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SUPERCONDUCPOR PROCUREMENT AND R&D FOR SSC

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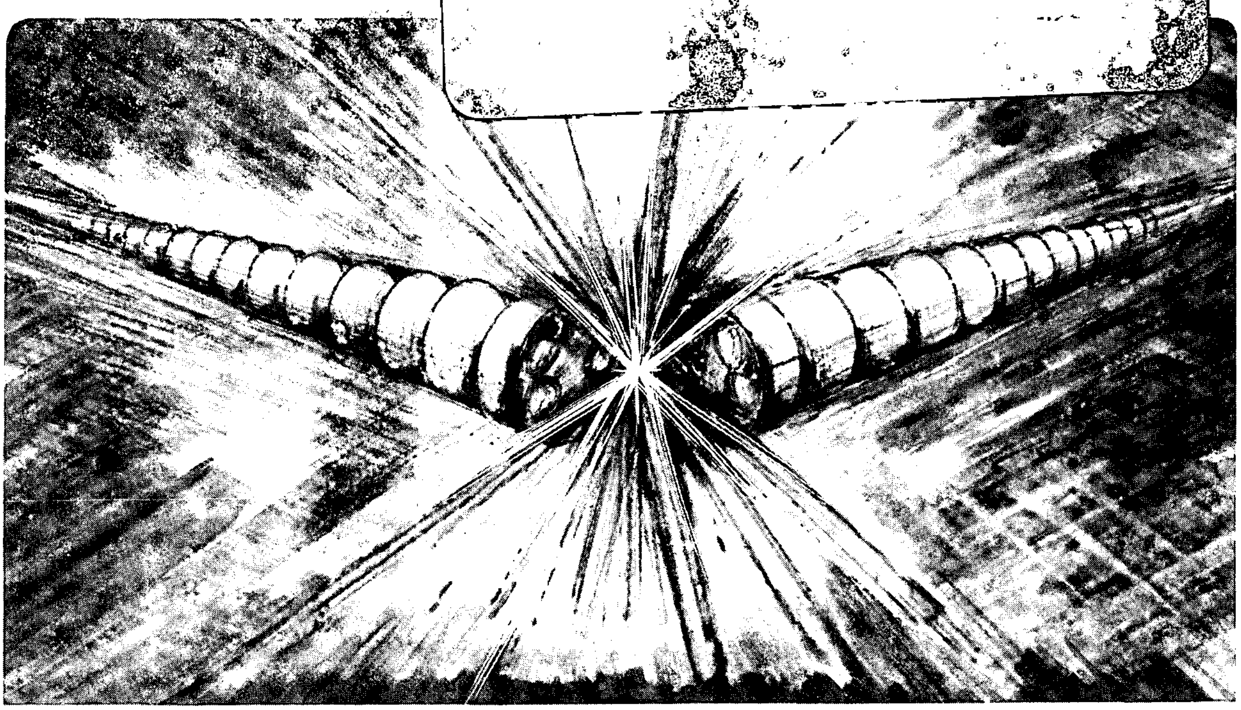
June 1985



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Introduction

In this section we describe the results of superconductor procurements for SSC dipole model magnets. Most results will pertain to LBL procurements for the LBL-BNL collaboration; however, where appropriate to complete the SSC data base, reference will be made to material purchased by FNAL and TAC. Also, most of the results to be presented will relate to the conventional SSC conductors, i.e., with filament sizes in the range of 15-25 μm. Some information on fine filament NbTi material, such as quantities and delivery schedules, will be presented here; fine filament NbTi R&D will be described in another section.

Conventional Conductor Procurements

The "New Era" for high critical current density NbTi was initiated in 1982 with the report by the Baoji group of a J_c = 3900 A/mm^2 at 5T[(1)] (using a more sensitive criterion for J_c, Larbalestier confirmed a value of about 3450 A/mm^2).[(2)] This announcement stimulated a new interest in binary NbTi alloys in the U.S., in particular by Larbalestier and coworkers at U. Wisc. This group made an extensive analysis of conductors being produced in the U.S. and found (1) the composition of the NbTi alloy was quite inhomogeneous, and (2) this lack of homogeneity prevented these alloys from responding effectively to the multiple heat treatments used by the Baoji group.[(3)]

After a series of discussions with the NbTi alloy manufacturer (Teledyne Wah-Chang, Albany) a collaborative experiment aimed at testing Larbalestier's ideas was begun in August, 1983. In this experiment a 10-inch billet (Billet 5183) was ordered by LBL. A special lot of high homogeneity alloy was purchased from TWCA and provided to IGC for processing. After extrusion, the material was divided into two lots - one for processing by IGC using their standard commercial process and the other to be held until Larbalestier could complete a J_c-optimization study and suggest an alternate treatment. As seen in Table I, Billet 5183 processed by conventional techniques produced an improved J_c (about 2300 A/mm^2 compared with about 2000 A/mm^2 for the best Doubler/CBA material). This result (see Billets 5198-1 and 5198-2 in Table I) was verified on two additional billets procured by LBL and processed by IGC while Larbalestier was completing his optimization studies. Larbalestier[4] recommended a new processing schedule and IGC processed the remainder of Billet 5183 (designated 5183-2) with this schedule. As seen in Table I, the J_c values improved significantly (from 2365 A/mm^2 to 2645 A/mm^2 for the .025" diam strand). Based on these results, LBL ordered two additional billets (5210-1 and -2) and FNAL ordered five billets (5209-1 through 5) from IGC in July, 1984. This material was delivered in January, 1985; the J_c values in all cases exceeded our specification value of 2400 A/mm^2. The only problem encountered was a switch of extruded rod labels at RMI; as a result IGC processed the billets with Larbalestier's heat treat schedule, but not at the specified wire sizes.

The final order for material for Design D dipoles was placed in November, 1984, after competitive bidding won by IGC. IGC delivered 820 lbs (Inner) and 830 lbs (Outer) in April, 1985 (see Table II); the J_c (5T) values are 2509 A/mm^2 for Inner and 2719 A/mm^2 for Outer layer material. With the exception of Billet 5210-2, all Outer layer material processed with the new heat treatment (3 x 40 hr at 375°C) has a significantly higher J_c than Inner layer material. The FNAL material (Billets 5209-1 through 5209-5) is equivalent to Outer layer material and also is consistent with this observation. A possible explanation for this behavior is that the additional cold working after extrusion in the case of the Outer layer material is beneficial in improving the J_c; if true, this result suggests that it may be possible to get somewhat higher J_c values in the fine filament conductors which also contain more cold working.

Another favorable result from these procurements has been the piece lengths compared with Doubler/CBA experience. A histograph of SSC experience is shown in Fig. 1. The longer piece length greatly facilitates cabling and also simplifies testing and quality control.

