150 7-14-78

sh. 271

ORNL/TM-6197

Evaluation of Pulse Coil Alternatives for the Large Coil Program

B. E. Nelson

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy $4.50; Microfiche $3.00

ORNL/TM-6197
Dist. Category UC-20 b

Contract No. W-7405-eng-26

ENGINEERING DIVISION

EVALUATION OF PULSE COIL ALTERNATIVES FOR THE LARGE COIL PROGRAM

B. E. Nelson

Date Published - July 1978

NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

SUMMARY

The Large Coil Program (LCP) is chartered to develop viable superconducting toroidal field (TF) coils for tokamak reactors. The Large Coil Test Facility (LCTF) portion of the LCP will include pulse coils designed to simulate the transient fields in future ignition tokamaks. The magnitude, distribution, pulse ramp rate, and duration of pulsed fields expected in a TF coil for an ignition reactor serve as criteria for the simulation. The LCP coil test stand is an arrangement of six tokamak TF coils in a compact toroidal geometry. The design of a pulse field coil tailored to this geometry and providing the proper simulation of time-variant fields is the subject of this report.

Several pulse coil candidate concepts are evaluated, including (1) a pair of poloidal coils outside the LCTF torus, (2) a single poloidal coil threaded through the torus, and (3) a pair of vertical axis coil windings inside the bore of the toroidal test coils.

The latter configuration was selected for use in the LCTF due to its versatility, ease of fabrication, and lower operating cost.

1. INTRODUCTION

The pulse coils described in this paper are resistive copper magnets driven by time-varying currents. They are included in the large coil program (LCP)[1] test stand to simulate the pulsed field environment of the toroidal coils in a tokamak ignition reactor. Since TNS (a 150-sec, 5-MA igniting tokamak conceived in 1976 at ORNL as "The Next Step") and EPR (the Oak Ridge Experimental Power Reactor) are representative of the first tokamaks to require the superconducting technology developed by LCP, the reference designs[2] for these machines, especially TNS, were used to derive the magnetic criteria for the pulse coils. These criteria include the magnitude, distribution, and rate of change of pulsed fields in the toroidal coil windings.

In addition to the magnetic requirements, there are facility-related considerations such as versatility of design, ease of fabrication, and cost of operation. Versatility of design includes the ability to pulse the test coils selectively, modify the field distribution, and remove or replace the test coils easily. Ease of fabrication means that the pulse coils should not be more difficult or expensive to build than the toroidal coils and should require a minimum of field construction. Finally, the cost of operation, primarily the refrigeration loads on the nitrogen and helium systems and the connected electrical power, should be as small as possible.

2. PULSE FIELD CRITERIA AND REQUIREMENTS

2.1 MAGNITUDE AND DISTRIBUTION OF PULSE FIELD

Since pulse fields are provided in the LCP facility to simulate the transient magnetic fields in future tokamaks, the characteristics of this environment must be predicted. The ORNL TNS and EPR reference designs were modeled for this purpose assuming time-dependent currents in the ohmic heating (OH) windings and plasma. It was soon concluded, after comparing the plasma histories (i.e., current vs time for all poloidal currents) and realizing that TNS may become the EPR or even the Demonstration (i.e., commercial prototype) reactor, that TNS would serve as a credible example of the pulsed fields in any foreseeable reactor design. The magnetic criteria, then, were established from TNS studies.

Figure 1 is the complete plasma history for TNS,[2] and Fig. 2 is an expanded plot of the first 10 sec. These diagrams show that the pulsed fields in the toroidal coil should be calculated at time equals 0, 1, 2, and 10 sec to determine the extreme magnitudes and rates of change in a reactor environment. Figures 3 through 6 include plots of (a) the plasma current density contours, (b) the component of the field (in the windings of the TF coil caused by the pulsed currents) that is perpendicular to the windings, and (c) the component of the field that is tangential to the windings. Figures 3(a) through 3(c) are plots at t = 0 sec; Figs. 4(a)-(c), 5(a)-(c), and 6(a)-(c) are the plots at t = 1, 2, and 10 sec, respectively.

