UCRL- 88111
PREPRINT

CONF-82108--15

Magnets for the Mirror Fusion Test
Facility: Testing of the First Yin-
Yang and the Design and Development
of Other Magnets

T. A. Kozman, S. T. Wang, Y. Chang,
E. N. C. Dalder, C. L. Hanson, R. E. Hinkle
J. O. Myall, C. R. Montoya, E. W. Owen,
R. L. Palasek, D. W. Shimer, J. H. Van Sant

This Paper was Prepared for Presentation
at: The Applied Superconductivity
Conference, Knoxville, Tennessee,
November 30 thru December 3, 1982

January 5, 1983

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceeding. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS PREPRINT IS UNLIMITED

MAGNETS FOR THE MIRROR FUSION TEST FACILITY: TESTING OF THE FIRST YIN-YANG AND THE DESIGN AND DEVELOPMENT OF OTHER MAGNETS

T. A. Kozman, S. T. Wang, Y. Chang, E. N. C. Dalder, C. L. Hanson, R. E. Hinkle, J. O. Myall,
C. R. Montoya, E. W. Owen, R. L. Palasek, D. W. Shimer, and J. N. VanSant

Lawrence Livermore National Laboratory,
University of California
P.O. Box 5511
Livermore, CA 94550

UCRL--88111

DEC3 003438

Abstract

Completed in May 1981, the first yin-yang magnet for the tandem Mirror Fusion Test Facility (MFTF-B) at Lawrence Livermore National Laboratory (LLNL) was successfully tested in February 1982 to its full design field (7.68 T) and current (5775 A). Since that time, the entire magnet array has been reconfigured--from the original A-cell to an axicell design. The MFTF-B magnet array now contains a total of 26 large superconducting coils: 2 sets of yin-yang pairs, 2 sets of transition magnets (each containing two coils), 2 sets of axicell magnets (each containing three coils), and 12 central-cell solenoids. This paper chronicles recent magnet history--from the testing of the initial yin-yang set, through the design of the axicell configuration, to the planned development of the system.

Testing of the First Yin-Yang Magnet

Testing Prior to Magnet Cooldown

The yin-yang magnet employed in MFTF-B is the largest superconducting magnet in the fusion field: it weighs 375 tons and stores 410 MJ of energy. Henning, et al.¹ have described the design and construction of the initial yin-yang magnet in detail; in addition, Kozman, et al.² have discussed its testing. Four tests were performed prior to magnet cooldown and our steady-state heat-load measurements.

Leak Checking. The magnet cases for the individual yin-yang coils serve not only to contain stresses but also as the coil winding forms and the liquid helium (LHe) containers for the magnet system. We leak checked all welds in these cases at a sensitivity better than 1×10^{-8} atm cc/s. Then we bagged (enclosed the cases in plastic bags and inserted He) the magnet cases; we certified an integrated leak of less than 4.4×10^{-7} atm cc/s.

After the yin-yang magnet had been moved from its construction site to the building, we installed a liquid nitrogen (LN₂) shield or liner before inserting the magnet in the vacuum vessel. The magnet thus was encased in two LHe vacuum jackets (the coil case and the guard vacuum) and one LN₂ jacket. We met the He leak requirements for both the coil case and the coil winding form: less than 1×10^{-8} atm cc/s for this test and 1×10^{-9} atm cc/s for future physics experiments (to be calibrated with room-temperature He gas). Second, we met the measured leak rate for the coil bundle: less than 1.3×10^{-10} atm cc/s. Third, we matched the required leak rate from the guard vacuum circuit: less than 1×10^{-4} atm cc/s (again with room-temperature He gas). After repairing the leaks and replacing some flange seals, we achieved an overall measured leak rate of less than 5×10^{-5} atm cc/s.

We set the leak rate for the LN₂ shield at 1×10^{-2} atm cc/s for this test and 1×10^{-6} atm cc/s for physics operation (with room temperature He gas). After many hours of leak checking and subsequent leak repair, we finally achieved an integrated leak rate

of 4×10^{-3} atm cc/s. We determined that this rate was sufficient for the upcoming technical demonstration.

Magnet Support Hangers and Current Leads. Before the yin-yang magnet was hung in the east end of the vacuum vessel, it was necessary to test the two main support struts and the current leads to assure that they would meet design requirements. The struts successfully performed to a load level of 363,000 kg. Next, the current leads were tested for steady-state heat leak; they achieved 10-min heating at full current without counterflow He gas.