We now have a substantial data base from these production-size billets (15 billets for a total weight of approximately 5000 lbs, including FNAL billets), and several conclusions can be drawn:

(1) The interim SSC specification value for J_c(5T) of 2400 A/mm^2 can be met in industrial scale production. Subsequent procurements can be made with a minimum acceptable value of 2400 A/mm^2 and an incentive payment formula for performance above 2400 A/mm^2.

(2) The specification of high homogeneity NbTi appears to reduce the spread in J_c values (although a more stringent test of this hypothesis will come when more than one manufacturer is in production).

(3) The use of high homogeneity NbTi has resulted in extremely long piece lengths.

Fine Filament Conductor Procurements

Figures 2a and 2b show transverse sections of the conventional SSC Inner and Outer superconductor (top micrographs). The pictures in the lower half are scanning electron micrographs of filaments extracted from the composites. The particles imbedded in the surface of the filaments are brittle intermetallic compounds formed during extrusion and intermediate heat treatments. As these micrographs indicate, this compound formation does not seriously affect the performance of filaments in this size range (15-25 μm). However, these particles do not co-reduce and hence seriously degrade the filament integrity and J_c when these wires are drawn to fine diameters. Therefore, if one desires fine filaments, the composite must be designed and processed with this in mind.

Several billets have been designed to yield fine filaments and are currently being processed. In addition to developing processes for fabricating fine filament NbTi and providing an economic analysis of the process, both IGC and Supercon are providing enough fine filament material for a 16-m model SSC magnet (see Table IV). IGC will provide material with 2 μm diam. filaments in the appropriate wire sizes; the yield should be sufficient for one 16-m model to be built at BNL. and several 1-m models to be built at

LBL. Supercon will provide 400 lbs of material which can be processed to .0318" diam. wire (8 μm filaments) or .011" diam. wire (2.8 μm filaments) for use in a 2-level cable; both options presently are being evaluated. In Phase II, Supercon will prepare 400 lbs of Outer layer material with either 4,000 filaments (6 μm filament size at final wire size) or 40,000 filaments (2 μm filament size at final wire size); the choice will depend on billet stacking experiments currently in progress. Again, this material will be sufficient for one 16-m dipole and several 1-m dipoles. The billets being prepared at LBL for hydrostatic extrusion will provide material for several additional 1-m model dipoles.

Recently, BNL issued an order to Oxford Superconducting Technology for enough material with a 5 μm filament size to build one additional 16-m model (see Table III). Thus, material presently being procured will provide for the construction of three 16-m dipoles and at least 6 1-m dipoles. From the standpoint of cable availability, dipole magnet construction could start as early as December, 1985.

Fine-Filament Nb-Ti R&D

Introduction

During the past few months, significant progress has been made in establishing the technical feasibility of fine-filament NbTi (see Fig. 3). Supercon have produced a .002" diam. wire with 3 μm filaments and a J_c(5T) value of 2950 A/mm^2. Intermagnetics General Corp. (IGC) have produced a .015" diam. wire with 3.7 μm filaments and a J_c value of 2711 A/mm^2 at 5T. Magnetic Corp. of America (MCA) have made a .0045" diam. wire with 4 μm filaments and a J_c (5T) = 2497 A/mm^2, and Furukawa Electric Co. have made a .0089" diam. wire with 2.85 μm filaments and a J_c (5T) = 2380 A/mm^2. These results(5) show that fine filaments are feasible; however, in each case the quantity produced was small and the process was not production scale. We will now discuss several problems which must be solved in the large scale manufacture of fine-filament NbTi and several R and D programs that are in progress.

Conventional production of Nb-Ti superconductor consists of a hot extrusion (500-600°C) of NbTi rods in a copper matrix. During this extrusion and the prior heating of the billet, a layer of titanium-copper intermetallic compound perhaps 1-2 μm thick, can form around the filaments. This brittle intermetallic layer does not co-reduce and thus can become nearly equal to the filament diameter at final wire size; this results in extensive filament breakage and sometimes strand breakage. This problem can be eliminated by enclosing the NbTi rods at extrusion size in a barrier material, such as Nb or Ta, which prevents the titanium-copper intermetallic formation.[6] This barrier need only be 0.1 to 0.2 mm thick, and will be reduced to an insignificant fraction of the filament cross section at final filament size.

Another problem can arise from the introduction of foreign particles during the billet preparation operations. Any "dirt" consisting of micron size particles or any inclusions of this size in the NbTi rods or the copper components can result in filament breakage at the final wire size. This type of problem is insidious since processing may proceed successfully until the final wire size in approached. Also,the size of inclusion which is tolerable depends upon the desired filament size, e.g., a one micron diameter inclusion is acceptable for a 20 micron filament, but not for a 2 micron filament. This problem can be minimized by careful selection of raw materials and by clean room practice in billet assembly.

When a large number of rods are stacked in a billet, as is necessary to achieve fine filaments, a large void fraction is present, and this can lead to non-uniform reduction in the extrusion step. The filaments are necked down locally and this also leads to filament breakage. This problem can be eliminated by compacting the billet before extrusion.

When these potential problems are eliminated by proper processing and quality control, there is no metallurgical reason why a J_c value of greater than 2400 A/mm^2 cannot be achieved in filaments less than 2.0 μm in diameter. In fact, the increased total reduction in area of the NbTi filaments may mean that it is possible to introduce more heat treat/cold work cycles and hence raise the value of J_c.

R&D Program

We discussed these potential problems and the proposed solutions with the superconducting material manufacturers between December, 1983 and August, 1984. In

September, 1984, both IGC and Supercon responded to LBL with proposals to investigate the production of high J_c, fine-filament Nb-Ti. The deliverable items include material with which we can optimize J_c and also construct model magnets. The final reports will include an economic analysis of the fabrication methods. The details of these projects are listed in Table III.

A practical problem to be solved in producing fine filament NbTi for the SSC Design D configuration is to devise a method of stacking a large number of elements to produce the end product (see Fig. 4). There are at least three promising approaches.

First, one can stack a large number of rods in a single billet, and this is the approach being investigated by Supercon (see Table III). To date, they have stacked a 12-inch billet with approximately 4000 rods and completed the extrusion successfully. Small amounts of this material are being processed to .0318" diam. wire (8 μm filament size) and .011" diam. wire (2.8 μm filament size). A decision on final configuration will be made after results are complete on this optimization study and on two-level cable experiments in progress (see discussion below). The second phase of the Supercon study will consist of another 12" diam. billet with a 1.8:1 Cu:SC ratio and a filament number yet to be specified. If Phase I results are promising and Supercon can demonstrate an acceptable stacking scheme, the Phase II billet will contain approximately 40,000 filaments and yield a final filament size of 2 μm. The fallback position is approximately 4,000 filaments and a 6 μm filament size at the final wire size of .025" diam.

