued production.

Production costs are developed by determining total annual operating costs for a particular operation and deducting the revenue generated from tin to attribute the remaining costs to co-product tantalite. The cost of production at Greenbushes is used as an example :

Production 1983	
tin metal	350 tonnes
Ta_2O_5	120,000 lbs.
Operating cost	$ 8.5 m
Tin revenue $ 6/lb.	$ 4.63 m
Tantalum revenue	$ 3.87 m
Cost	$ 32.25 per lb. Ta_2O_5

Thus the cost of production for Greenbushes is $ 32.25 per lb. after allowing for tin revenue based on a tin price of $ 6 per lb. and a production rate of 120,000 lbs. Production can be increased but not without increasing total operating cost and reducing tin production.

Although no hard numbers are available on costs of production in Africa, on the basis of the grade of deposits, the production rate and the number of employees (if the Manono pegmatite was in production in the U.S.A. or Australia), cost of production would compare closely with the Greenbushes example.

In Brazil decomposed pegmatite mining is also giving way to hard rock mining. A smaller scale operation producing 70 tonnes of tin and 50,000 lbs. of Ta_2O_5 employs some 240 people and has the following cost :

Production	
tin metal	70 tonnes
Ta_2O_5	50,000 lbs.
Operating costs	$ 2.4 m
Tin revenue $ 6/lb.	$ 0.92 m
Ta_2O_5 revenue	$ 1.48 m
Cost	$ 29.6 per lb. Ta_2O_5

Some tantalite produced is a by-product from tin mining and has a lower cost of production, but the total pounds produced is not significant. Due to the rise in demand and price of tantalum during the last six years, most tin mines producing tantalite by-product have come to rely on the revenue so that production is now considered a co-product. For these operations a cost of production of $ 28 to $ 34 is indicated.

TANTALITES — SECONDARY DEPOSITS

Secondary deposits are described as alluvial, tailing retreatment and amang operations. Typically these operations employ less than fifty people and each produce less than 50,000 lbs. Ta_2O_5. Alluvial operations are responsible for significant total production especially in Africa and South America.

	(1,000 lb. units Ta_2O_5) 1983	Capacity
S.E. Asia	20	200
Africa	20	200
S. America	50	100
Australia	10	50
Other	10	50
	110	600

The operators of these types of production are extremely flexible and production can be adapted to demand. This source has been a significant producer in the past peak demand periods. Costs are directly related to grade in the ground and progressively the richer alluvial areas are being worked out. Certainly this is true for Brazil and Australia although not in Africa where significant high grade deposits still exist.

With each past peak production period in the 1940's, 60's and again late 70's the highest grade easily accessible alluvial deposits were brought into production. In the short term, potential production capacity exists for one more repeat but, in the longer term, capacity from this source is declining. The estimated cost of production from various grades or deposits is :

Deposit type	*Grade tantalite kg/cu.m*	*Cost $/cu.m*	*Cost $/lb. Ta_2O_5*
Alluvials	0.2	8	45
	0.4	8	22
Tailings	0.2	4	22
Amang	—	—	10

It costs $ 8 per cubic metre to mine and process alluvial ore at the rate of 250,000 cubic metres per annum through a simple gravity treatment plant. Cost of production from this source will range from $ 22 to $ 45 depending on grade. Cost of production from tailings will be at the lower end due to cheaper mining costs.

TANTALITES — PRIMARY DEPOSITS

Primary tantalite deposits are defined as hard rock mines the revenue from which in solely or predominantly due to tantalum. Tanco is the only known source of production. The Greenbushes new development also falls into this category.

	(1,000 lb. units Ta_2O_5) 1983	Capacity
Production		
Canada	—	350
Australia	—	400
		750

Grade — Economic	
Historically	0.1 -0.4 % Ta_2O_5
Currently	0.05-0.1 % Ta_2O_5
Future	0.01-0.05 % Ta_2O_5

There is no production in this category in 1983 as the Tanco mine is closed. Tanco with a grade of 0.12 % Ta_2O_5 belongs to the high grade historical category while Greenbushes at 0.075 % Ta_2O_5 equivalent belongs to the medium category. Future producers include the Egyptian, Chinese and Canadian identified resources at around 0.025 % Ta_2O_5.

The hard rock primary deposits already identified hold the key to the future supply side of the tantalum industry. Cost of production for this type of deposit is dominated by the recoverable grade of Ta_2O_5. The estimated cost of production for Tanco is $ 26 per lb., based on a production rate of 280,000 lbs. from 250,000 tonnes and a mining and treatment cost of $ 30 per tonne. Actual costs for 1982 were higher but an increased production would reduce unit costs to the levels estimated.