Coil Hi Pot Test. The test for high voltage breakdown (called the coil hi pot or high potential test) of the yin-yang magnet took place when the current leads, instrumentation, and magnet protection resistors were in place and the coil space had been filled with atmosphere He gas. We measured breakdown voltages of 650 to 1100 V for M1 and 1500 V for the M2 in the east vessel (see Fig. 1). However, these voltages did not improve as the magnet was cooled to LHe temperatures. Therefore, we concluded that voltage breakdown might have occurred at the upper region of the current leads or at the feedthroughs of the voltage taps, where the temperature remains at room temperature although the entire magnet is cooled to 4.5 K. These results were acceptable because we have since lowered the discharge voltage of the coils to 250 V for both magnets.

Power Supplies, Discharge Resistors, and Protection and Control Circuits. Prior to the magnet power tests, two power supplies, two slow-dump discharge resistors, two fast-dump resistors, and the protection and control circuits were fully tested for dummy load operation, voltage breakdown, and control function. We matched our requirements in all cases.

Magnet Cooldown and Steady-State Heat-Load Measurements

The process called magnet cooldown takes four stages:

- Cooldown of the LN₂ shield within 4 h;
- Cooldown of the magnet to 5 K within 120 h;
- Regeneration of magnet surface to 15 K within 8 h;
- Warmup of the magnet to 300 K within 130 h.

Our test results follow. First, the shield was cooled to LN temperature (80 K) in <4 h. Second, although cooldown of the magnet was accomplished in 269 h, 117 h of this total were wasted because of a delay in cryogenic system and vacuum vessel maintenance; therefore, the actual time to cool the magnet was 152 h (vs the 120 h calculated). Third, we needed nearly 20 h to regenerate the surface instead of the required 8 h. This time lag resulted because the LN₂ shield could not be warmed as rapidly as required and there was a delay in draining the LHe from the magnet. Finally, the total time needed to warm up the magnet was 14 h longer than the required span of 130 h.

Fig. 1. Magnet array for the Axicell MFTF-B with the on-axis field profile showing three operating modes: MARS, KELLEY, and TARA.

There were no significant thermal stresses throughout the cooldown. However, magnet support struts Nos. 1, 2, and 4 did not cool down as planned because there was insufficient nitrogen pressure and flow. Pressure and flow must be adequate to overcome the hydraulic head of the shield so that nitrogen can cool the shield around the support structure.

We calculated the total steady-state heat load to be 510 W at 4.5 K. After the magnet was filled with LHe and steady state reached, the heat load was measured to be 481 W. This small difference in heat load is probably due to our conservative estimate of radiation from the LHe shield; we assumed an emissivity value of 0.3. However, after extended periods of operation, we expect the emissivity will be degraded because gases will condense on the magnet surface.

Magnet Power Test

The power testing of the yin-yang magnet began on January 28, 1982 and concluded on Feb. 5. Full current (5775 A) and full field (7.68 T) were achieved on Feb. 4, 1982. Figure 2 shows the charging characteristics of the two coils, and Fig. 3 depicts their on-axis magnetic field at full current.

Fig. 2. Charging characteristics of the initial yin-yang magnet in the east vessel of MFTF-R.

Fig. 3. On-axis magnetic field profile for the yin-yang magnet.

The magnet was energized in steps: 500, 1500, 3000, 4500, 5200, and then, 5775 A. At each of the above current levels, both coils were fast-discharged to zero current. We recorded the temperature rise of the air-cooled dump resistors as well as the magnet terminal voltages. At 5200 A, an alarm sounded, caused by the crack detector at the thick welds. However, we later determined by visual inspection that this and subsequent crack-detector alarms occurring during the energization process between 5200 and 5775 A were erroneous. In addition, a slow dump was triggered at 3600 A, caused by a large number of conductor motions.

We conducted the power test by remote operation from the control room—hundreds of meters from the magnet site in the east vessel. Initially, both coils were energized to 5000 A using the 4-h energizing trajectory with no intermediate stops. After reaching 5000 A, M2 was held at 5000 A, and M1 was allowed to freewheel to 4500 A and then was resistively discharged to 4000 A. This test helped prove that the yin-yang pair could be adjusted to achieve uneven peak mirror fields.