IGC proposed to investigate a double extrusion approach as well as a large stack approach. LBL agreed to fund the double extrusion approach and IGC elected to proceed in parallel with the single stack approach using their internal funding (see IGC data point in Fig. 3). In the LBL-funded program, IGC has completed both Phase I extrusions (an initial 6" diam. billet with 7 NbTi rods and a second 6" billet with 7 x 858 NbTi filaments). Approximately 100 lbs of this material should be drawn to final wire size by July, 1985, and will be cabled in order to produce samples for I_c and magnetization measurements. IGC are proceeding with Phase II and have procured the raw material for two 10-inch first stage billets. Material from these billets will then be restacked to produce a 10-inch billet of Inner layer and a 10-inch billet of Outer layer material. This wire should be ready for cabling in December, 1985. If this phase is successful, there will be enough cable for one 16-m model dipole and several 1-m models.

A promising alternative to the use of conventional hot extrusion with diffusion barriers is cold hydrostatic extrusion. Production-size hydrostatic presses providing toll extrusion services are available in Europe (but not in the U.S.), and the costs are competitive with conventional extrusion. The maximum billet diameter is 6.5", but billets to 62" long can be extruded (see Table IV for complete list of parameters available at LDM; similar services are available at National Standard in Scotland). Hence, one can process approximately the same weight of material using hydrostatic extrusion as can be produced from a 10" diam. conventional extrusion. However, the yield of useful material can be much higher in the hydrostatic extrusion case because of reduced end losses. This factor is especially important in a double extrusion process.

In order to evaluate, both technically and economically, the potential of hydrostatic extrusion for producing fine filament NbTi, LBL personnel are assembling three billets for hydrostatic extrusion (see Table I). The elements for stacking the first two billets are being prepared at LBL using a bundle and draw approach. NbTi rods are clad with Cu, then 19 of these rods are loaded into another Cu tube, drawn and bundled to form the billet stacking elements. The billets will be sent to National Standard for extrusion and then returned to the U.S., where they will be drawn to wire (see schedule in Fig. 5). An additional billet will be prepared using excess first stage material from IGC (PO 7541106); this will provide some material containing diffusion barriers for comparison with the other two billets.

At the conclusion of this R&D phase in November, 1985, we will have a data base on both cost and technical feasibility of various fine filament options. This will allow the SSC management to evaluate the fine filament option and to begin incorporating fine filament NbTi into the SSC long range plan.

A preliminary estimate of the costs for fine filament Nb-Ti produced by these alternate methods has been made. The rough estimate of the costs of fine filament Nb-Ti indicate a 15 to 30% premium compared with the costs of conventional 20 μm filament material. More accurate cost information will be obtained at the end of the R and D work (Sept. 1985).

Cable Fabrication

Introduction

At the commencement of the LBL-BNL collaboration on Design A dipoles, both BNL and LBL had active programs for cable R&D and cable procurement. In an effort to reduce duplication of effort within the collaboration, the decision was made to assign to LBL primary responsibility for cable R&D. The BNL team continue to provide valuable support to this effort in the areas of cable property measurements (both mechanical and electrical) and liason with New England Electric Wire (NEEW). In addition, many of the quality control and record maintenance systems developed for CBA are being adopted for use in SSC cable procurements.

Conventional Cable Fabrication

During the past year, the cable development effort has been proceeding along two paths - cabling experiments at LBL and process improvements at NEEW. We have built an experimental cabling machine at LBL that can produce long continuous lengths of cable (up to about 5,000 ft. with the present spool system) at production speeds e.g., 12 ft./min. In addition, the machine has several features not found on conventional machines, but essential for developing the optimum cabling parameters. These include variable planetary motion for the supply spools, precise tension control for the individual strands, capacity for 36 spools, and easy adjustment of cable twist pitch or cabling direction.

Several trial runs were made at NEEW between February and November, 1984. These trials were disappointing, especially for the 30-strand Outer cable. Many crossovers occurred and only about 450 ft. could be produced before crossovers recurred. In order to determine whether we were approaching some practical limit on strand number with the 30-strand cable, we attempted a 36 strand cable at LBL and made a successful cable. Additional trials on the LBL experimental cabling machine showed that two conditions contributed to crossovers - uneven tension from strand to strand and a small mandrel diameter (0.250"). When these two conditions were corrected at NEEW, the crossover problem disappeared. Additional problems encountered and the solutions adopted are described in Table V. After these changes were made, a total of approximately 12,000 feet of cable have been made at LBL at a speed of 10-12 ft./min. and a yield of over 95%. This speed is comparable to that used at NEEW on Doubler/CBA cable and the yields are better than 95% vs. about 80%. The increased yield is due (1) to improved wire lengths and quality, and (2) to improved cabling parameters. At this time, we feel that the Design D cable can be made for the same cost, or perhaps somewhat less, than the Doubler/CBA cable.

Cabling R&D

Currently, we are investigating several new cables which could have advantages for SSC dipoles. These include two level cables, internal wedge cables, and internal flat cables. The two-level cable is of interest from the standpoint of fine filaments and increased flexibility. For example, we can use the 4,000 filament material being produced by Supercon as a .0318" diam. strand with 8 μm diam. filaments, or we can reduce the wire diam. to .011" (filament diam. = 2.8 μm), fabricate a 7 element cable, and then fabricate a 23 strand cable from these elements. At LBL, we recently produced a mechanical model of this cable using surplus Isabelle strand material (Fig. 6). The cabling was completed without problems and at a typical production line speed of 10 ft./min. This cable will be wound into 1-m coils in order to evaluate its applicability for flush-end magnets. As soon as the new material is completed by Supercon, we will repeat this experiment with high-J_c strand material and make electrical measurements.

Use of an internal wedge in the SSC cables may produce a keystoned cable without the I_c degradation experienced in conventional cables. We have ordered Cu strip and are preparing hollow mandrels in order to evaluate this option.

Finally, internal flat cables[7] offer the advantages of higher effective modulus in compression and perhaps less I_c degradation. Short lengths have been made at LBL and BNL; however, scale-up to production is quite challenging. Several internal flat techniques are currently being evaluated at LBL.

Footnotes

(1) Li Chengren, Wu Xiao-zu, Zhou Nong, IEEE Trans., MAG 19, 284 (1983).

(2) Larbalestier, D.C., West, A.W., "The metallurgical and superconducting properties of niobium titanium alloys," Annales de Chimie - Francaises Science des Materiaux, 9, 813 (1984).

(3) Larbalestier, D.C., "Towards a microstructural description of the superconducting properties," to appear in IEEE Trans. on Magnetics, MAG 21, 257, 1985.