The Greenbushes new development falls into the currently exploitable reserves category at 0.75 % Ta_2O_5 equivalent and our latest development programme is summarised as follows :

		1985	*1987*	*1990*
Capital expenditure	$ mm	11.4	10	
Operating cost	$ mm	9.0	18	18
Tin revenue	$ mm	4.0	7	7
Ta_2O_5 revenue req.	$ mm	5.0	11	11
Production (1,000 lbs. Ta_2O_5)		180	380	380
Cost of production ($/lb. Ta_2O_5)		27	29	29
Depreciation ($/lb. Ta_2O_5)		7	7	7
Total cost $ per lb.		34	36	36

The programme is based on minimum capital expenditure and a production level of 380,000 lbs. to be achieved by 1986 with first production in 1985 at a rate dictated by market requirements. Depreciation of the development capital required is included in the $ 36 cost of production for the purpose of comparison with Tanco. The operating costs stated are direct costs only and do not include interest, other deferred costs or overheads.

All additional resources identified to date fall into the future grade category. The identified deposits of Egypt, Canada and China have grades around 0.02 % Ta_2O_5 with unknown recovery factors. Any development of these deposits would require substantial capital investments. A simple comparison to the cost of production from this grade of deposit shows the costs to be double those of the current high cost producer.

SUMMARY

I have summarised the production and cost data from the five different sources of raw material in the following table and have made some projections from them.

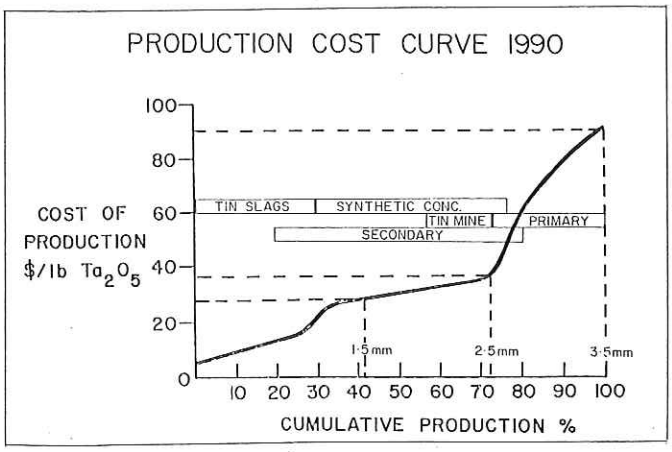
PRODUCTION - CAPACITY - COST

Ta_2O_5 LBS. DERIVED FROM	1983	1986	1990	PRODUCTION 1990-2000	COST OF PRODUCTION
SLAGS > 10%	780	990	970	STEADY	5 - 15
SLAG < 10%	230	330	420	STEADY	22 - 40
TIN MINES CO PRODUCT	220	420	300	DECREASING	29 - 32
SECONDARY DEPOSITS	170	610	140	DECREASING	10 - 45
PRIMARY DEPOSITS		370	800	INCREASING	26 - 36
	1400	2720	2630		

A number of important conclusions can be drawn from the data presented :

1. Production from slags is steady through 2000.
2. Production from tin mines and secondary deposits is declining.
3. Production from primary deposits can increase.
4. Production capacity exists for 2,600,000 lbs. per annum through 1990.
5. Cost of production varies from $ 5 to $ 45 per lb.

Perhaps a more useful way to view this data is by way of a plot of cumulative production percentage against cost.



This tells us the first 1,500,000 lbs. Ta_2O_5 can be produced for less than $ 28 per lb. Ta_2O_5. The next 1,000,000 lbs. Ta_2O_5 can be produced for less than $ 35 per lb. After 2,500,000 lbs. Ta_2O_5 production, however, the cost of production increases rapidly to $ 45 per lb. for the next 300,000 lbs. If a production rate in excess of 2,800,000 lbs. is required for a sustained period after 1990 then the cost of production will be more than $ 90 per lb. Ta_2O_5.

FURTHER PROCESSING

Having made and analysed the cost of producing a feed for the solvent extraction process it may be useful just to put the cost of production into perspective to show some costs of further processing.

Again using US $ per lb. of Ta_2O_5 content or equivalent content recovered, the following costs are based on conversion contracts available during 1983.

Process	*Recovery (%)*	*Cost ($/lb.)*
Ore — K-salt, Ta_2O_5	92	12-15
K-salt — metal powder	96	10
Metal — E-B ingot	98	7
	85	29-32

The factors which will affect actual costs are niobium credit, the grade of feed and the production rate.