In comparing Figs. 3 through 6, it becomes evident that t = 0 sec is the instant when the field magnitude is greatest. The major contribution to the field, from Fig. 1, is seen to be the ohmic heating (OH) system. An assumption has been made that TNS and other reactors will require designs that minimize the stray field from the OH coils in the region of the TF coil. Therefore, a relevant design for pulse coils would be one which simulates the pulse effects from only the plasma and equilibrium coils and essentially ignores the OH field contributions.

When the TF coils are assumed to be completely shielded from the OH coils, a new set of plots can be generated to show the pulsed fields, as in Figs. 7, 8, 9, and 10. Additional plots can also be made assuming any intermediate percentage of OH field. Eventually it is possible to construct Fig. 11, which is a pulsed field history of TNS using the maximum field which occurs in the TF coils at each point of time in the operating cycle.

Assuming that OH shielding is available, t = 2 sec is the instant when the magnitude of pulse field in the TNS toroidal coils is greatest. The criterion for the LCTF, therefore, is to furnish a pulse coil system which produces a field in the LCP test coils with a magnitude and distribution similar to that of TNS at t = 2 sec (Fig. 9).

2.2 PULSE FIELD CYCLE

The pulse fields in the TNS design considered were produced by separate transient currents in 30 OH coils, 20 equilibrium field coils, and the plasma. Each contributes a varying percentage of the total field, depending on the given point in the operating cycle. This causes the distribution of field in the TF coils, as well as the magnitude, to shift with time. Even assuming no effect from OH windings, the locations of the maximum fields in the TF coils vary, so it is impossible to duplicate the TNS environment in LCTF with a single pulse coil regardless of its current cycle. It is possible, however, to devise a current cycle which, when coupled with a particular field distribution, will approximate the TNS environment.

By choosing t = 2 sec in the TNS operating cycle as the criterion for the field distribution, it is left only to find an appropriate current cycle. Figure 11 indicates a 1-sec ramp to maximum current, a dwell of 30 sec, a 5-sec decay to zero current, and a 114-sec dwell to complete the pulse. This cycle could be duplicated in LCTF, but the 1-sec ramp to full current requires a large power supply because of the high inductive power demands of moderate current density coils. A slower ramp up time coupled with a fast decay or discharge requires a smaller power supply and yet provides a sufficiently fast magnetic flux change.

To ensure that LCTF provides a pulsed field environment as severe as that which will be encountered in TNS but at the same time minimizes its own power supply requirements, the current programs for the pulse system in LCTF have been chosen as follows:

(1) A 2-sec ramp to the magnitude and approximate distribution of the pulsed field in TNS at t = 2 sec.

(2) Hold at this current for 30 sec.

(3) Ramp down to zero current in 1 sec.

(4) Hold at zero current for 117 sec.

The normal peak field magnitude perpendicular to the windings would be 0.14 T, but a magnitude of 0.2 T will also be provided by increasing the peak current.

3. LCTF PULSE COIL CONCEPTS

3.1 DETERMINATION OF CANDIDATE DESIGNS AND GEOMETRY

To provide a pulsed field environment for the LCP test coils that is consistent with the criteria derived from TNS, three different pulse coil concepts appear feasible. The first concept, as suggested by Komarek,[3] is a pair of poloidal coils outside the toroidal field coils. This arrangement provides a vertical field over the entire torus of the test coils. The second concept is a single poloidal coil, analogous to the plasma current, threaded through the toroidal field coils. The third concept is a pair of vertical axis coils inside the bore of one or more test coils that produce a localized vertical field.

