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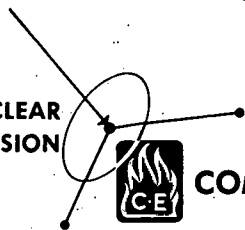
MASTER

VANADIUM
PURIFICATION

FOURTH QUARTERLY PROGRESS REPORT

Issued November 1967

NUCLEAR
DIVISION



COMBUSTION ENGINEERING, INC.

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VANADIUM PURIFICATION
FOURTH QUARTERLY
PROGRESS REPORT

For Period
May 1 to September 30, 1967

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VANPUR QUARTERLY

ABSTRACT

During this report period, a 27.1 pound high purity vanadium ingot was produced using commercial melting equipment and techniques. However, this ingot does not meet the target requirements of the program in that the interstitial content is high, and the ingot too small.

As specified for this program, the target impurity levels are $O \leq 300$, $N \leq 100$ and $C \leq 100$ ppm with a final ingot weight of approximately 100 pounds. Chemical analysis on the 27 pound ingot showed generally a high nitrogen content (approximately 300 ppm) with the remaining impurity elements within the target values. Although this ingot did not meet the target requirements, much information was learned concerning control of chemistry as a result of processing this ingot. Fabrication of a third ingot has been started and information derived from processing the second ingot will be used to control the chemistry within the target requirements and produce a 100 pound ingot.

I. SUMMARY

The vanadium purification program is divided into three tasks:

Task I, Melting Studies

This task is aimed at developing a commercial melting process for high purity vanadium production.

Task II, Fabrication and Mechanical Testing

After a melting process is developed, a vanadium alloy will be melted, fabricated into sheet and tested to determine its mechanical properties.

Task III, Weldability

This task will determine the weldability of the vanadium alloy steel processed under Task II.

During this report period, a high purity ingot weighing 27.1 pounds was produced. Feedstock for the process was vanadium metal obtained by aluminothermic reduction of V_2O_5 . The bomb-reduced metal was purified by electron beam melting five times with two intermediate yttrium doped arc melts after the third electron beam melt. Results of the experiment indicate:

1. Nitrogen is not removed during electron beam or vacuum arc melting. However, by careful control of nitrogen content in the initial bomb reduction, the nitrogen content can be kept below the specification limit of less than 100 ppm.
2. The silicon content remained essentially unchanged during the electron beam processing of the ingot. Silicon evaporates at about the same rate as vanadium during vacuum melting and therefore cannot be removed by melting.
3. Other impurities such as iron, aluminum and carbon decrease with each subsequent electron beam melt. They do not appear to be a problem in this investigation.

4. The oxygen content decreased with subsequent electron beam melting. However, three electron beam melts were not capable of lowering the oxygen content to meet the target concentrations. Therefore, doping with yttrium was required.

5. The hardness of the vanadium ingot is primarily dependent on the oxygen content. Oxygen readily combines interstitially with vanadium, causing an increase in hardness. Therefore, decreasing the oxygen content will result in a decrease in hardness. The hardness of vanadium is also affected by solid solution hardening due to the silicon content. This was observed during the production of Ingot No. 1. By keeping the silicon and oxygen contents within the target value, ingots with hardness values of approximately 100 BHN can be produced. A third ingot was started using melting procedures derived from fabrication of the first two ingots.

INTRODUCTION

The potential of vanadium and its alloys for use as fast reactor cladding and structural materials, has been the subject of several reviews. Nuclear considerations (primarily breeding ratio) have provided the major impetus, but properties such as high temperature strength, compatibility with liquid sodium and fabricability have also made these alloys suitable candidates for liquid metal cooled, fast breeder reactor systems.

One problem that is basic to the use of vanadium alloys, however, is control of their interstitial impurity content. This difficulty is common to the body-centered cubic refractory metals, and its effects are well known to workers in this field.

Normally, an increase in interstitial content results in embrittlement that causes higher tensile strength and lower elongation. For example, the room temperature tensile strength of niobium containing 1200 ppm oxygen is twice that of material containing only 200 ppm oxygen. Similarly, the room temperature tensile strength of vanadium increases from 20,000 to 60,000 psi as the metal's nitrogen content is increased from 50 to 1160 ppm. These results indicate that the mechanical properties of vanadium alloys can be optimized by proper control of their interstitial levels. A systematic approach to their control requires that high purity alloys be produced for evaluation against intentionally contaminated materials.

Interstitials also play a role in the corrosion behavior of the refractory metals. DiStefano and Hoffman, who studied the compatibility of the Nb-Li system, showed that the attack on niobium by lithium increases as a function of the oxygen present in the niobium prior to testing. Lithium has a greater affinity for oxygen than niobium and scavenges it from the cladding.

Potassium and sodium, on the other hand, lose oxygen to niobium which becomes

embrittled as a result. Similar behavior can be expected from vanadium alloys, and once again, its study requires a source of high purity vanadium to compare with contaminated metal.

Another aspect is the compatibility of cladding alloys with the oxides, carbides and nitrides that are proposed as fuels for fast breeder reactors. At the surface temperatures which are currently contemplated, diffusion of interstitials across the fuel-cladding interface could lead to changes in fuel stoichiometry or embrittlement of the cladding. The development of low interstitial vanadium alloys is necessary in order to investigate this interaction. This program was undertaken to (1) develop a commercial process for producing high purity vanadium and (2) determine the mechanical properties and welding characteristics of a high purity vanadium alloy.

Purification studies, based on the addition of gettering agents to vanadium melting stock, have been previously reported in the second quarterly report. This report covers the melting of a second and third ingot, after the first 100 pound ingot was found to have a high silicon content and subsequently sent to the Bureau of Mines for further evaluation.

Experimental Effort and Discussion

Two ingots have been produced to date under Task I. Ingot No. 1, reported in the third quarterly (CEND-3742-311) weighed 109 pounds and had the following chemistry:

IMPURITY CONTENT OF INGOT NO. 1

(Impurity Content, wt%)

Section	C	N	O	Al	Si	Fe	Y	Cu	Mo	Sn	Ti
TOP											
1	0.016	0.028	0.036	0.042	0.440	0.101	0.006	<0.004	0.035	0.020	<0.005
2	0.014	0.032		0.202	0.440	0.108	0.025	"	0.035	0.030	"
3	0.013	0.023	0.030	0.074	0.420	0.088	0.016	"	0.035	0.250	"
4	0.013	0.018	0.028	0.135	0.380	0.122	0.024	"	0.040	0.250	"
5	0.015	0.016		0.074	0.410	0.091	0.007	"	0.035	0.250	"
6	0.010	0.007	0.027	0.054	0.420	0.101		"	0.040	0.030	"
7	0.008	0.006		0.039	0.430	0.076		"	0.040	0.035	"
8	0.009	0.008		0.024	0.440	0.056		"	0.040	0.030	"
9	0.011	0.010	0.019	0.022	0.570	0.072		"	0.050	0.035	"
10	0.016	0.011		0.039	0.320	0.142		"	0.035	0.050	"

BOTTOM

Due to the solution hardening of the high silicon content (average approximately 4300 ppm), the hardness of Ingot No. 1 was approximately 180 DPH (10K grams), too high to be satisfactory for Tasks II and III. The high silicon content resulted from the initial silicon content of V_2O_5 and reactant aluminum. By carefully controlling the silicon content of these materials, the silicon content of the ingot can be reduced. A modification to the chemistry requirements for this program was made whereby the silicon content should not exceed 500 ppm. The new target values are

shown below:

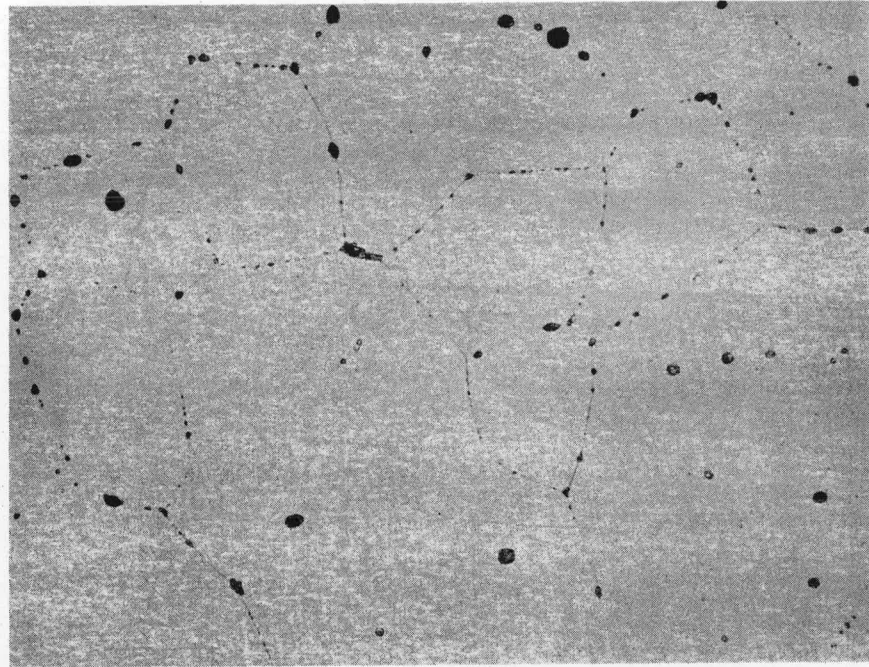
O \leq 300 ppm	Si \leq 500 ppm
N \leq 100 ppm	Al \leq 1000 ppm
C \leq 100 ppm	Fe \leq 100 ppm