Appendix : Production and cost, by country

1983 – LBS Ta_2O_5 000's	< 15	15-25	25-35	35-45	> 45
AFRICA					
NAMIBIA	50				
NIGERIA		40	50		
MOZAMBIQUE			50		
RWANDA			30		
ZAIRE	10		60		
ZIMBABWE	50	20			
	110	60.	190		
ASIA					
MALAYSIA			180		
THAILAND	600	35			
SINGAPORE		30			
	600	65	180		
AUSTRALIA	30		70		
SOUTH AMERICA					
BRAZIL	30		50		
EUROPE	10		5		
	780	125	205		

1984-1986 LBS Ta_2O_5 000's	< 15	15-25	25-35	35-45	> 45
AFRICA					
NAMIBIA	50				
NIGERIA		90			
MOZAMBIQUE			70		
RWANDA			30		
ZAIRE	10	20	80		
ZIMBABWE	70	40			
ASIA					
MALAYSIA			330		
THAILAND	750	100			
SINGAPORE		50			
AUSTRALIA	50		210	140	
NTH. AMERICA					
CANADA			300		
AMERICA			20		
SOUTH AMERICA					
BRAZIL	50		180		
EUROPE	10		20		
	990	300	1240	140	

1987-1990 LBS Ta_2O_5 000's	< 15	15-25	25-35	35-45	>45
AFRICA					
NAMIBIA	60				
NIGERIA		70	30		
MOZAMBIQUE			80		
RWANDA			40		
ZAIRE		10	100		
ZIMBABWE	90	10			
ASIA					
MALAYSIA			320		
THAILAND	700	50			
SINGAPORE			50		
AUSTRALIA	60		600		
NTH. AMERICA					
CANADA			100		
AMERICA			50		
STH. AMERICA					
BRAZIL	50		100	50	
	960	140	1470	50	

ASIA - PRODUCTION & CAPACITY

LBS Ta_2O_5 x 1000

	1983					1986					1990				
	SLAG > 10	SLAG < 10	TIN	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS
MALAYSIA															
BEH MINERALS				30					100					20	
DATUK KERAMAT		50					80					100			
MALAYSIA SMELT CORP.		100					150					200			
THAILAND															
BHUKET UNION				15					50					20	
THAISARCO	600					750					700				
S.A. MINERALS				20					100					30	
SINGAPORE															
KIMETAL		30					50					50			
	600	180		65		750	280		250		700	350		70	
	845					1,280					1,120				

AFRICA - PRODUCTION & CAPACITY

LBS Ta_2O_5 x 1000

	1983					1986					1990				
	SLAG > 10	SLAG < 10	TIN	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS
…IA															
…COR	50					50					60				
NIGERIA															
MAKERI		50					50					70			
COLUMBITES				40					40					30	
MOZAMBIQUE															
MINAS GERAIS			50					70					80		
RWANDA															
SOMIRWA			30					30					40		
ZAIRE															
ZAIRETAIN	10		20			10		20	20				20	10	
SOMINKI			40					60					80		
ZIMBABWE															
KAMATIVI TIN	50					70					90				
OTHER				20					40					10	
	110	50	140	60		130	50	180	100		150	70	220	50	
	360					460					490				

AUSTRALIA - AMERICAS - EUROPE

PRODUCTION AND CAPACITY

LBS Ta_2O_5 x 1000

	1983					1986					1990				
	SLAG > 10	SLAG < 10	TIN	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS	SLAG > 10	SLAG < 10	TIN MINES	SECONDARY DEPOSITS	PRIMARY DEPOSITS
AUSTRALIA	30		50	20		50		160	140	50	60				600
	30		50	20		50		160	140	50	60				600
NTH. AMERICA															
CANADA					NIL					300					100
AMERICA										20					50
										320					150
STH. AMERICA															
BRAZIL	30		30	20		50		80	100		50		80	20	50
OTHER															
	30		30	20		50		80	100		50		80	20	50
EUROPE	10			5		10			20		10				

Malaysia as a source of tantalum

A paper presented at the Nineteenth General Assembly by Dr Abdullah Hasbi bin Haji Hassan, Southeast Asia Tin Research and Development Centre, Ipoh, Malaysia.

INTRODUCTION

It is a well-known fact that tantalum is a by-product of the tin mining industry in Malaysia. What is not so well-known, perhaps, is the fact that tantalum is only one of the many by-products of the Malaysian tin industry. In addition to the tin itself and tantalum-bearing minerals and slags, the tin industry recovers ilmenite, monazite, zircon, xenotime and gold, which are processed and marketed. It can also be seen from the following table that tantalum is a very minor by-product in comparison to the tin, and in terms of tonnage it is dwarfed by ilmenite.

MALAYSIAN PRODUCTION/EXPORT OF CASSITERITE CONCENTRATE AND BYPRODUCTS

	PRODUCTION/EXPORTS (m.t.) 1979	1980	1981	1983
Tin in concentrate	63,995	61,404	59,938	52,342
Tin Slags*	7,824	20,315	7,609	3,588
Struverite*	911	751	395	90
Columbite*	40	33	22	8
Ilmenite*	199,819	189,121	172,757	103,937
Monazite*	542	347	300	546
Zircon*	1,271	552	1,307	2,116
Xenotime*	NA	NA	80	71
Gold*(troy oz.)	3,531	2,588	90,873gr.	NA
*-Exports				