(4) Larbalestier, D.C., West, A.W., Starch, W., Warnes, W., Lee, P., McDonald, W.K., O'Larey, P., Hemachalam, K., Zeitlin, B., Scanlan, R., and Taylor, C., "High critical current densities in industrial scale composites made from high homogeneity Nb 46.5 Ti," IEEE Trans. on Magnetics, MAG 21, 265, 1985.

(5) J_c values have been confirmed by W. B. Sampson et al.

(6) P. Dubots et al., Proc. ICEC 8, 505 (1980).

(7) A. R. Borden and R. C. Wolgast, ASC Knoxville, 1982.

TABLE I

Designation	Strand Diameter	J_c Value ($10^{-12}\Omega$-cm) 5T	8T	Intermediate Heat Treatment	Final Heat Treatment
5183 - 1 (Cu/SC = 1.36/1)	.0318" .0250"	2280 2365	930 1015	IGC	IGC
5198 - 1 (Cu/SC + 1.35/1)	.0318"	2238	885	IGC	IGC
5198 - 2 (Cu/SC = 2.05/1)	.0250	2273	880	IGC	IGC
5183 - 2 (Cu/SC = 1.36/1)	.0318" .0250"	2545 2645	1030 1070	U. Wisc. (3 X 40 hr at 375°C)	260°C
5210 - 1 (Cu/SC = 1.25/1)	.0318"	2505	1034	*	260°C
5210 - 2 (Cu/SC = 1.80/1	.0255"	2435	1070	*	260°C
5212 - 3 (Cu/SC - 1.77:1	.0255"	2717	1146	U. Wisc.	260°C
5212 - 1 (Cu/SC = 1.28:1	.0318"	2509	1083	U. Wisc.	260°

*U. Wisc. heat treatment with slight variation.

TABLE II

STATUS REPORT OF SSC SUPERCONDUCTOR INVENTORY AND PROCUREMENTS FOR DESIGN D MODELS

Designation	Weight (LBS)	Strand Length (FT)	Cable Length and Designation	Status	Comments
Billet 5210-1 (Inner Cable)	426	160,617	4160 FT (XT12-2317)	3360 FT at BNL awaiting insulation 300 FT sent to FNAL.	Strand J_c (5T) = 2505 A/mm^2
			2200 FT (XT14-2317)	Sent to BNL 4-29-85.	SC #296
Billet 5212-1 (Inner Cable)	Approx. 420	Approx. 160,000	Approx. 7,000 FT	Strand Complete 4-15-85.	Strand J_c (5T) = 2509 A/mm^2
Billet 5212-2 (Inner Cable)	Approx. 420	Approx. 160,000	3,200 FT (XT20-2317)	3200 Ft. cabled and sent to BNL 5-28-85. Remainder of strand material at LBL awaiting firm schedule for additional model magnets.	SC #299
Billet XXXX (Inner Cable)	Approx. 300	Approx. 114,000	Approx. 5,000 FT	In process at Supercon. To be held at 1.0" diameter.	Material ordered by TAC. Conductor could be used in Design D magnets, but actual use has not been determined at this time.

Key: 4.5 m Design "D" Dipole Requires 1020 FT Inner, 1260 FT Outer

16.6 m Design "D" Dipole Requires 3550 FT Inner, 4420 Outer

TABLE II
STATUS REPORT OF SSC SUPERCONDUCTOR INVENTORY AND PROCUREMENTS FOR DESIGN D MODELS

Designation	Weight (LBS)	Strand Length (FT)	Cable Length and Designation	Status	Comments
Billet 5210-2 (Outer Cable)	426	241,145	4400 FT (XT13-3012)	At BNL, for use in 4.5 m models.	Strand J_c (5T) = 2435 A/mm^2
			1000 FT (SC #293)	At LBL, for use in 1-m models.	
			1200 FT (SC #295)	367 FT sent to FNAL. Remainder at LBL for use in 1-m models.	
Billet 5212-3 (Outer Cable)	Approx. 800	Approx. 452,854	Approx. 10,000 FT	Strand Complete 4-15-85. Remainder held as strand at LBL awaiting firm schedule for additional model magnets.	Strand J_c (5T) = 2719 A/mm^2 SC #297
			2656 FT (XT15-3012)	Cabled and sent to BNL 5-8-85	
			2656 FT (XT19-3012)	Cabled and sent to BNL 5-28-85.	
Billet 5209-4 5209-5B (Outer Cable)	Approx. 1305	Approx. 739,000	Approx. 24,000 FT	On hold at IGC at .460" diameter.	Fermi order.
Billet 5209-5A 5209-1B (Outer Cable)	Approx. 870	Approx. 492,000	Approx. 16,000 FT	On hold at IGC as .0255" diameter strand	Fermi Order. Strand J_c = 2500 - 2700 A/mm^2 at final size.

TABLE III - FINE FILAMENT R AND D EFFORTS

ORGANIZATION	BILLET SIZE AND Cu:SC RATIO	FINAL WIRE SIZE AND FILAMENT SIZE	QUANTITY	DELIVERY DATE
IGC (LBL PO 7541106)				
PHASE I	6" Diam. Billet 1.8:1	.0255" Diam. Wire 4μm Filaments	100 LBS.	July 1985
PHASE II	10" Diam. Billet 1.3:1	.0318" Diam. Wire 2μm Filaments	400 LBS.	Nov. 1985
	10" Diam. Billet 1.8:1	.0255" Diam. Wire 2μm Filaments	400 LBS.	Nov. 1985
SUPERCON (LBL PO 7456406)				
PHASE I	12" Diam. Billet 1.3:1	.0318" Diam. Wire 8μm Filaments .009" Diam. Wire For 2-Level Cable 2μm Filaments	400 LBS	Aug. 1985
PHASE II	12" Diam. Billet 1.8:1	.0255" Diam Wire 2μm Filaments	400 LBS	Oct. 1985
LBL HYDROSTATIC BILLETS	6.5" Diam. Billet 1.3:1	.0318" Diam. Wire 2.5μm Filaments	200 LBS	Oct. 1985
	6.5" Diam. Billet 1.8:1	.0255" Diam. Wire 2.5μm Filaments	200 LBS	Oct. 1985
OST (BNL PO ____)				
	11" Diam. Billet 1.3:1	.0318" Diam. Wire 5μm Filaments	341 LBS	Dec. 1985
	11: Diam. Billet 1.8:1	.0255" Diam. Wire 2.5μm Filaments	366 LBS	Dec. 1985

TABLE IV

LDM
DATA SHEET

-Hydrostatic extrusion press.