Ingot No. 2 produced during this quarter, was melted using V_2O_5 and aluminum with low silicon content. However, the ingot failed to meet the target requirements, due to high nitrogen content. Difficulties were also experienced in removing oxygen. Five electron beam melts in conjunction with two yttrium dopings were required to bring the oxygen content within target values. As a result of the excessive number of melts required, the resulting ingot weighed 27.1 pounds. Work was immediately started to fabricate a third ingot.

Detailed chemical analyses and hardness data at each melting operation on all of the material processed to date are given in Appendix A. Based on this information, an analysis has been made on the effect of melting operations on ingot chemistry and hardness.

Figure 1 shows the hardness history of all three ingots as a function of melting operations. Figure 2 is included to compare the hardness of a typical niobium ingot through its commercial purification process. Both vanadium and niobium show a large hardness range, due to inhomogeneity of the initial ingot. This is reduced by subsequent vacuum melts. The large range of hardness for Ingots No. 2 and 3, can be traced to the presence of excessive amounts of oxygen in solution with the vanadium. This was caused by insufficient additions of aluminum in the aluminothermic reduction of V_2O_5 . As a result, there was poor slag separation in the reductions. This is substantiated by the amount of aluminum and oxygen present after the consolidation melt as shown in Figures 3 and 4, where the aluminum content is high, the oxygen

content is low. Figure 1 also shows that hardness decreases with each successive vacuum melt and reaches a minimum when the ingot is doped with yttrium forming a high oxygen solid solution with the yttrium metal. This can be seen in the structure below:



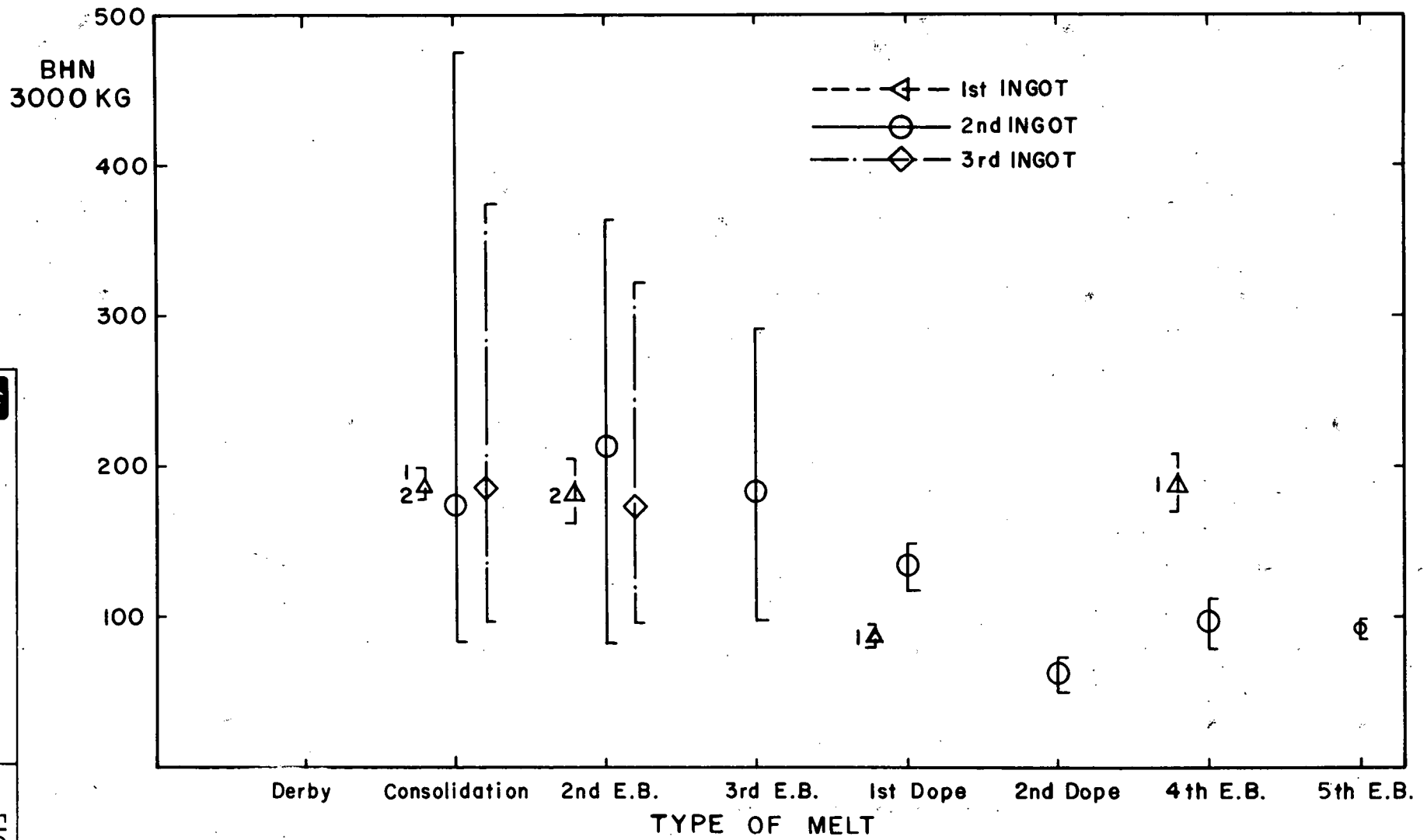
Mag. 500X

A rise in hardness follows the removal of the yttrium by electron beam melting. This is believed due to incomplete removal of the oxygen and/or the solutioning of nitrogen.

Figures 3 and 4, the effect of vacuum melting on the oxygen and aluminum content respectively, are interrelated and can be discussed together.

The derbies (aluminothermic reductions) of the second ingot had a high oxygen content resulting from a poor reduction by the reactant aluminum. This reduction used high purity granular aluminum instead of powder, as was used for the first ingot,