TANTALUM-BEARING MINERALS AND THEIR SOURCES

All tantalum-bearing minerals of economic importance, namely struverite, columbite and tantalum-bearing cassiterite, are found in association with alluvial tin deposits, mined principally by gravel pumping or dredging techniques. Since the ore is fairly coarse and essentially liberated, the primary concentration process is fairly simple, relying on wet gravity separation methods. In addition to cassiterite, other associated heavy minerals are also recovered in the concentrate. The minerals include ilmenite, zircon, monazite, xenotime, struverite, gold, columbite, wolframite and scheelite. Secondary concentration involves treatment of the first concentrate using essentially wet gravity separation techniques. Cassiterite being the heaviest mineral present is recovered in the concentrate product, and sold direct to the smelter. A middlings by-product or by-products which consist of the accessory heavy minerals are also produced and stockpiled. These by-products, which are locally known by the collective term "amang", are sold periodically to specialised retreatment plants, which are inevitably referred to as "amang plants", for further processing into the various export-grade mineral products.

Cassiterite concentrates produced by alluvial tin mines in certain localities contain small amounts of Ta_2O_5 ranging from 0.02 % to 0.68 %, probably averaging only about 0.2 %. The tantalum in these concentrates ultimately ends up in the tin slag of the tin smelters.

Struverite is commonly found in the amang produced by the tin mines in the Kinta valley. Although it occurs in very low concentrations, normally in the region of 0.1-0.2 % of the amang, several hundred tons of the mineral have been produced yearly from the hundreds of thousands of tons of amang that have been treated and are continually being treated. Outside the Kinta Valley tin-field, only very minor quantities of the mineral are found in isolated areas, and are of no commercial value. Analyses of 18 bulk struverite samples from various localities show that the mineral consists essentially of titanium (40-77 % TiO_2), niobium 9-17 % Nb_2O_5), tantalum (5-26 % Ta_2O_5), iron (5-13 % FeO) and tin (2-7 % SnO_2), while minor constituents include tungsten, manganese and zirconium.

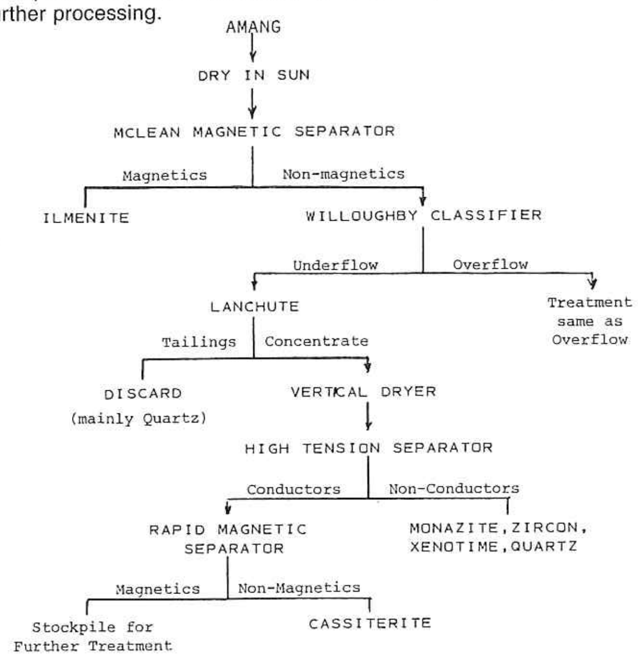
Economic quantities of columbite-tantalite are confined to two minor tin districts, namely in Semiling, in the state of Kedah, and Bakri, in the state of Johor, which are situated at the northern and southern tips, respectively, of the Western Tin Belt. Columbite from these two areas generally contains in the region of 15-18 % Ta_2O_5 and 55-60 % Nb_2O_5. Although the presence of tantalite has been reported, columbite is the only Nb-Ta mineral of economic importance found in these two areas.

RECOVERY OF STRUVERITE

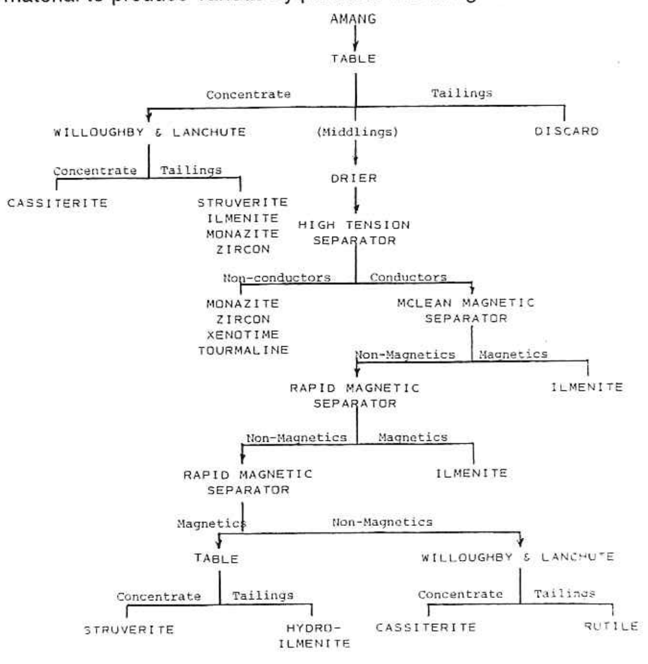
The first amang plants commenced operation in the mid-1950's, with the primary objective being to scavenge cassiterite from neglected amang dumps. With the rapid growth of the retreatment industry and the increasing sophistication of its operators, other by-product minerals were recovered and exported. These minerals include ilmenite, monazite, zircon and xenotime, with struverite being added to the list only fairly recently.