Type	ASEA QEN 40
Press force	40 MN

-Container

Max. pressure	1400 MPa
Max. operating pressure	1300 MPa
Length	1600 mm

-Billet dimensions

Billet diameter	ø 160 mm or ø 80 mm	
Billet length	400 mm	850 mm
and		1200 mm
Tube extrusion billet	790 mm	-----

Other billet dimensions on request

-Extrusion data

Extrusion ratios at room temp: 10 : 1 up to 25 : 1
at elev. temp: 40 : 1 up to 600 : 1

Ram speed (16 steps)	from 0,0014 to 0,023 m/s.
Ram diameter	ø 180 mm
Produkt diameter max.	ø 60 mm
Adiabatic temp. rise of produkt	≈0,25° C/MPa
Incl. extrusion die angle	40° up to 110°
Incl. billet cone angle	Incl. extrusion die angle minus 6°-10°
Billet nose diam.	Rod diam. minus 1 mm

Time for press adaptation ≈ 30 minutes : to special tooling
Inert gas-protection : N2
Direct watercooling of product
Optional: coiling of product : ≈ 1000 to 1500 mm.

Number of extrusions/per hour depending on:

- -number of extrusions per order
- -warm or cold extrusion
- -specific product experience
- -Billet heating rate °C/min
- -extrusion speed selection
- -data collection
- -special lubrication requirements
- -product cooling rate
- -sampling procedures

Billet Heating Equipment

-ASEA fully controllable medium frequency billet-heater
-Dimension : ø 170 length 2400 mm.
Electric data: 600 kW 470 Hz.

-Smit Net frequency billet-heater (step-control)
Dimension ø 165 length 1317 mm.
Electric data: 540 kW 50 Hz.

Rod drawing equipment

-Chain drawbench: 400 KN length 30 m.
Ranging from 48 mm, inlet diameter down to 10 mm
-Vertical Bull Block: 180 KN Drum diam. 2130 mm
Ranging from 33 mm inlet diam. down to 3,5 mm
-Horizontal Bull Block 45 KN Drum diam. 915 mm
Ranging from 15 mm inlet diam. down to 2 mm.

Table V.

PROBLEMS ENCOUNTERED IN PRODUCTION OF SSC CABLE AND SOLUTIONS ADOPTED

PROBLEM	CAUSE	SOLUTION	COMMENTS
Periodic Crossovers of Strands During Cabling	a) Uneven Strand tension	Recommend NEEW Rebuild Cabling Machines	After Changes, 8000 FT of Cable Made at NEEW and 12,000 FT of Cable Made at LBL Without Crossovers.
	b) Mandrel Design	Developed New Mandrel Design at LBL	
Excessive Variability in Cable Keystone Angle	a) Worn Turksheads	Used New BNL Turksheads at NEEW.	All Cable Made After Changes Have Keystone Angle Within Spec.
	b) Variability in Turkshead Assembly	Developed New Operating Mode for Turkshead	
Difficulty Reported By BNL in Winding Dipoles From 30 Strand Cable	c) Cable Twist Pitch Too Long	Reduced Outer Cable Twist Pitch From 2.9" to 2.7" and Inner Cable T.P. from 3.125" to 2.9"	Improved Cable Mechanical Properties With Slight Change In Metal Density (Approx. 0.5%). No Additional Degradation in I_c Due to Tighter T.P.
Sharp Edge on Cable Damaging Insulation	Turkshead Assembly Procedure	Tendency Greatly Reduced With New T.H. Operating Mode. Brushing Station Incorporated in BNL Clean-ing Line.	No Problem in Insula-tion for 4.5 m Dipoles

FIGURE 1.