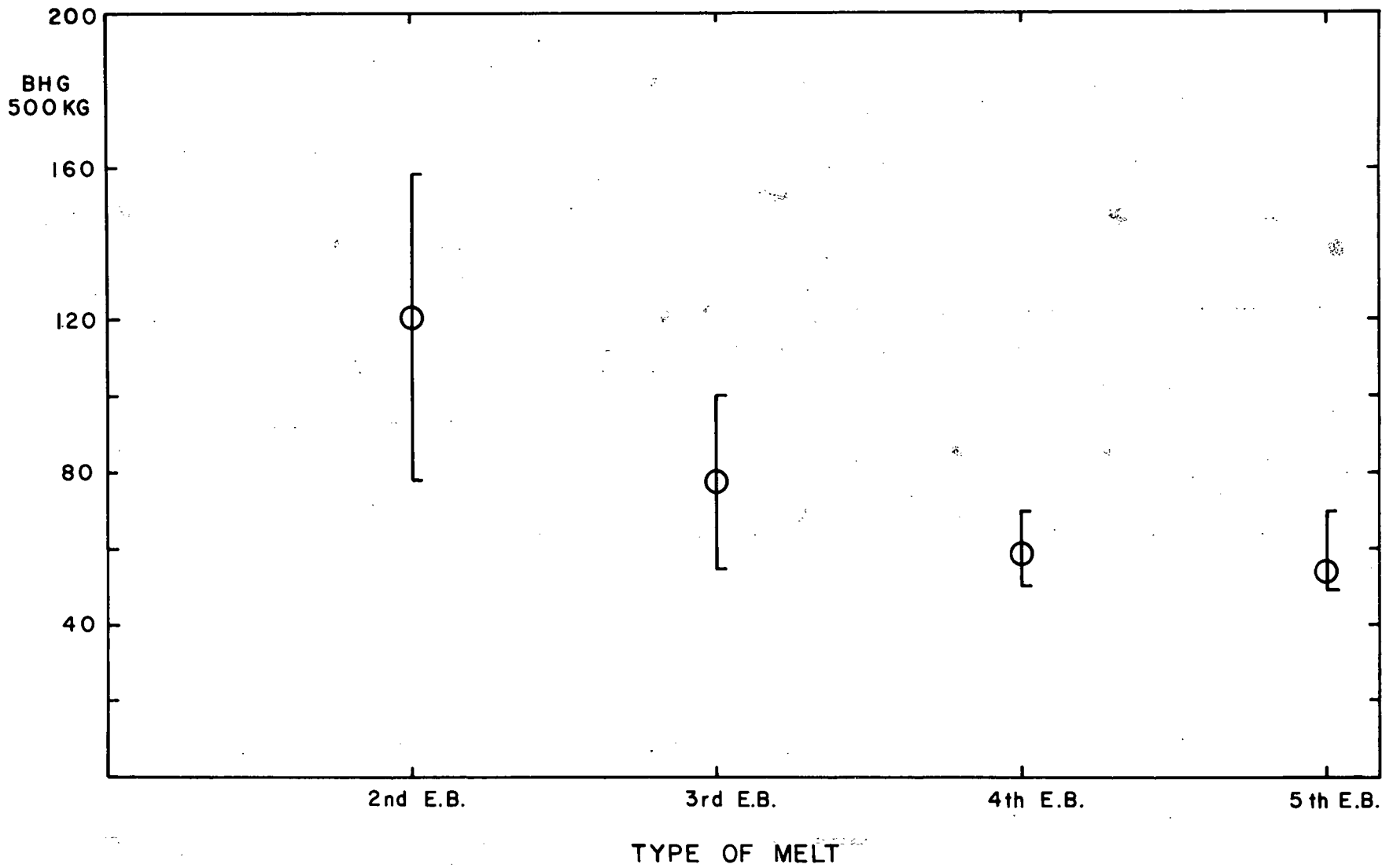
EFFECT OF VACUUM MELTING ON THE HARDNESS READING OF VANADIUM



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FIG. I

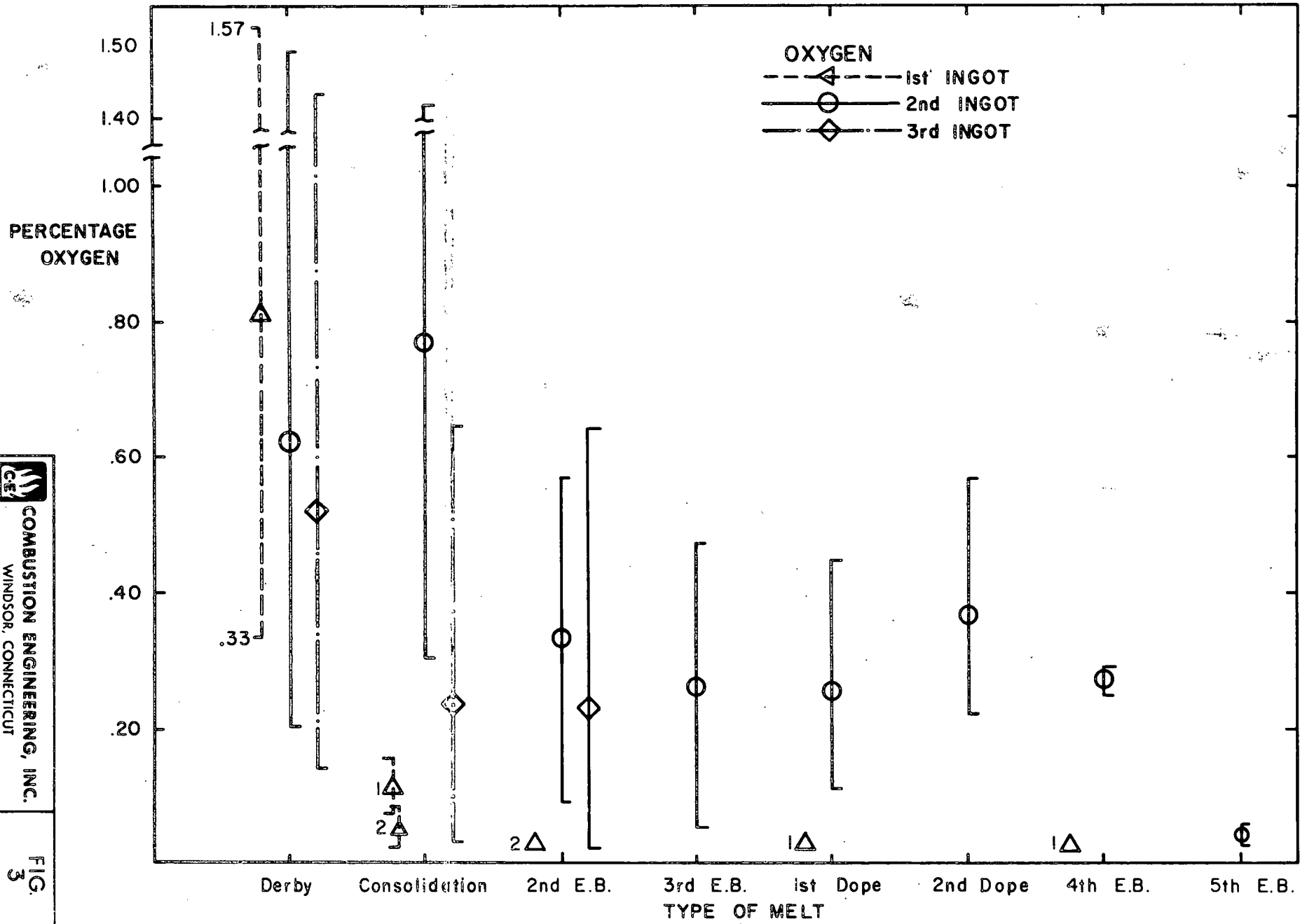
EFFECT OF THE VACUUM MELTING ON THE HARDNESS VALUE OF
NIOBIUM



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FIG.
2

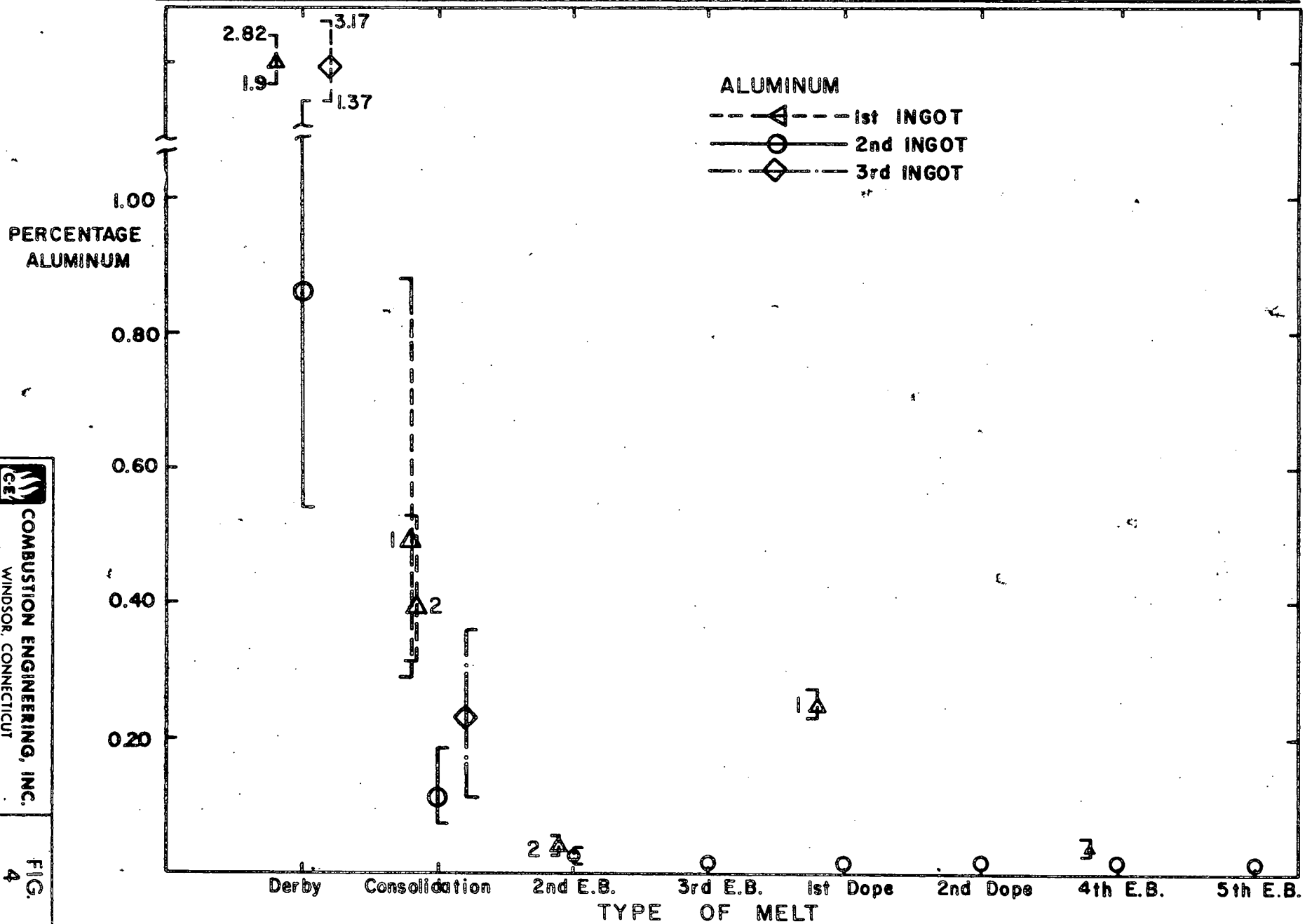
EFFECT OF VACUUM MELTING ON THE OXYGEN CONTENT IN VANADIUM



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FIG. 3

EFFECT OF VACUUM MELTING ON THE ALUMINUM CONTENT IN VANADIUM




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FIG. 4

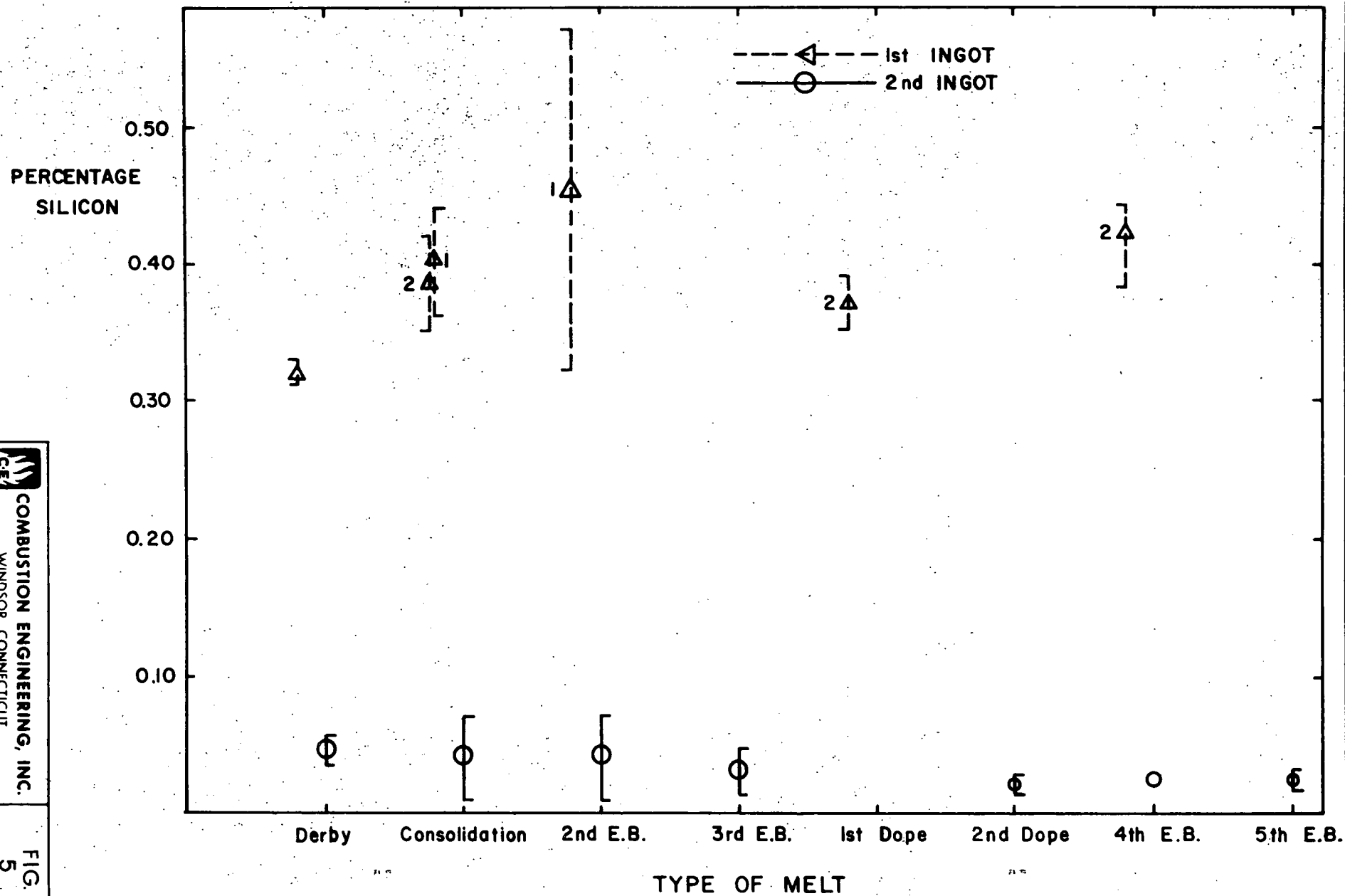
to reduce silicon contamination. The amount of reactant aluminum was not sufficient for total reduction, resulting in excessive oxygen present in the derbies. Three electron beam melts decreased the oxygen level from 6000 ppm to 2600 ppm, however, this level was far above the target value of 300 ppm. In an effort to reduce the oxygen content, the ingot was doped with yttrium. Due to the high oxygen content, a large addition of yttrium was required thereby necessitating two postdoping electron beam melts to remove the yttrium. All of these extra vacuum melts caused the weight of the ingot to be reduced to 27.1 pounds, since approximately 20 to 30 percent of the ingot is lost during scalping and processing the ingot.

As can be seen in Figure 3, the doping and subsequent electron beam melts were successful in reducing the oxygen content to within target values.

In contrast, the first ingot reacted target values after the electron beam melt. The low oxygen values are a result of sufficient aluminum addition in the aluminothermic reduction allowing the oxygen to be present as Al_2O_3 in the consolidation ingot. Subsequent electron beam melting allows the Al_2O_3 to be boiled off along with any residual aluminum resulting in a low oxygen content in Ingots No. 1 and 3. If insufficient aluminum is added to the reduction bomb, high oxygen will result as seen in Ingot No. 2.

Figure 5 shows that the initial silicon content obtained by the reduction process will not change through any of the subsequent melting operations. This indicates that the silicon boils off at about the same rate as vanadium. Therefore, high purity, low silicon content material must be used in the initial bomb reduction process if low silicon material is to be produced. After using low silicon V_2O_5 and aluminum for Ingot No. 2, it can be seen that silicon is no longer a problem. Low silicon starting material was used in processing Ingot No. 2, and as can be seen