The methods employed for recovery are fairly simple, making use of the physical properties of these minerals. Gravity separation, using the shaking table, lanchute (a short coffinshaped sluice) or air table is employed mainly to remove quartz and tourmaline, which are the most common light minerals, and to upgrade cassiterite, which is the heaviest. Ilmenite, monazite, zircon, xenotime and struverite have fairly similar specific gravities and require magnetic and high tension separations to separate them and obtain clean concentrates.

There are at present about seventy amang plants in Malaysia of varying sizes and degrees of sophistication. The majority of these plants are small and operate essentially as scavengers to recover cassiterite from amang. Using a fairly simple flowsheet, such a plant would produce a high grade cassiterite concentrate as well as rough concentrates of the other associated minerals. The cassiterite concentrate is sold to the smelter, while the other by-products are stockpiled and sold periodically to more sophisticated plants for further processing.



Struverite is recovered from general amang produced by gravel pump mines, rough concentrates of ilmenite and monazite produced by the tin sheds of dredging properties and unsophisticated amang plants. A fairly typical example of a flowsheet to treat the above material to produce various by-products including struverite follows :



The separation of the minerals is based on their physical properties : struverite, for example, is magnetic, but less magnetic than ilmenite, it is a conductor of electricity and it is fairly heavy but less so than cassiterite. These properties are exploited to their full extent by the amang plant operators.

Materials which cannot be marketed at any particular time are stockpiled in dumps surrounding the plant. The sudden and dramatic rise in Malaysia's export of struverite in the mid-1970's was not due to any discovery of a major struverite deposit. Rather, it was due to the fact that an amang plant operator realised that some of the dumps he had been accumulating for many years contained struverite which could be separated and marketed. In time, other operators followed his lead, and now the more sophisticated plants include provision for the recovery of struverite in their regular amang treatment.

Another interesting feature of the amang treatment industry is its flexibility, due mainly to the variety of its products. The amang plant operator would normally produce cassiterite and ilmenite on a routine basis, while the other minerals would be stockpiled and processed into export-grade materials only when there is a demand and the price is right. Hence, besides ilmenite, the export of the other by-product minerals fluctuates considerably over the years. This is influenced mainly by market forces. For example, the export of zircon shot up in 1974, coincident with the high price of zircon at that time. Over the years, the drop in price of some minerals is often compensated by the increase in others, which has kept the industry going. In the late 1960's, xenotime was the glamourous mineral, to be followed in turn by zircon, monazite, struverite, of course, and more recently xenotime. At present, none of the minerals seems to be doing w not even cassiterite.

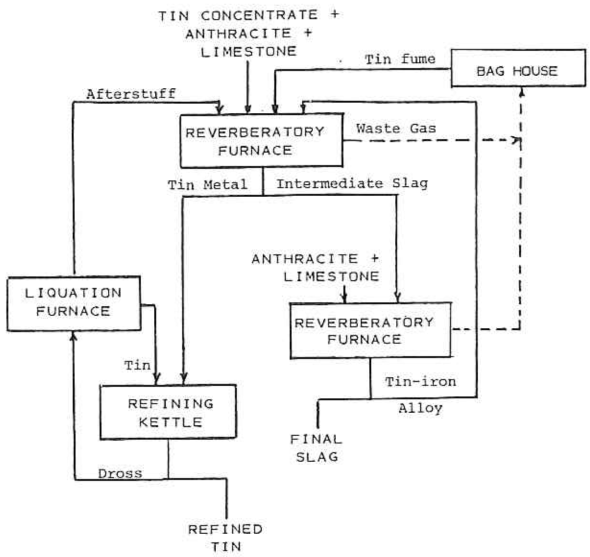
PROCESSING OF COLUMBITE

Columbite is recovered as a by-product of the gravel pump tin mining operations in Semiling and Bakri. The heavy mineral concentrate consists essentially of cassiterite and columbite, separated from each other by means of an electro-magnetic separator. In Semiling, for every 100 tons of cassiterite concentrate produced, between 15 and 30 tons of columbite are also produced. In Bakri, the columbite normally constitutes 10 % to 15 % of the heavy mineral concentrate, but this figure may go up to 70 % in certain areas.