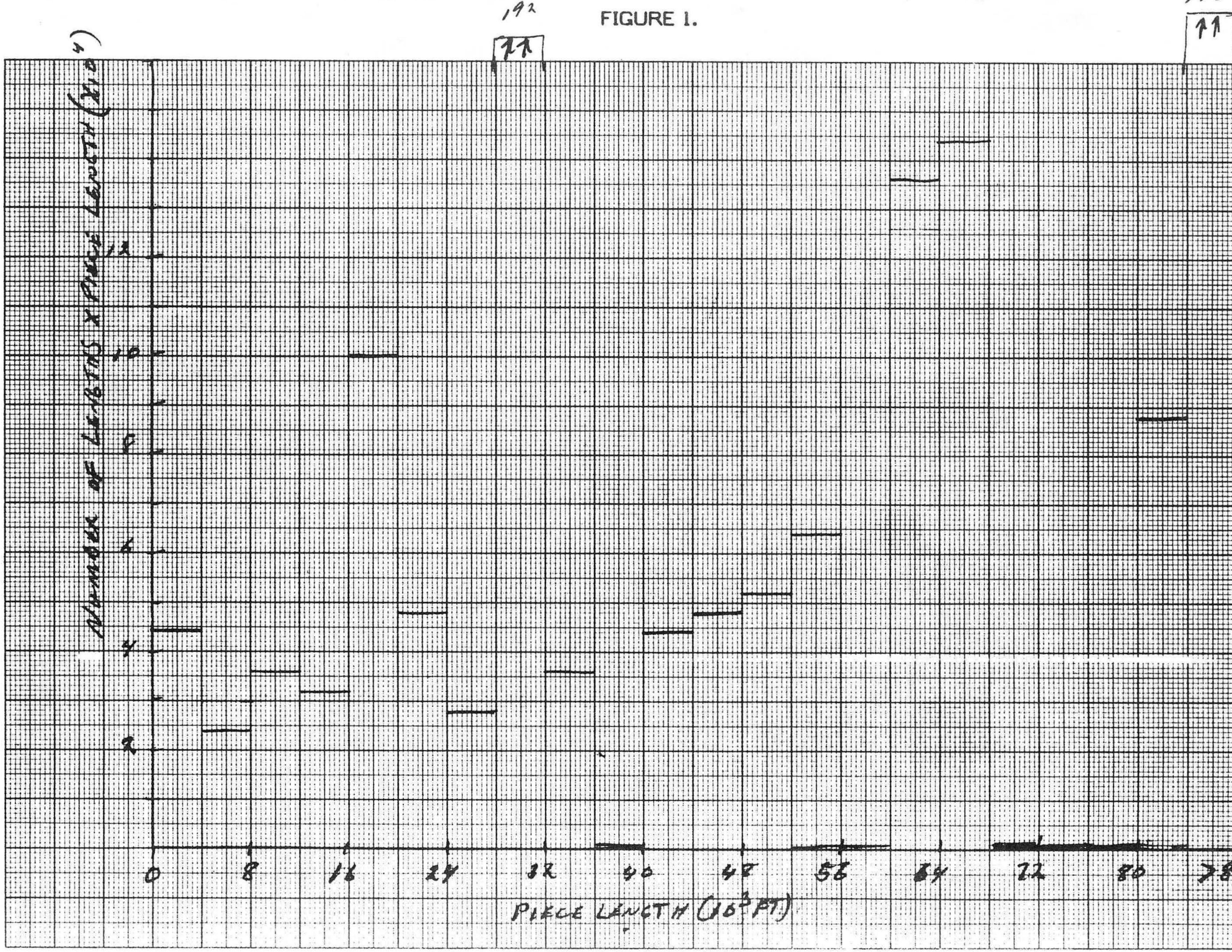
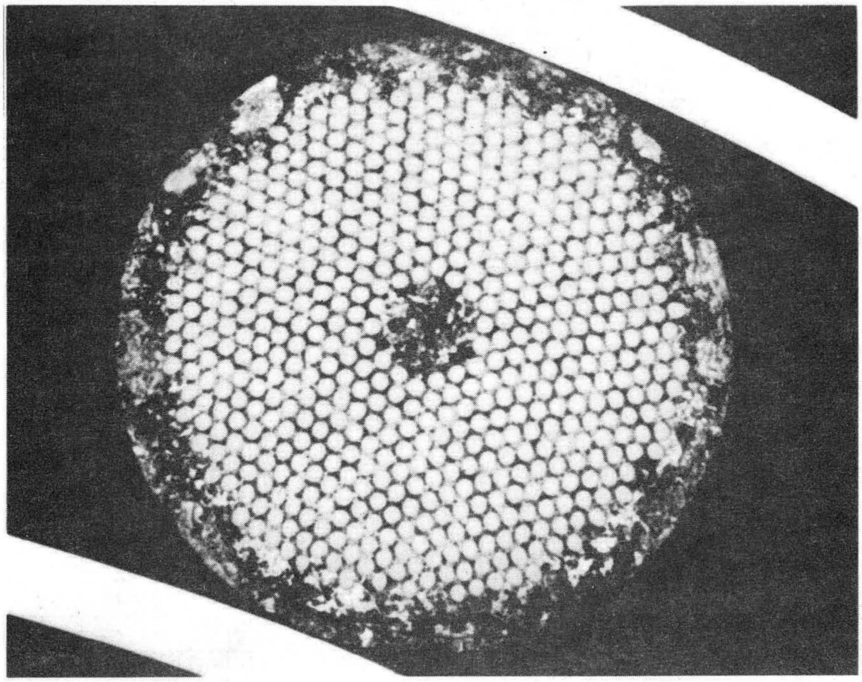
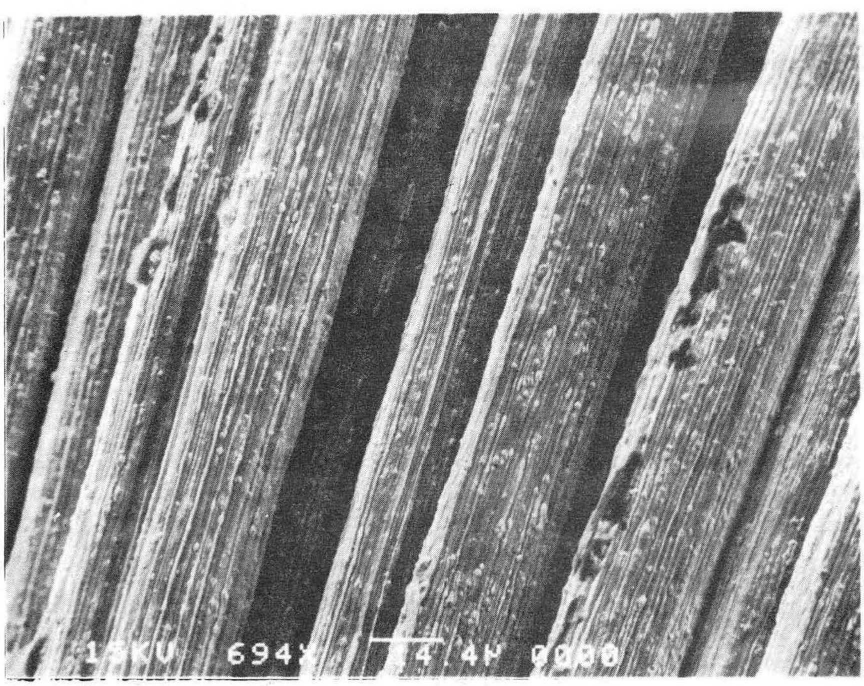

192
176
NUMBER OF LENGTHS X PIECE LENGTH (X10^4)
2
4
6
8
10
12
0
8
16
24
32
40
48
56
64
72
80
>88
PIECE LENGTH (10^3 FT)

FIGURE 2a.