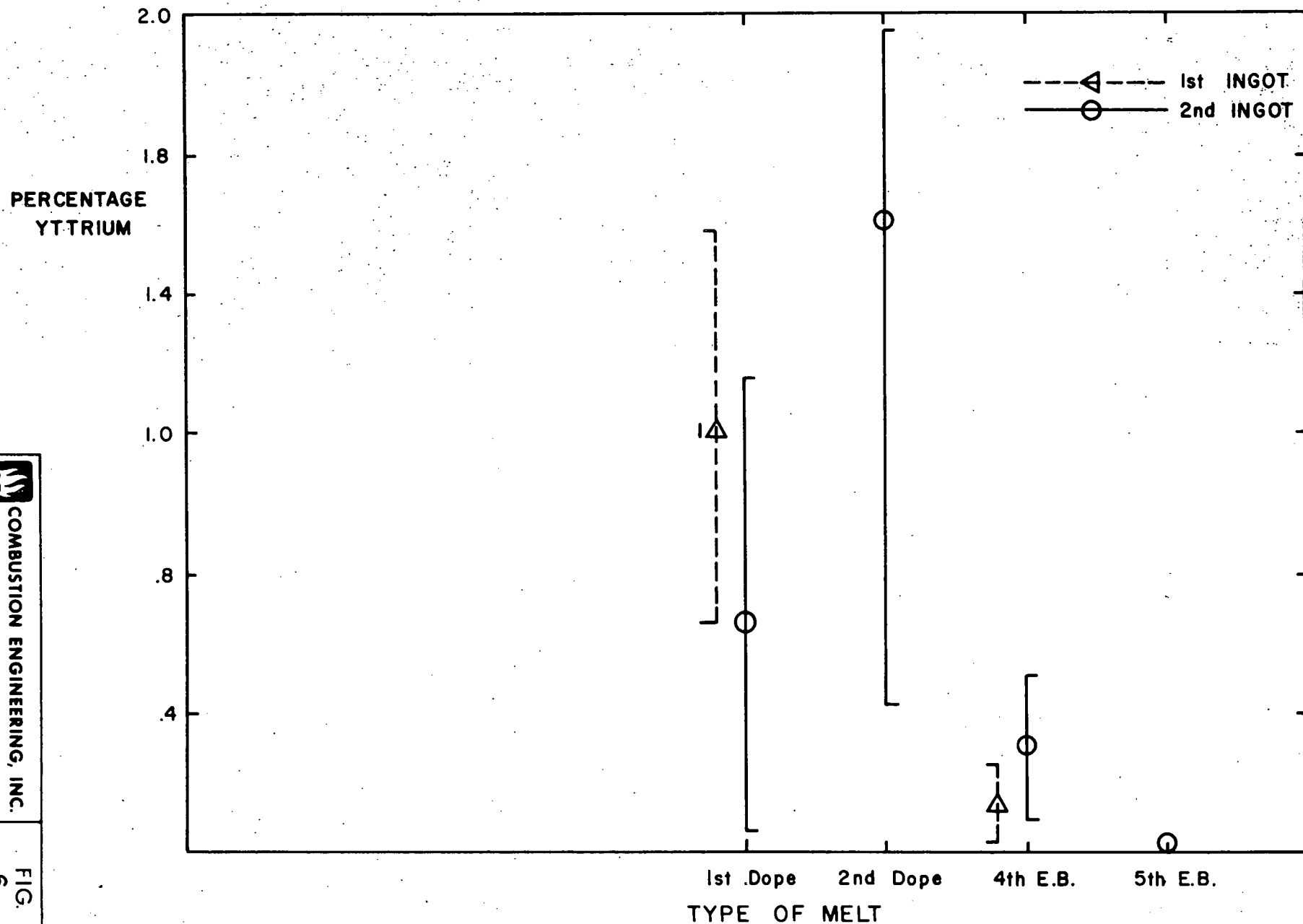
EFFECT OF VACUUM MELTING ON THE SILICON CONTENT IN VANADIUM



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FIG. 5

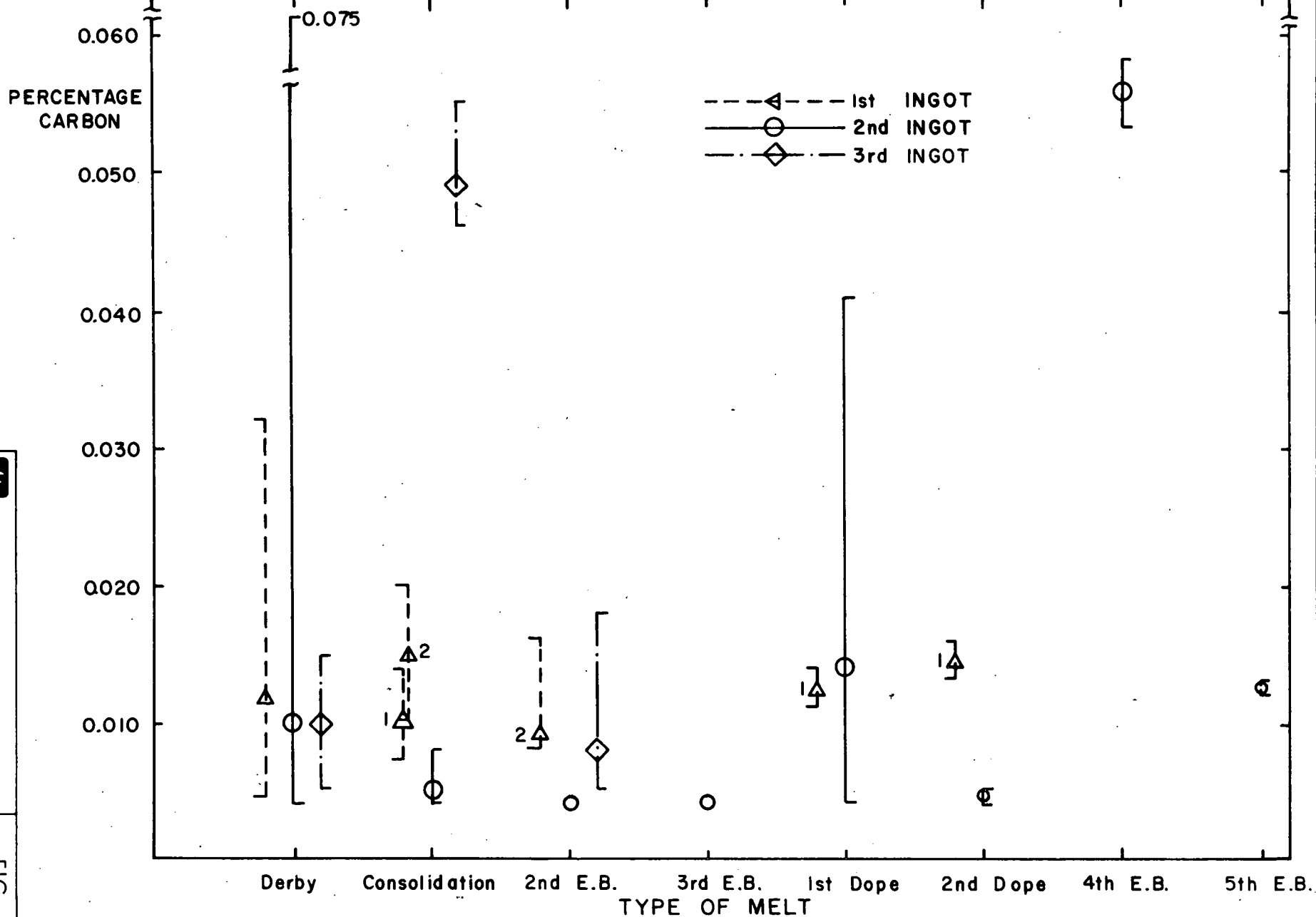
EFFECT OF VACUUM MELTING ON THE YTTRIUM CONTENT OF VANADIUM



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FIG. 6

EFFECT OF VACUUM MELTING ON THE CARBON CONTENT IN VANADIUM



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FIG. 7

in Figure 5, the silicon level is within the target value.

The effect of vacuum melting on the yttrium content is shown in Figure 6. As can be seen, Y_2O_3 and/or YO quickly boils off during electron beam melting. Only one electron beam melt should be necessary to remove the yttrium after doping. However, in processing Ingot No. 2, a large amount of yttrium (1.7 w/o as compared to 1.0 w/o for Ingot No. 1) was required due to the high O_2 content and as a result two electron beam melts were necessary to remove the yttrium.