When the magnet was energized, conductor motion was noticed and recorded by the acoustic emission data acquisition system as well as the fast response recorder. There were more conductor movements at

each new level of magnet energization. Most of the conductor motion occurred in the coil at the minor radius region because the conductors were packed more loosely in this region than at the major radius site.

Overall, the magnet power supplies, the dump switches, the air-cooled protection resistors, and the quench detection system performed satisfactorily. However, the power supplies and the control circuits were excited into oscillation several times. Such excitation occurs when an excessive amount of conductor motion occurs. We are now studying ways to eliminate these oscillations in the power supplies.

Design and Development of the MFTF-B Magnets

Changing to an Axicell Magnet Configuration

In the original MFTF-B tandem design, a C-shaped coil was arranged on the outboard end of each set of yin-yang coils to form an additional mirror cell (called the A-cell) of high mirror ratio. With this cell, potential and thermal barriers could be created by a sloshing-ion distribution augmented by microwave heating (ECRH) of the electrons at two locations.

Although this A-cell design remains viable, construction of the MFTF-B is now based on an improved axicell design.³ Since approval of the A-cell design by the Department of Energy in 1980, a study by Carlson, et al.⁴ was carried out to compare four different end-plug designs for tandem mirror reactors, including the A-cell design at LLNL and the axicell design of the TARA tandem mirror facility at the Massachusetts Institute of Technology. Because of this study, the MFTF-B configuration was revamped to an axicell design this year. The new arrangement (as shown in Fig. 1) promises higher power gain (in the central-cell region), lower capital cost (simplified end-plug magnet complexity), and reduced radial transport of the plasma (as a result of nonaxisymmetric magnetic fields). With a more nearly axisymmetric geometry in the end-plug region, the axicell design promises to be a superior reactor design. All coils (except the insert coil mentioned later) will employ superconducting niobium-titanium (NbTi) conductor.

Wang, et al. discuss the preliminary axicell configuration in Ref. 5; here we give a complete design update of the necessary alterations to the original A-cell design. Specifically, converting the magnet system involves the following changes:

- Elimination of the A-cell coils on each end;
- Addition of two high-field axisymmetric mirror coils (axicells) at each end of the 5-m-diam central-cell solenoids;
- Addition of two transition coils at each end between the yin-yang and axicell regions to map the elliptical plasma cross section leaving the yin-yang cell to enter the circular cross section of the central cell;
- Expansion of the original yin-yang coil separation by an additional 1.7 m to generate a mirror ratio of 3.0, a mirror field of 3.0 T, a field of 1.0 T at the mirror center, and a 5.1-m mirror-to-mirror length;
- Reduction of the 14 central-cell solenoids to 12, each 1.25 m apart, to gain space for the axicells and transition coils. By this arrangement, the central-cell field is raised to 1.6 T over a uniform field length of 12.8 m.

The magnetohydrodynamic (MHD) stability and adiabaticity requirements set limits on the magnet array and provide the basic criteria for our proposed

MFTF-B axicell magnet arrangement. Refer to Fig. 1 for the exact magnet-coil configuration and the profiles of on-axis fields. As illustrated, the MFTF-B magnets will provide three different field distributions: the Mirror Advanced Reactor Study or MARS-like operating mode (reference mode), the Kelley mode, and the TARA mode. The magnet parameters for the reference case are shown in Table 1.

Besides these on-axis field requirements, the magnet-coil design must reflect other requirements such as the penetration access for the plasma heating beams, the diagnostics array, and the space for cryopumping.

At the time that this paper was written, we had completed the magnet design requirements. Currently, the conceptual design of the axicell coils is in progress at the Convair Division of General Dynamics in San Diego.

Magnet Design

Yin-Yang Magnets (M1 and M2). In the Axicell MFTF-B, the yin-yang magnets must be modified to accommodate the additional 1.7-m separation, the overlap of transition coil T2 onto M1, and the new slot cut through one side of the M1 guard vacuum structure in its major radius region. We have designed a new intercoil box beam and case extension structure to handle the spreading load of the expanded yin-yang magnet. In our stress analysis of the modified yin-yang coil cases, we have determined that the case stresses for the new version will remain high (56 ksi), although the magnet currents will be only 66% (for M1) and 76% (for M2) of the original. This continued high stress is caused by the reduced percentage of coil-spreading load (about 20%) reacted through the intercoil structure. This intercoil structure is less-reactive because the increased spacing causes greater flexibility.