The miners in the two areas are used to large fluctuations in the price of columbite and make it their habit to stockpile the mineral and sell it only when the price is to their satisfaction. Depending on their financial situations, some of the bigger mines may keep the columbite in their stockpile for two or three years.

PRODUCTION OF TANTALUM-BEARING SLAGS

Tin concentrates from Malaysia are smelted either at Datuk Kramat Smelting in Penang or Malaysia Smelting Corporation in Butterworth. The smelting operations at the two smelters are similar in all major aspects.



With 70 tons of high grade Malaysian tin concentrate in the charge, approximately 7 tons of final slag will be produced. Since essentially all the tantalum in the concentrate will be in the final slag, there is a concentration ratio of 10 : 1 for the tantalum during the tin smelting operation.

Interest in the Malaysian tin slag for its tantalum content came first in the early 1950's. Records show that between 1952 and 1954, about 9,000 tons of slag were shipped to Union Carbide, U.S.A., by one of the Malaysian tin smelters. This was followed by big shipments in 1957, 1963 and 1967. Since tin concentrates from Thailand, which were being smelted by the Malaysian smelters, were generally richer in tantalum, it was the general practice to smelt them separately, store the intermediate slags in different stockpiles and resmelt them separately. In addition, Malaysian concentrates were also segregated into two categories, namely those that would produce high tantalum grade slags and those producing low tantalum grade slags. The resulting final slags assaying over 8 % combined pentoxides were stockpiled for sale, while those assaying less than 8 % combined pentoxides were discarded.

Besides current slags, some old pre-war slags that had been dumped as land fill in nearby areas were also dug up for export. Since the tin content of the material was relatively high, it was the normal practice to resmelt it to recover the tin before it was exported.

In the years 1968 to 1970, one of the smelters reported that roughly between 30 % and 40 % of the slags resulting from the smelting of Malaysian concentrates could be classified as high grade (containing over 8 % combined Ta_2O_5 and Nb_2O_5), 50 % to 60 % as low grade (5 % to 8 % combined pentoxides) and 10 % to 15 % as very low grade or reject slags (less than 5 % combined pentoxides). Slags from the Indonesian concentrates in general contain less than 1 % combined pentoxides, and the Australian slags, with the exception of those from Greenbushes, contain negligible amounts of tantalum and niobium.

paper on tantalum-bearing slags would be complete without some mention of the recent "slag-fever" in Penang and Butterworth. Tin smelting has been practised in Penang and Butterworth since the turn of the century. In the early days, the slag produced had no commercial value, and was used as land fill for the low-lying areas, foundation material for roads and buildings or simply dumped on idle ground. Even when high grade tantalum-bearing slags had found a market, low grade slags still had to be discarded as before. Following the upsurge in the price of tantalum in the world market in 1979 there was a large and sudden demand for tantalum-bearing tin slags. Besides the two smelters, the Penang Municipal Council as well as members of the general public participated in the tantalum rush. The Municipal Council entered into a joint venture with one of the tin smelters in January 1980 to recover approximately 9,000 tons of tin slags assaying around 2 % Ta_2O_5 which were dumped on council land long ago. In the same year the council also awarded a tender to a local industrialist to recover old slag on council land, believed to contain 1,000 tons of the material assaying 2.5 % to 3 % Ta_2O_5. Many inhabitants of Penang and Butterworth participated in the slag fever by digging up idle ground, gardens, compounds of houses, sides of public roads, football fields, etc. for old slags. There were many cases of illegal digging on public property, especially by the roadsides, as well as thefts on vacant land belonging to one of the smelters. The police were kept busy for a while but soon managed to take control of the situation. The most sought-after slags were pre-war slags because of their higher tantalum contents and because they were in big lumps rather than being granulated, and could therefore be cleaned easily to remove earthy material. Most of the slags dug up assayed between 2 % and 3 % Ta_2O_5. Earthy material contamination, especially in the case of granulated slags, was removed by passing the material over a sluice. Pre-war slags dug up by the smelters, which contain in the region of 2 % to 5 % Sn may be resmelted before export, in order to recover much of the tin.

The slag fever, which started in January 1980, ended as suddenly as it had begun towards the end of 1980, when the demand fizzled out.

SUMMARY AND CONCLUSIONS

Tantalum is one of the by-products of the Malaysian tin industry. It is exported as struverite, columbite and tantalum-bearing slag produced by the tin smelting operation.

On the whole, tantalum is a minor by-product, and does not make any significant contribution to the success or failure of the tin industry at any level. However, once the tantalum-bearing minerals are recovered in the heavy mineral concentrate, great care is taken by the treatment plant operators and tin smelters to produce tantalum-bearing marketable products.