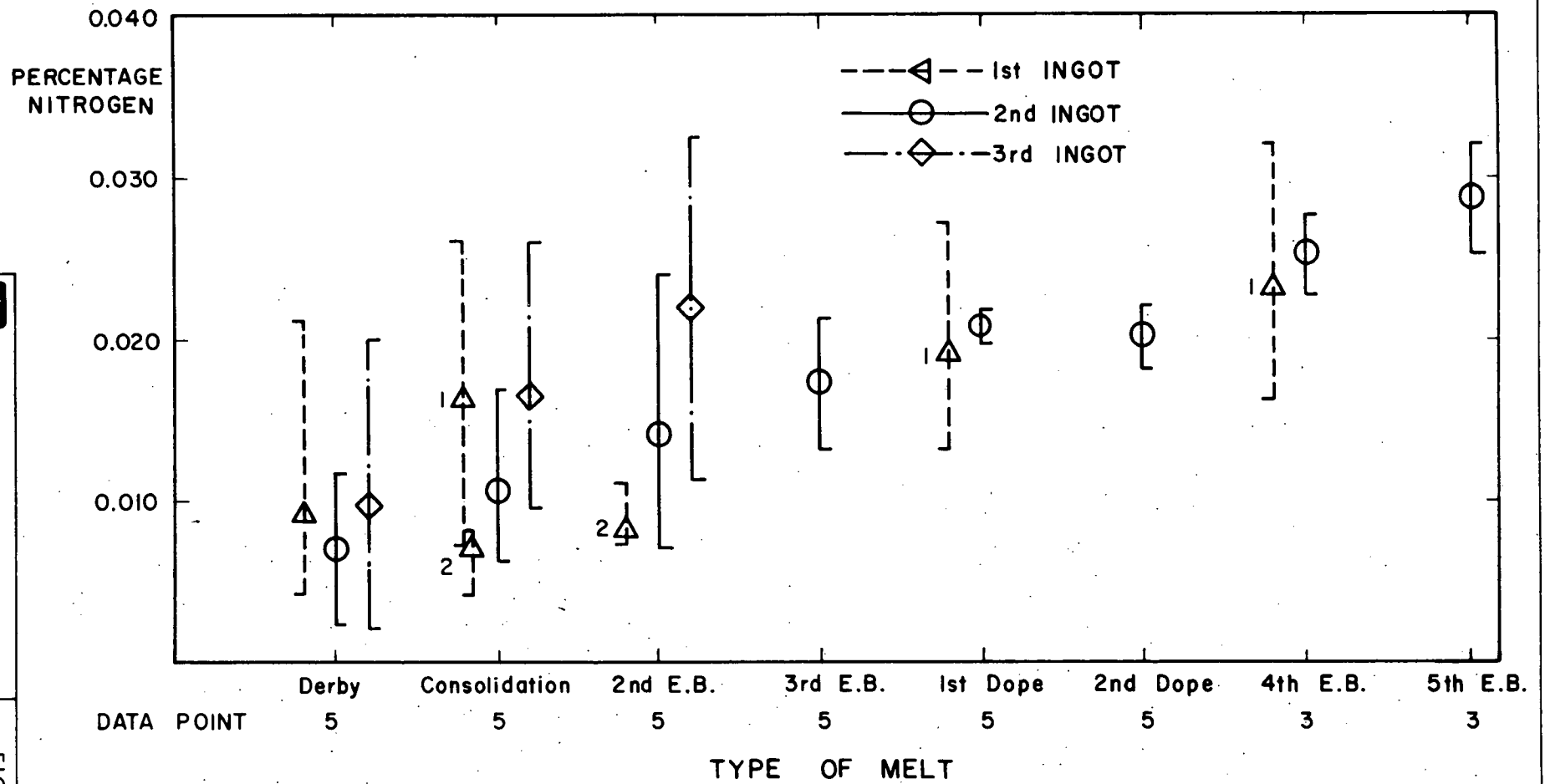
The effect of vacuum melting on the carbon content is shown in Figure 7. This indicates no problems in controlling the carbon content to meet the target values. Some anomalies are present in Figure 7 and are assumed attributed to either laboratory or sampling error. The carbon content of the fourth electron beam melt of the second ingot and that of the consolidation melt of the third ingot are too high to be plausible when compared to the carbon contents of prior and subsequent melts.

The high initial carbon content in the derbies is reduced during the consolidation melt, with oxygen forming CO. The carbon then stays relatively constant throughout subsequent melting processes. There is no problem in controlling carbon content with the target values.

Figure 8 shows the effect of vacuum melting on the nitrogen content. The data indicate that nitrogen content is not reduced as a result of electron beam melting. Thus, it is assumed that N_2 boils off at a slower rate than the vanadium, thereby steadily increasing the relative nitrogen content. The initial nitrogen content of the derby then governs the final nitrogen level of the ingot. It is, therefore, essential to obtain low nitrogen derbies.

Difficulty has been experienced in igniting the aluminothermic bomb for reducing V_2O_5 as a result of using aluminum pellets instead of powder. Several tries

EFFECT OF VACUUM MELTING ON THE NITROGEN CONTENT IN VANADIUM



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FIG. 8

are required, each one meaning loss of vacuum and disturbing the system to replace ignition wires. This results in N_2 contamination. Contamination from this and possible leaks in the system must be controlled if target values are to be obtained in the ingot.

These precautions were not applied to the reductions of the third ingot. From chemical data available on the second electron beam melts on the third ingot, it is fairly evident that this ingot will have a high nitrogen level (approximately 200 ppm). In order to meet the requirements of this contract, a fourth ingot will be processed and care will be taken to ensure low nitrogen contamination in the bomb reduction.

II CONCLUSIONS

As a result of the work performed to date under this contract, the following conclusions can be made with respect to the melting processes on ingot chemistry;

1. Nitrogen remains in the vanadium and will not be removed by electron beam melting.
2. Silicon content remains essentially unchanged during the electron beam processing of the ingot.
3. Iron, aluminum and carbon contents are reduced during electron beam melting to acceptable levels.
4. Oxygen content is reduced during electron beam melting; however, a yttrium doping is required to bring the level to acceptable limits.
5. Decreasing hardness follows decreasing oxygen content.

We believe that a commercial process has been developed capable of producing high purity vanadium. This process consists of:

1. Aluminothermic reduction of V_2O_5 by aluminum.
2. Electron beam consolidation of derbies.
3. Electron beam melting to further reduce Al, Fe, Cr, C, O_2 , etc.
4. Yttrium arc doping.
5. Electron beam melting to remove yttrium and oxygen.

Future Work

Fabrication of the third ingot will continue even though it is apparent that the final nitrogen content will be slightly above target values.

The remaining processing steps are:

1. Yttrium arc doping with approximately 0.4 percent Y.
2. Single electron beam melt.

A fourth ingot will be started and care will be taken to prevent nitrogen contamination during the aluminothermic reductions. The full process will be:

1. Aluminothermic reduction of V_2O_5 by aluminum.
2. Electron beam consolidation of derbies.
3. Electron beam melting to further reduce Al, Fe, Cr, C, O_2 , etc.
4. Yttrium arc doping.
5. Electron beam melting to remove yttrium and oxygen.

APPENDIX A

HARDNESS AND CHEMICAL DATA

OF INGOTS NO. 1, 2 AND 3

TABLE I

CHEMICAL ANALYSES OF THE DERBIES FOR THE FIRST INGOT

Impurity Content (wt %)

Identification	C	N	O	Al	Fe	Cu	Si	Mo
2-24-67	0.004	0.021	1.060	2.820	0.870	0.180	0.310	0.030
3-04-67	0.009	0.005	1.570	2.010	-	-	0.330	0.025
3-13-67	<0.004	0.004	0.330	2.740	0.640	0.250	0.330	0.020
3-18-67	0.032	0.008	0.950	1.900	0.710	0.350	0.330	0.030

TABLE II

CHEMICAL ANALYSES OF INGOT NO. 1 AFTER THE CONSOLIDATION E. B. MELT

Section	C	N	O	Al	Impurity Content, (wt%)				Co	Cu	Mo	Sn	Ti
					Si	Fe	B	Cd					
TOP													
1	0.010	0.023	0.158	0.880	0.360	0.280	<0.001	<0.001	<0.002	0.010	0.018	0.050	<0.005
2	0.012	0.026		0.570	0.400	0.185	"	"	"	0.004	0.030	0.025	"
3	0.014	0.025	0.035	0.290	0.440	0.122	"	"	"	0.010	0.030	0.030	"
4	0.009	0.011		0.060	0.360	0.204	"	"	"	0.005	0.050	0.020	"
5	0.007	0.007	0.074	0.360	0.380	0.135	"	"	"	0.005	0.040	0.020	"
6	0.009	0.011		0.290	0.400	0.124	"	"	"	0.005	0.050	0.025	"
7	0.011	0.005	0.024	0.370	0.420	0.140	"	"	"	0.005	0.040	0.025	"
8	0.014	0.005		0.310	0.460	0.120	"	"	"	0.005	0.040	0.025	"
9	0.018	0.006	0.084	0.370	0.380	0.207	"	"	"	0.005	0.050	0.025	0.100
10	0.020	0.012		0.530	0.350	0.258	"	"	"	0.005	0.050	0.030	0.010
BOTTOM													

TABLE III

CHEMICAL ANALYSES OF INGOT NO. 1 AFTER DOPING WITH 1% YTTRIUM

Section	Impurity Content (wt%)										
	C	N	O	Al	Si	Fe	Y	Cu	Mo	Sn	Ti
TOP											
1	0.014	0.027	0.026	0.226	0.390	0.195	1.590	0.004	0.035	<0.010	<0.005
2	0.014	0.022	---	0.269	0.380	0.178	0.910	0.008	0.030	"	"
3	0.012	0.019	0.032	0.232	0.380	0.173	0.890	0.010	0.035	"	"
4	0.012	0.014	---	0.243	0.350	0.157	1.240	0.010	0.035	"	"
5	0.011	0.013	0.029	0.276	0.380	0.155	0.650	0.010	0.065	"	"