Transition Coils (T1 and T2). In the Axicell MFTF-B, the transition coils and the yin-yang magnets are the only C-shaped coils in the system. Figure 4 shows the cross sections of the two transition coils (T1 and T2) and the 12 solenoid or circular coils. To promote uniform convective cooling in the coil bundles, T1 and T2 will be oriented at 45° to the gravitational force. Their coil packs are virtually identical to the yin-yang coils; however, because T1 and T2 have sweep angles greater than 180°, each coil will require additional ventilation ports. In addition, T2 might require superstructure to support the spreading loads. Stress analyses on the 10-cm-thick coil case for T1 are underway to evaluate the possibility of eliminating its superstructure.

Axicell Coils (A1 and A2). Most of the burden of confining the higher density central-cell plasma resulting from the new design rests on the two sets of higher-mirror-ratio axicell coils. The two axisymmetric mirror coils or axicells at each end of the vessel differ in function and material. As illustrated in Fig. 1, the first axicell (A1) will produce a 6-T on-axis peak field in the MARS-like operating mode, whereas the second axicell (A2), consisting of the outer coil A20 and an inner or insert coil A21, will generate a 12-T on-axis peak field. For simplicity of design and fabrication, both A1 and A20 are identical. Figure 5 illustrates the coil design of A20 and A21.

Among the MFTF-B coils, the axicells have the highest peak fields and the largest hoop stress (about 40 ksi) on the conductors. These coils will use the surplus conductor and conductor insulations

Coil parameters	Coil names						
	M1/M2	T1	T2	A20	A21	A1	S1 to S6
Current density (A/cm ²)	1977/2271	2844	3075	2380	1874	2101	1828-1932
Ampere-turns (A-turn)	5.34/6.12	2605	3.524	9.75	4.55	8.605	1.00
Central field (T)	3.0/3.0	2.0	1.0	12.0	12.0	6.0	1.0
Conductor length (km)	24.8/24.8	5.2	10.62	12.8	1.252	12.8	9.43
Weight/coil (ton)	200/200	28	45	27	6	25	16
Peak field (T)	5.7	6.1	5.0	7.75	12.7	7.71	2.0
Operating current (A)	3832/4402	5427	5874	4542	1500	4010	1668-1763
Inductance (L)	11.5/11.5	0.9	2.7	7.0	4.6	7.0	6.8
Stored energy/coil (MJ)	113/113	16.7	51	90.7	14.8	70	30.0
Nuclear heating (W)	8/8	1	8	33	76	149	17
Total LHe heat load ((W)	323/323	75	115	112	69	209	68
LN ₂ heat load (kW)	22.5/22.5	6.4	11.3	2.6	2.5	5.2	3.7
Water-liner heat load (kW)	1185/1185	585	1050	285	285	570	420

Fig. 5. Cross sections for the axicell coils, A20 and A21. All dimensions are in centimeters.

from the original A-cell configuration magnets. Specifically, A1 and A20 will be layer wound to both minimize the number of splices and permit the convenience of conductor grading. Grade I (high-field grade) will be used in the first 10 layers and Grade II (low-field grade) in the next 19 layers. Table 2 details the conductor parameters for the axicells.

The conductor, turn insulation, layer insulation, and plenum insulation are similar to those of the yin-yang magnets and the transition coils.⁵ However, the U-shaped 5-cm-thick coil form, the ground insulation, and the insulation for the side-wall ventilation resemble those of the 5-m-diam solenoid magnets. Our main concern will be the high stress and strain (0.5%) on the conductor and the conductor splice; we must analyze the interlayer deflections. Currently we are studying the possibility of hoop load reinforcement by employing a float ring made of 304 low nitrogen (LN) stainless steel (S.S.) slipped over the tenth layer.

The Nb₃Sn Insert Coil. Figure 6 shows the cross section of the Nb₃Sn insert coil and its double-pancake structure, including the three conceptual designs for the multifilamentary cryostable Nb₃Sn conductor—monolithic, soldered monolithic, and soldered cable. We will operate the insert coil at: 1500 A, 12.65 T, and 4.5 K. There will be nearly zero resultant strain on the Nb₃Sn filament when the coil is at full current, although the maximum allowed strain is 0.4% in tension and 0.6% in compression.