SSC INNER CABLE SUPERCONDUCTOR

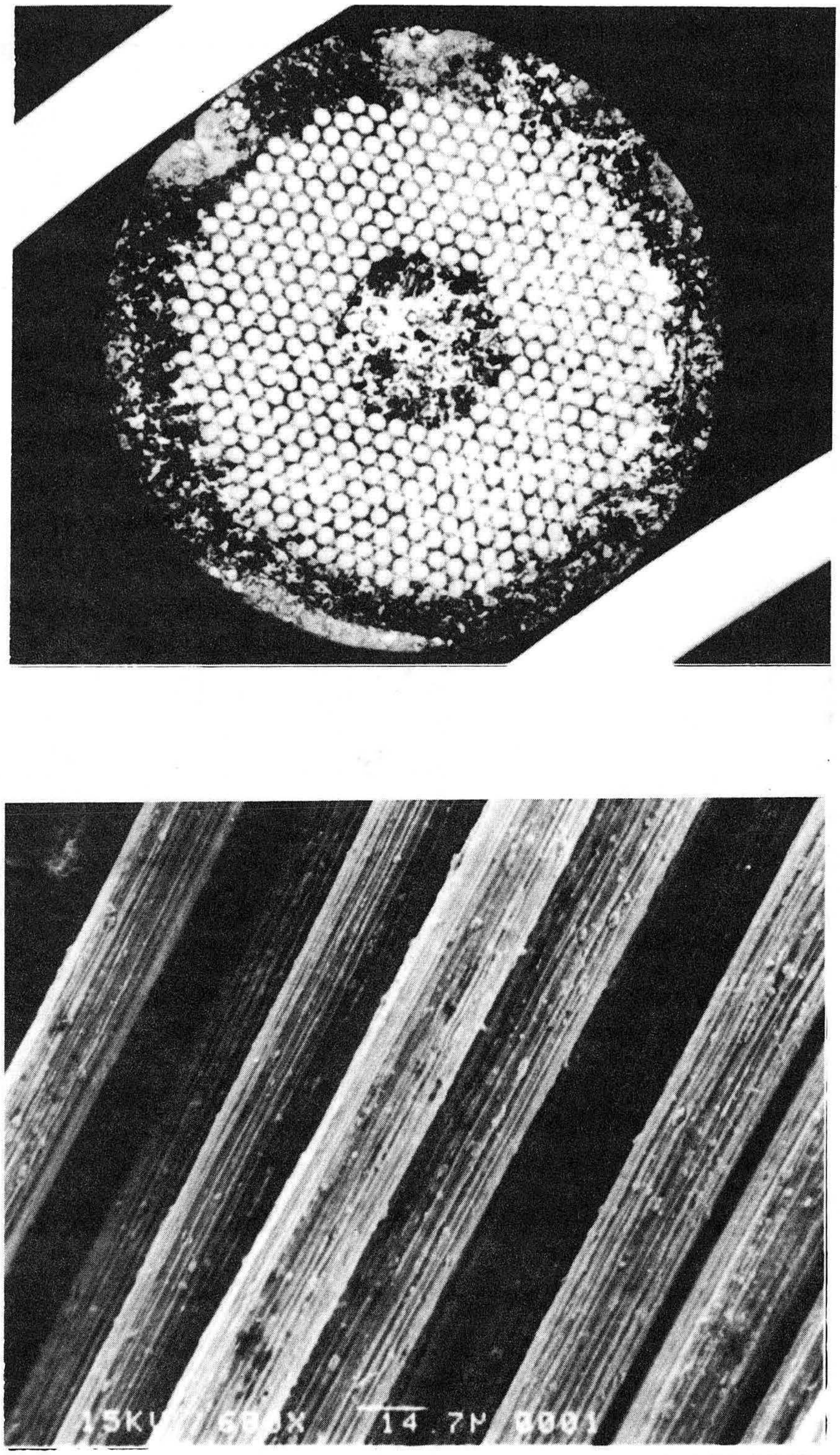




CBB 854-2987

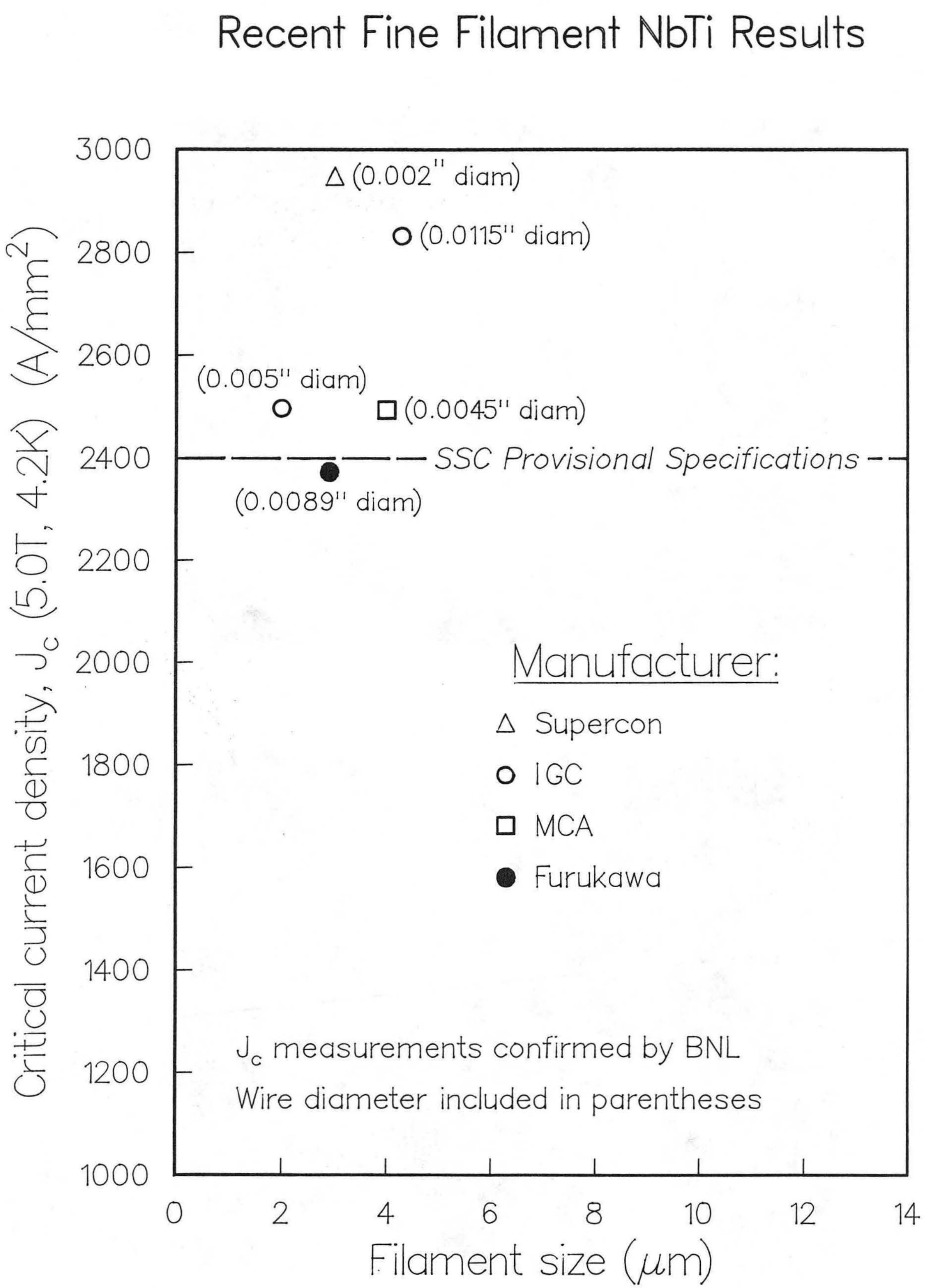
FIGURE 2b.