T.I.C. tantalum production and shipments

The T.I.C. data for the production and shipment of tantalum-bearing tin-slags and concentrates for 1982 are as follows, including the total production and shipments for 1979, 1980 and 1981 for comparison :

(figures given in lbs. Ta_2O_5 contained)

	Slags	*Concentrates*	*Total*
1979			
Production	1,204,945	893,157	2,098,102
Shipments	1,182,163	938,723	2,120,886
1980			
Production	1,383,704	792,528	2,176,232
Shipments	1,589,729	726,480	2,316,209
1981			
Production	1,228,246	926,241	2,154,487
Shipments	1,020,598	738,628	1,759,226
1982			
Production	1,210,140	685,845	1,895,985
Shipments	957,802	442,184	1,399,986

In the first half of 1982, 25 out of 28 companies reported, and in the second half 27 out of 28 companies responded. Failure of two or three companies to report probably results in only a small error as the total reporting will not be made by the data collection agency unless the six major producers plus at least two-thirds of the minor producers' data is included.

The total production in 1982 presents a significant decrease of 12 % from the production of 1981. Shipments, as well, declined from 1981 by 20.5 %. Thus it appears that producers built their inventories by approximately 495,000 lbs. in 1982, about 26 % of total production. Considering the inventory build-up in 1981, it would appear that producers' inventories had reached about 900,000 lbs. contained Ta_2O_5 by the end of 1982.

Data covering processors' shipments are also available for the first time, having been received from all of the sixteen free-world processors requested to report. The data for 1982 is not complete, however, as the total information for the fourth quarter is not yet available.

(figures given in lbs. tantalum contained)

1981	1,755,139
1982 (first three quarters)	1,157,994

Conversion of this data to equivalent pounds of Ta_2O_5, including an allowance for unrecoverable losses in processing, would indicate that the total source material consumption in 1981 was about 2,300,000 lbs. Ta_2O_5 and about 1,500,000 lbs. in the first three quarters of 1982. Thus it seems to be indicated that processors drew down their inventories by about 500,000 lbs. in 1981. It would appear, however, that there was very little drawn-down in 1982. It may be further concluded that the combined inventories of both producers and processors increased by about 400,000 lbs. Ta_2O_5 in the two years, about one quarter of one year's demand at the probable 1982 consumption level.

With expectations by the industry that 1983 consumption will at least equal 1982 and perhaps even increase by 10 % to 15 %, the inventory build-up of the past two years could be significantly consumed in 1983, particularly when the impact of the current International Tin Council export controls for tin are considered in their effect on tantalum production. However, this does not indicate a potential shortage of tantalum at any time in the near future as total inventories alone are adequate to supply demand for two or more years. In addition, producers have demonstrated their ability to escalate production rapidly when demand requires this, as they did from 1978 to 1979, increasing their output by almost 25 %.

Fabricating characteristics of tantalum and niobium

Even though the fabricating characteristics of tantalum and niobium are well known to processors, a series of articles will be presented in the T.I.C. "Bulletin" covering fabrication for the benefit of those readers not so familiar. The information used has been gathered from a number of persons in the industry and from various publications.

Tantalum and niobium are the preferred refractory metals for fabrication of hardware for use under conditions which require corrosion resistance and high strength-temperature properties. Both are very ductile in the pure state. They have a high interstitial solubility for carbon, nitrogen, oxygen and hydrogen. These embrittlement contaminants, therefore, do not normally cause fabrication problems. But at elevated temperatures, tantalum and niobium disolve sufficient oxygen to destroy the ductility at normal temperatures. Therefore, fabrication at elevated temperatures is performed only when necessary.

The physical and mechanical properties of tantalum, niobium and some of their alloys follows :

	Pure Nb	FS-85	1 Zr-Nb	Pure Ta	10W-Ta
Composition, %	Nb (99.8 min)	Nb 87.5 Ta 11 W 0.9 Zr	Nb 1 Zr	Ta (99.9 min)	Ta 10 W
Physical properties:					
Density - g/cc	8.58	10.60	8.58	16.60	16.83
Melting point -°C	2468	2590	2407	2996	3035
Stress relief -°C	802	1010	900	980	1090
Mechanical properties:					
Tensile stregth-10^6kg/cm^2					
- At 21°C	2.5	6.1	3.5	3.2	5.6
- At 1300°C	.4	2.7	.8	.9	2.8
Yield strength-10^6KG/cm^2					
- At 21°C	1.4	4.9	2.6	2.5	4.7
- At 1300°C	.1	1.4	.7	.5	2.5
Elongation in 2" - %					
- At 21°C	25	22	15	35	25

The ductility of unalloyed niobium makes it easy to fabricate at ambient temperatures if the starting material is carefully controlled. In general, niobium alloys compromise high-temperature strength for good fabricability. The structural properties are satisfactory up to 1650 °C but an oxidation protecting coating is required for service over 425 °C.

The Nb-1Zr alloy was developed for nuclear applications where low thermal neutron absorption was required. It is still one of the most extensively used alloys as it combines reasonable strength with excellent fabricability.