Table 2. Parameters for the niobium-tin (NbTi) conductor employed in the Axicell MFTF-B magnets.

Field grading	"MFTF-type" conductor		Solenoid conductor
	Grade I	Grade II	
Specifications	11 kA (7.5 T, 4.2 K)	7.2 kA (5.1 T, 4.5 K)	3.4 kA (3.1 T, 4.5 K)
Conductor	Nb, 46% Ti	Nb, 46% Ti	Nb, 46% Ti
Composite size (mm)	6.5 x 6.5	6.5 x 6.5	1.829 x 3.073
Composite RR	150	150	110
Filament diameter (mm)	0.20	0.20	0.23
Twist pitch (mm)	180	180	110
Conductor size (mm)	12.4 x 12.4	12.4 x 12.4	12.49 x 5.0
Stabilizer RRR	220	220	110
Overall Cu/NbTi ratio	6.7	18.7	32.0
4.5-K operating points:			
M1/M2	4403 A, 5.7 T	---	---
T1	5427 A, 6.1 T	5427 A, 5.25 T	---
T2	---	5874 A, 5.0 T	---
A20	4542 A, 7.75 T	4542 A, 5.7 T	---
A1	4010 A, 7.50 T	4010 A, 5.1 T	---
S1 to S6	---	---	1668-1763 A, 2.0 T

OPTION 1: MONOLITHIC Nb_3Sn

OPTION 2: SOLDERED Nb_3Sn MONOLITHIC INSERT

OPTION 3: SOLDERED Nb_3Sn CABLE

Fig. 6. Cross section of the Nb_3Sn conductor, including three options. All dimensions are in centimeters.

In the first case of the monolithic conductor, we have proposed a 304 LM S.S. strip to be co-wound with the conductor. Seventy-five percent of both broad faces of the conductor will be cooled by the use of a 0.75-mm-thick, G-10, cryogenic-grade (CR), insulation strip that is punched in fish-bone-like structure. For the second and third cases called the soldered-type conductors (either cable or monolithic), we will solder the superconducting inserts onto a work-hardened copper stabilizer with a yield stress of 39 ksi at 4 K. The turn insulation will be a 1-mm-thick G-10 strip, again slotted in fish-bone-like structure with a 75% cooling rate. The insulation between pancake coils will be a 1-mm-thick, G-10, CR sheet, perforated to achieve a 50% cooling rate at the conductor edges.

Central-Cell Solenoids (S1 to S6). The Axicell MFTF-B contains a total of 12 identical 5-m-diam solenoids in the central cell, arranged so that two coils form a modular pair. Figure 4 depicts their U-shaped coil form and conductor design. The turn insulation consists of 1.5-mm-thick, G-10, CR buttons; the layer insulation is a 1.5-mm-thick, G-10, CR blanket that is slotted for a 60% cooling rate at the conductor edges. The conductor is layer wound against its hard axis. The ground plane of the coil winding form and the side wall are both insulated with solid and slotted G-10 CR sheets as well as by Kapton sheets.

Unlike the previous cases in which we will add new coils for the axicell and transition regions, in

the central cell we will merely modify the existing design. First, we will use only 12 coils instead of the original 14 designated in the A-cell design. Next, we will pack the 12 coils more closely (1.25 vs 2.0 m apart) to achieve room for the axicells and transition coils. Third, we will generate a higher central field (1.6 vs 1.0 T). This higher central field will require local strengthening in the coil case side plate along the lead-in pocket and at the current lead cutout in the outer LHe shell.

Steady-State Cryostable Conductors. The magnet system will operate in a steady-state dc mode, and the coils will remain cold over the complete operating cycle—typically 8 to 13 weeks. To minimize disruption and assure reliable operation, the design of all the magnets is based on the steady-state cryostability criterion, employing the well-established condition of 4.5-K, pool-boiling LHe over a wetted surface area. Margins in critical field, critical current, and cryostability are provided in the design. Figure 7 shows the critical current-magnetic field or I-H curves and the operating points for all NbTi conductors in MFTF-B. The important conductor parameters are tabulated in Table 2.