SSC OUTER CABLE SUPERCONDUCTOR



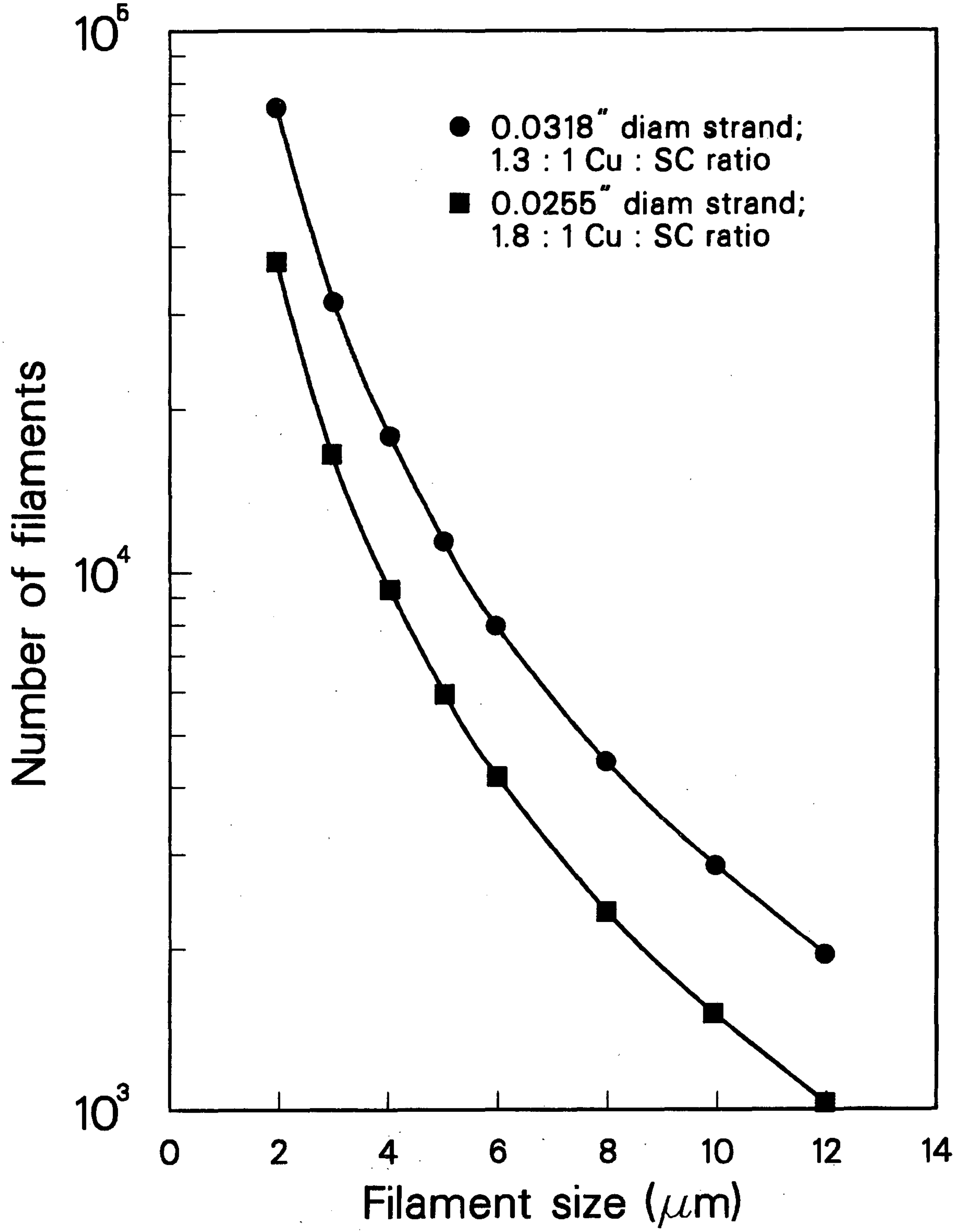
CBB 854-2989

FIGURE 3.



XCG 855–267

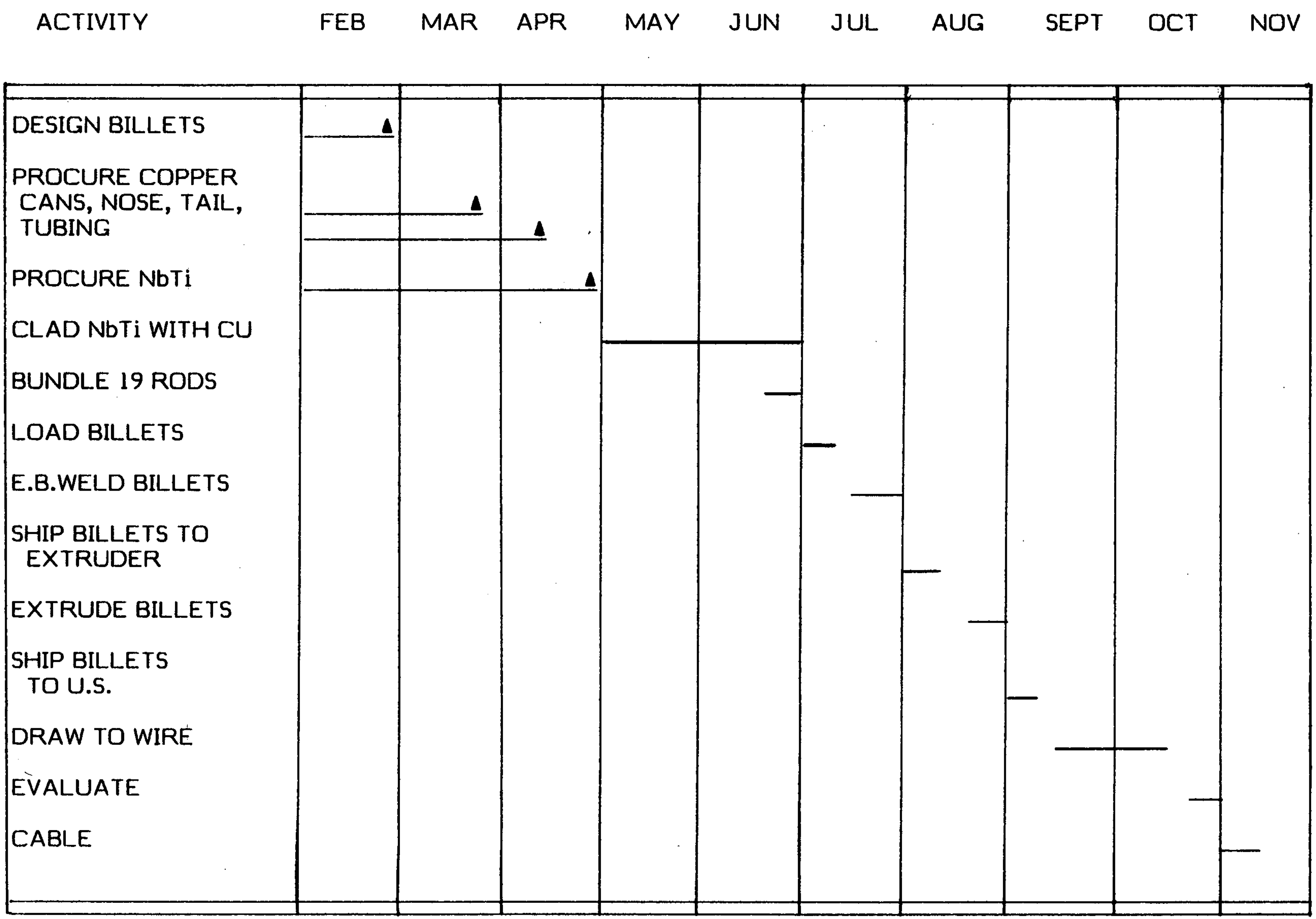
FIGURE 4.



XCG 856-300

Figure 5.

HYDROSTATIC EXTRUSION OF NbTi BILLETS



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