Unalloyed tantalum has almost double the strength of unalloyed niobium. It can be used in operating conditions from 1350 °C to 1900 °C. Protective coating is required over 500 °C. Thus, in a mechanical sense, it is only somewhat better than niobium. But its exceptional resistance to chemical corrosion, compared to niobium, gives it a significant edge in corrosive environments.

Tantalum alloys have good fabrication characteristics as well as enhanced mechanical properties which makes them attractive for high-temperature applications. Tantalum — 10 % tungsten is the oldest and most widely used alloy. It is stronger than pure tantalum and has reasonable fabricability. Other tantalum alloys, most notably those containing less than 10 % tungsten, have also been developed for their better fabricability at the expense of a small reduction in the high-temperature properties.

PRODUCTION OF TANTALUM AND NIOBIUM

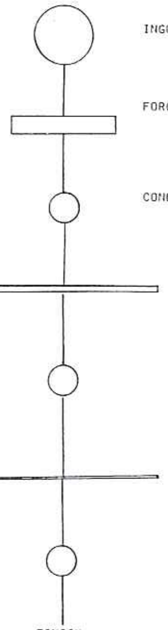
Although the method of reducing the base metal from chemical salts differs for tantalum and niobium, the processing into metal products is almost identical for both metals. Reduced metal is consolidated into an ingot by electron-beam melting. Alloys are often vacuum-arc melted by stripping electron-beam melted electrodes with the alloying materials, thus assuring alloy homogeneity. Ingots range from 10 cm. in diameter to as large as 40 cm, often over three meters long. Niobium ingots as heavy as three tons have been produced and tantalum ingots over two tons.

Ingots are forged into bars or slabs with typical reductions of 50 % per heat at temperatures ranging from 1000 °C for niobium to 1100 °C for tantalum. The ingots are heated in an oxidizing atmosphere. Working the ingot down to lower finishing temperatures, 650 °C for niobium and 925 °C for tantalum, improves the microstructure of the metals.

After forging, the bars and slabs can be rolled down on conventional mill equipment to rod and strip. For rolling, much lower temperatures are used to minimize the oxidation of the unprotected metal. Initial rolling for niobium is at about 300 °C with a 50 % reduction and for tantalum at 375 °C with an 80 % reduction. After intermediate annealing in a vacuum furnace, similar reductions can again be made until the metal approaches finished size. Finish rolling is usually done at ambient temperature in order to attain good surface quality. After annealing, finish rolling can be at reductions as high as 50 % for niobium and 90 % for tantalum.

Due to the limits in the size of ingots, it would seem that there would be a rather low limit to the width to which strip can be rolled. But due to the ease of fabricating these metals, large sheets up to 120 cm. wide by 500 cm. long have been produced. A narrow sheet bar can be cut in length equal to the width of a rolling mill and then cross-rolled to obtain spread equal to the width of sheet desired. After rerolling lengthwise into thinner plate, the plates are then welded end to end in a vacuum to provide the needed length. The composite plate is then further cold-rolled, with intermediate anneals, to the desired gauge, a procedure which strengthens the welds. The only size limitation seems to be the size of vacuum annealing furnaces to provide the intermediate anneals before coiling can be used.

A typical forging and rolling schedule for tantalum sheet could be as follows :



Both tantalum and niobium extrude with ease. Bars and narrow slabs for subsequent rolling are extruded. But the principal advantage of extrusion is to fabricate shapes which are difficult to roll. Extrusion is also used to make tube hollows for subsequent cold rolling or drawing. Hot extrusion temperatures range from 1050 °C for niobium to 1100 °C for tantalum and up to 1650 °C for the 10 %tungsten-tantalum alloy. Extrusion ratios range from 4 to 1 for niobium to as high as 10 to 1 for tantalum.

Another fabrication process for tantalum, particularly to make foil and wire for capacitors, is to press tantalum powder into bars ranging from 2.5 cm. square to 2.5 x 8 cm. rectangular. Both mechanical and isostatic pressing are used. Then the bars are sintered in a vacuum to consolidate the compacts. These bars are then cold-worked with intermediate anneals to produce foil as thin as 0.01 mm. and wire as fine as 0.1 mm. In view of the great ductility of tantalum, comparatively few intermediate anneals are required to attain the enormous reductions to very small dimensions.

Note : Subsequent articles will cover fabrication procedures making tubing, for spinning, die forming, machining and welding.

NEW MEMBERSHIP

The following four companies ware elected to membership by the Nineteenth General Assembly :

Lien Metals, Inc.
20521 Chagrin Boulevard,
Cleveland, Ohio 44122, U.S.A.

Murex Ltd.
89/95 Ferry Lane,
Rainham, Essex RM13 9DP, England.

National Resources Trading Inc.
576 Fifth Avenue,
New York, N.Y. 10036, U.S.A.

Perangsang International Sdn Bhd.
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