BOTTOM

TABLE IV

CHEMICAL ANALYSES OF INGOT NO. 1 AFTER FINAL E. B. MELT

Section	Impurity Content, (wt%)										
	C	N	O	Al	Si	Fe	Y	Cu	Mo	Sn	Ti
TOP											
1	0.016	0.028	0.036	0.042	0.440	0.101	0.006	<0.004	0.035	0.020	<0.005
2	0.014	0.032		0.202	0.440	0.108	0.025	"	0.035	0.030	"
3	0.013	0.023	0.030	0.074	0.420	0.088	0.016	"	0.035	0.250	"
4	0.013	0.018		0.135	0.380	0.122	0.024	"	0.040	0.250	"
5	0.015	0.016	0.028	0.074	0.410	0.091	0.007	"	0.035	0.250	"
6	0.010	0.007		0.054	0.420	0.101	"	0.040	0.030	"	
7	0.008	0.006	0.027	0.039	0.430	0.076	"	0.040	0.035	"	
8	0.009	0.008		0.024	0.440	0.056	"	0.040	0.030	"	
9	0.011	0.010	0.019	0.022	0.570	0.072	"	0.050	0.035	"	
10	0.016	0.011		0.039	0.320	0.142	"	0.035	0.050	"	
BOTTOM											

TABLE V

ANALYSES OF THE ALUMINUM PELLETS:
FOR INGOTS 2 & 3 (wt%)

N - <0.0005

B - <0.0005

Cd - <0.0005

Co - <0.0010

Cr - <0.0020

Cu - <0.0040

Fe - <0.0100

Mg - <0.0020

Mn - <0.0020

Mo - < 0.0020

Ni - 0.0050

Pb - <0.0020

Si - <0.0100

Sn - <0.0020

Ti - <0.0050

V - <0.0020

TABLE VI

REDUCTION DATA OF VANADIUM DERBIES FOR
INGOT NO. 2

Lot No.	V ₂ O ₅ , lbs	Al, lbs	Yield Derby, lbs	Ratio V ₂ O ₅ -Al-Derby
7-19-67	104	56	54	1:0.548:0.52
7-22-67	102	50	42	1:0.49:0.41
7-23-67	100	50	33	1:0.50:0.33
7-26-67	100	50	43	1:0.50:0.43
7-28-67	100	50	46	1:0.50:0.46

Theoretical Ratio V₂O₅:Al:V - 1:0.494:0.56

TABLE VII
 CHEMICAL ANALYSES OF THE DERBIES
 FOR THE INGOT NO. 2 (wt%)

Lot No.	7-19-67	7-23-67	7-22-67	7-28-67	7-26-67
C	0.006	0.145	<0.004	<0.040	0.075
O	0.20	0.900	0.20	0.21	1.500
N	0.0072	0.0118	0.0100	0.0085	0.0026
Al	0.850	0.540	>0.1	>0.1	1.370
Si	0.045	0.033	0.0330	0.047	0.056
Fe	>0.100	>0.100	>0.100	>0.100	>0.100
B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Co	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Cr	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Cu	>0.100	>0.100	>0.100	>0.100	>0.100
Mg	0.003	0.0035	0.0035	0.002	---
Mn	<0.002	<0.002	<0.002	<0.002	<0.002
Mo	<0.002	<0.002	<0.002	<0.002	<0.002
Ni	<0.002	<0.002	<0.002	<0.002	<0.002
Pb	<0.002	<0.002	<0.002	<0.002	<0.002
Sn	0.015	0.025	0.015	0.020	0.020
Ti	<0.005	<0.005	<0.005	<0.005	<0.005

TABLE VIII

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER THE
CONSOLIDATION E.B. MELT

(Ht#940010) 127.6 Pounds

Hardness, BHN		Chemical Analysis, %						
			1	2	3	4	4.5	5
TOP	157	C	0.006	<0.004	<0.004	0.004	0.011	0.0088
	102	O	0.60	---	---	1.420	---	0.300
	223	N	0.0060	0.0070	0.010	0.0125	0.0150	0.0170
	103	Al	0.1020	0.1460	0.1860	0.0515	0.0150	0.0710
	81	Si	0.0710	0.0430	0.0090	0.0140	0.0140	0.0430
	363	Fe	0.0078	0.0066	0.0078	0.0083	0.0316	0.0079
	363	B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	477	Cd	<0.0005	0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	444	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	187	Cr	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	116	Cu	<0.0040	0.0040	0.0040	0.020	0.0075	<0.0040
BOTTOM	143	Mg	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Mo	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Pb	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Sn	0.0050	0.0050	0.0050	0.0050	0.0075	0.0050
		Ti	0.0050	0.0075	0.0075	0.0100	0.0050	0.0050

TABLE IX

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER THE SECOND E.B. MELT

(Ht#940012) 82 Pounds

Hardness, BHN		Chemical Analysis, %						
		1	2	3	4	5		
TOP	81	H	0.00027					
	105	C	<0.004	<0.004	<0.004	<0.004	0.004	
	123	N	0.007	0.012	0.013	0.017	0.024	
	121	O	0.086				0.570	
	321	Al	0.031	0.043	0.048	0.036	0.009	
	352	Si	0.070	0.040	0.007	0.024	0.012	
	131	Fe	0.023	0.026	0.020	0.025	0.021	
	217	B		Less than 0.0001				
	321	Cd		Less than 0.0005				
	BOTTOM	363	Co		Less than 0.0010			
			Cr		Less than 0.0020			
			Cu	0.005	Less than 0.0040			
			Mg	0.002	0.002	0.002	0.002	0.007
		Mn		Less than 0.0020				
		Mo		Less than 0.0020				
		Ni		Less than 0.0020				
		Pb		Less than 0.0020				
		Sn	0.005	0.008	0.005	0.005	0.005	
		Ti	0.008	0.010	0.020	0.005	0.005	

TABLE X

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER THE THIRD E.B. MELT

(Ht#940013) 62.9 Pounds

Hardness, BHN		Chemical Analysis, %					
		1	2	3	4	5	
TOP	262	C	0.0060	<0.0040	<0.0040	0.0040	0.0080
	277	O	0.470	0.540	0.320	0.100	0.054
	293	N	0.0205	0.0175	0.0165	0.0165	0.0145
	229	Al	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
	179	Si	0.0047	0.023	0.012	<0.049	0.051
	176	Fe	<0.0100	<0.0100	<0.0100	* <0.0100	<0.0100
	229	B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	207	Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	118	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	118	Cr	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	130	Cu	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
	101	Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	105	Mo	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	BOTTOM	116	Ni	<0.0020	<0.0020	<0.0020	<0.0020
		Ti	0.0005	0.0005	0.0005	0.0005	0.0005
		H					<0.0007

TABLE XI

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER
FIRST DOPING WITH 1% YTTRIUM

(Ht#950044) 56.1 Pounds

Hardness, BHN			Impurity Level, %				
			1	2	3	4	5
TOP	126	C	0.041	0.011	0.009	0.004	0.004
	121	O	0.450	---	0.190	---	0.110
	140	N	0.0215	0.0222	0.0198	0.0198	0.0219
	143	Al	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
	159	Si	--	--	--	--	--
	143	Fe	<0.010	<0.020	<0.010	<0.010	<0.010
	143	B	0.0001	0.0001	0.0001	0.0001	0.0001
	143	Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	163	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	BOTTOM	179	Cr	<0.0020	<0.0020	<0.0020	<0.0020
		Cu	0.0050	<0.0040	<0.0040	<0.0040	<0.0050
		Mg	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Mo	<0.0020	<0.0020	<0.0020	<0.0030	<0.0050
		Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Pb	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Sn	<0.0020	<0.0025	<0.0020	<0.0020	<0.0020
		Ti	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
		Y	0.084	1.080	1.170	0.360	0.620

TABLE XII

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER THE
SECOND DOPING WITH 1.0% and 0.5% YTTRIUM