Fig. 7. Graph depicting the critical current and magnetic field (I-H curves) for the NbTi superconducting coils employed in the tandem MFTF-B. The term MFTF-A refers to the original single-cell machine.

Magnet Support System

Based on the axial force pattern, we plan to mechanically group the individual coils with the intercoil struts to minimize the resultant axial electromagnetic loads to the vessel. However, to avoid large axial thermal stresses, we must guarantee

Fig. 8. Support structure for the magnet in the vacuum vessel with calculations for the worst axial loads on the vessel.

that each interconnected assembly not be too long. Fig. 8 shows our conceptual design of the magnet support system for the AxiCell MFTF-B. The axial struts, vertical hangers, and horizontal struts are sized to support the axial electromagnetic loads, the magnet weight, and the earthquake loads. The magnet weights are listed in Table 1, and the maximum axial fault loads are indicated in Fig. 8.

Heat Load and Thermal Design

We will install several LHe dewars ranging in capacity from 500 to 2000 liters on top of the vacuum vessel, directly above the superconducting coils. These dewars will supply LHe to the bottom of each magnet; the return flow will be from the top of each magnet to the dewar above. Liquid-nitrogen-cooled liners--similar in design to the yin-yang coils--will be installed to shield the 4.5-K, cold mass, coil superstructures and the magnet support struts. In turn, the LN₂ liners will be shielded by water-cooled liners, which will be used to intercept the low density hot plasma.

We have calculated the heat load to the LHe system, the LN₂ liners, and the water-cooled liners in Table 1. For the entire magnet system, the total heat load to the LHe system is about 2070 W without nuclear heating and 2950 W with heating; the total heat load is 164 kW for the LN₂ liner-system and 6572 kW for the water-cooled liners. In addition to these heat loads, there will be 0.11-g/s/kA-pair, counterflow He gas to cool the current leads, thus yielding a total He gas flow of about 10.0 g/s for all current leads.

Magnet Development and Verification Test Plan

The magnet system for the AxiCell MFTF-B is based on a design that was successfully demonstrated within the state-of-the art superconducting magnet technology. However, to ascertain that the design is feasible, we will perform certain development and verification tests. Table 3 lists our test program and the development items required for each type of coil. Initial testing is now in progress. The Nb₃Sn conductor will be our most challenging task in the development of AxiCell MFTF-B.

Table 3. Magnet development and the verification test program for the AxiCell MFTF-B.

Development/test	Coil systems
Nb ₃ Sn conductor development	A2I
Conductor-splice development and testing	S1-S6, A1, A20, A2I, M1/M2
Current-lead development	A1I coils
Current-lead test	A1I coils
Conductor short-sample test	A1I coils
I-H characteristics vs stress/strain test	A2I
Main-magnet hanger tests	A1I coils
Coil hi-pot test	A1I coils
Mechanical properties of conductor test	A2I, A1 or A2
Measurement of Nb ₃ Sn irreversible compressive limit	A2I conductor
Entering lead-splice test	A1I coils
Calibration of carbon-glass sensor and CLT sensors	A1I coils
High-voltage feedthrough test	A1I coils
Air-cooled heating test of discharge resistor	A1I coils
Solenoid coil-case stiffener test	S1-S6
Tensile and fracture toughness of structural materials and welds test	A1I coils

References

1. Henning, C. D., et al., The Mirror Fusion Test Facility Magnet System--Final Design Report, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52955 (1980).
2. Kozman, T. A., et al., "The Testing of the MFTF Magnets," in Proc. of 9th Intl. Cryogenic Eng. Conf., Kobe, Japan, 1982 (Butterworth & Co., United Kingdom, 1982), paper JD-2, pp. 434-437.
3. Thomassen, K. I., and V. N. Karpenko, An Axicell Design for the End Plugs of MFTF-B, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19318 (April 1982).
4. Carlson, G. A., et al., Comparative End-Plug Study for Tandem Mirror Reactors, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19271 (1981).
5. Wang, S. T., et al., "The Axicell MFTF-B Superconducting Magnet System," in Proc. 9th Intl. Cryogenic Eng. Conf., Kobe, Japan, 1982 (Butterworth & Co., United Kingdom, 1982), paper JD-1, pp. 424-433.

Acknowledgments

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract Number W-7405-ENG-48.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government thereof, and shall not be used for advertising or product endorsement purposes.