(Ht#950046) 57.0 Pounds

Hardness, BHN			Impurity Level, %				
			1	2	3	4	5
TOP	53.4	C	0.0050	0.0040	0.0050	0.0040	0.0040
	56.8	O	0.570	---	0.290	---	0.220
	55.1	N	0.0205	0.0180	0.0200	0.0205	0.0220
	53.4	Al	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
	51.8	Si	0.0250	0.0230	0.0200	0.0200	0.0130
	57.5	Fe	<0.0100	<0.0100	<0.0100	<0.0100	<0.0100
	56.8	B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	60.5	Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	69.1	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	BOTTOM	74.1	Cu	<0.0040	<0.0040	<0.0040	<0.0040
		Mg	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Mn	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
		Mo	0.0050	0.0050	0.0050	0.0020	0.0020
		Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Pb	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Sn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
		Ti	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
		Y	0.0409	1.230	1.400	1.950	1.950
		H	0.0024	---	0.0013	---	0.0012
	Cr	<0.002	<0.002	<0.002	<0.002	<0.002	

TABLE XIII

HARDNESS AND CHEMICAL ANALYSIS OF INGOT NO. 2 AFTER THE
FOURTH E.B. MELT (First E.B. Melt After Doping)

(Ht#940015) 35.2 Pounds

Hardness, BHN		Impurity Level, %			
		Sample No.	1	2	3
TOP	114	C	0.0240	0.0190	0.0200
	89	O	0.290	-----	0.259
	92	N	0.0245	0.0275	0.0225
	100	Al	<0.0025	<0.0025	<0.0025
	74	Si	0.0500	0.0500	0.0500
	81	Fe	<0.010	<0.010	<0.010
	BOTTOM	111	B	<0.0001	<0.0001
		Cd	<0.0005	<0.0005	<0.0005
		Co	<0.0010	<0.0010	<0.0010
		Cr	<0.0020	<0.0020	<0.0020
		Cu	0.040	<0.004	<0.004
		Mg	<0.002	<0.002	<0.002
		Mn	<0.002	<0.002	<0.002
		Mo	<0.002	<0.002	<0.002
		Ni	<0.002	<0.002	<0.002
		Pb	<0.002	<0.002	<0.002
		Sn	<0.002	<0.002	<0.002
		Ti	<0.005	<0.005	<0.005
		Y	0.097	0.3420	0.0494

TABLE XIV

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 2 AFTER THE
FIFTH E. B. MELT (Second E.B. Melt After Doping)

(Ht#940018) 27.1 Pounds

Hardness, BHN		Sample No.	Impurity, Level %		
			1	2	3
TOP	89	C	0.0120	0.0130	0.0120
	100	O	0.0300	---	0.0520
	100	N	0.0270	0.0320	0.0255
	92.6	Al	<0.0025	<0.0025	---
BOTTOM	100	Si	0.0390	<0.0440	---
		Fe	<0.010	<0.010	---
		B	<0.0001	<0.0001	---
		Cd	<0.0005	<0.0005	---
		Co	<0.001	<0.001	---
		Cr	<0.002	<0.002	---
		Cu	<0.004	<0.0075	---
		Mg	<0.002	<0.002	---
		Mn	<0.002	<0.002	---
		Mo	<0.010	<0.010	---
		Ni	<0.002	<0.002	---
		Pb	<0.002	<0.002	---
		Sn	<0.002	<0.002	---
		Ti	<0.002	<0.002	---
		Y	0.0380	0.0340	0.3440
		H	0.00049	---	0.00049

TABLE XV

MELTING DATA INGOT NO. 2

Heat No.	Power KW/KVA	Vacuum Micron	Input lbs.*	Output lbs.**	Yield
940010-V-XIA 1st E.B.	150	0.1	213.7	126.7	59.5%
940012-V-XIB 2nd E.B.	150	0.1	103.0	82.0	79.5%
940013-V-S2C 3rd E.B.	210	0.05	77.0	62.9	81.5%
6-950044-VY 1st Dope	180	20-50	59.3	62.0	100.0%
66-950046-VY 2nd Dope	240	1.5-2.5	59.0	58.2	98.5%
950015-V-XIA 4th E.B.	140	0.1	57.0	35.2	61.5%
940018-V-S3B 5th E.B.	210	0.05	34.6	30.4	87.9%

NOTE: *Melting stock with the base material but not including the stub.

**As-cast weight as adjusted to take into account the difference between the input stub and output.

TABLE XVI

CHEMICAL ANALYSES, OF THE DERBIES FOR INGOT NO. 3, (wt%)

	8-7-67	8-8-67	8-9-67	8-10-67	8-11-67	8-24-67	8-25-67	Ave.
O	0.13	0.14	0.39	1.01	1.44	0.1400	0.4360	0.526
N	0.0070	0.0045	0.0115	0.0144	0.0230	0.0020	0.0040	0.0096
C	0.0080	0.0050	0.0140	0.0090	0.0120	0.0150	0.0100	0.0104
H	0.0050	---	---	0.0047	---	0.0034	0.0031	0.0040
Si	0.0600	0.04	0.04	0.03	0.03	0.027	0.026	0.0361
Al	1.40	1.48	1.56	1.89	1.31	3.17	2.69	1.93
Fe	0.0370	0.0440	0.0410	0.0390	0.0360	0.025	0.043	0.0378
B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cr	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Cu	0.0500	0.0500	0.0040	0.10	0.10	0.0100	0.0040	0.0454
Mg	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Mo	<0.0020	0.0025	0.0020	0.0020	0.0020	<0.0020	<0.0020	0.0020
Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Pb	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Sn	0.0100	0.0075	0.0075	0.0100	0.0200	<0.0020	<0.0020	0.0084
Ti	0.0100	0.0075	0.0050	<0.0050	0.0100	<0.0050	<0.0050	0.0068

TABLE XVII

HARDNESS AND CHEMICAL ANALYSES OF INGOT NO. 3 AFTER THE CONSOLIDATION E. B. MELT

(Ht#'s 940017 and 940014) 233 Pounds

Hardness, BHN	Sample No.	Impurity Level, %						
		940014			940017		Ave	
		1	2	3	1	2		
	375							
	241	O	0.1600	---	0.0320	0.65	0.10	0.2355
	277	N	0.0225	0.0095	0.0125	0.0260	0.0125	0.0166
	277	C	0.0550	0.0500	0.0500	0.0460	0.0470	0.0496
Ht# 940017	311	H	0.0011	---	0.0008	0.00026	0.0003	0.00011
	156	Si	0.0690	0.0610	0.0350	0.0440	0.0440	0.0506
	179	Al	0.20	0.40	0.15	0.3600	0.1010	0.2422
	174	Fe	0.0450	0.0590	0.0410	0.0470	0.0400	0.0464
	116	B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
		Ti	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
	96	Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	163	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	207	Cr	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	167	Cu	0.0150	<0.0040	0.0040	0.0040	0.0040	0.0062
	179	Mg	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Ht# 940014	192	Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	152	Mo	0.0075	0.0025	0.0075	0.0075	0.0020	0.0054
	152	Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	174	Pb	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	96	Sn	<0.0010	<0.0010	<0.0010	<0.0020	<0.0020	<0.0014
	107							

TABLE XVIII

HARDNESS AND LIMITED CHEMICAL ANALYSIS OF
INGOT NO. 3 AFTER THE SECOND E.B. MELT

(Ht#940020) 204 Pounds

Hardness, BHN		Sample No.	Impurity Level, %				
			1	2	3	4	5
TOP	96	O	0.0630		0.0360		0.0440
	143	N	0.0135	0.0305	0.0350	0.0120	0.0250
	143	C	0.0060	0.0060	0.0050	0.0050	0.0100
	170	H	0.0009	0	0.0009	0	0.0006
	183	Si	0.0420	0.0350	0.0460	0.0610	0.0870
	293						
	262	Al	0.0330	0.0100	0.0150	0.0070	0.0115
	229						
	255	Fe	<0.0100	<0.0100	<0.0100	<0.0100	<0.0100
	285						
	302	B	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	321						
	229	Cd	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	96						
	105	Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
	121	Cu	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
	156	Mg	<0.0020	<0.0020	0.0020	0.0020	0.0020
	137	Mn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	179	Mo	0.0300	0.0100	0.0075	0.0250	0.0250
	183	Ni	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
	183	Pb	0.0025	<0.0020	<0.0020	<0.0020	<0.0020
	167	Sn	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
BOTTOM	174	Ti	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050

TABLE XIX

MELTING DATA INGOT NO. 3

Heat No.	Power, KW/KVA	Vacuum Micron	Input, lbs	Output, lbs	Yield
940014-XIA 1st E.B.	150	<0.1	342.0	139	68%
940017-XIA 1st E.B.	150	<0.1		94	
940020-S3B 2nd E.B.	150	<0.05	231.9	204.1	88%

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