In order to evaluate and compare these three concepts, certain quantities (including the coil geometries, ampere-turns, and current density) had to be determined. The coil geometries were found by iterating single current filament model magnetic field calculations several times to provide the best approximation to the field distribution shown in Fig. 9. A current density of 2250 A/cm^2 in the conductor was chosen as a credible value for LN_2-cooled copper, water-cooled copper, or even superconducting windings.

Combining the current density and ampere-turns fixed the cross-sectional area for each coil. The coil models were adjusted to account for this finite cross section and, after several more iterations, the final geometries shown in Fig. 12 were chosen.

3.2 COMPARISON OF FEATURES

3.2.1 Field Distribution

The first comparison to be made between the three pulse coil concepts regards the field distribution each produces in the TF coils. Figure 13 illustrates the contrast between these distributions and the distribution of the TNS system at t = 2 sec. It is apparent that none of the concepts exactly duplicates the desired TNS conditions, but the third design, i.e., a pair of vertical axis coils in the bore of a TF coil, provides the best match of the tangential field component and as good a match as any of the concepts for the perpendicular field component.

3.2.2 Versatility

A second area of comparison between the three pulse coil concepts regards the versatility of the design. This is a qualitative evaluation based on such factors as the capability to pulse the LCP test coils selectively, modify the field distribution, and remove or replace the test coils easily.

The first concept, the pair of poloidal coils outside the toroidal coils, is fairly versatile. Although it cannot pulse a single test coil, it does allow some field modification by operating the windings of different currents, where some tailoring of the perpendicular field is possible. Also, this concept presents no significant obstacle to removal or replacement of the test coils.

The second concept, the single poloidal coil, is very limited in versatility. There is no way to pulse the test coils selectively, and since it is a single winding, its field distribution cannot be adjusted without altering its geometry. In addition, removing or replacing any of the test coils would require virtual dismantling and refabrication of the pulse coil.

The third concept, the pair of vertical axis coils in the bore of one or more test coils, seems to offer the greatest versatility. Either the desired test coil only would be pulsed, or any combination depending on the number of pulse coils installed. The field distribution could be modified by operating the two windings at different currents, as in the first concept, or by pulsing only the top or bottom winding. Finally, this system would present no great difficulty during installation or removal of test coils because of its comparatively small size.

3.2.3 Fabrication

The relative ease of fabrication is a third basis for comparison of the pulse coil concepts. Factors such as the quantity of materials needed (especially copper), the type of structure necessary, and the amount of field work vs shop work required are important to this evaluation.

The pair of poloidal coils outside the torus would require approximately 25,000 kG (28 tons) of copper and a large quantity of structural material. The structure must not only support the weight of the copper, but also the magnetic loads imposed by all six test coils and the pulse coils. The sheer dimensions of this concept would require a good deal of field construction, since installing the system as a unit in the LCTF would be difficult due to facility load handling limits. One redeeming feature is the fact that no demountable hardware is necessary because once in place, this system would not be disturbed by changing out a test coil. The envelope for the LCTF vacuum vessel must also accommodate this design, however, so it is desirable to keep its diameter minimized for facility cost and construction reasons.

The single poloidal coil threaded through the bore of the test coils would require only 6000 kG (6.5 tons) of copper but a much more complex structure than that of the first concept. This is because a single coil would be loaded with nearly the same magnetic forces as both coils of the first concept combined and would have less space available for supports. Another problem would be installing the pulse system with the toroidal coils in place. Readily breakable field joints as in the Princeton Large Torus (PLT) would pose a difficult design problem for a multiturn coil, as would the alternative of unwinding and rewinding the coil in place whenever a test coil was changed. In any event, an unacceptable amount of field work and tooling would be anticipated.

The pair of vertical axis pulse coils in the bore of one or more test coils brings the amount of copper needed down to 3000 kG (3.33 tons) and would require less supporting material than the other concepts since the external magnetic loads would be due almost entirely to a single test coil. In addition, both coil windings could be wound on a common bobbin in the shop and installed as a single unit with a minimum of field work.

3.2.4 Operation

Operating parameters form the final basis for comparison of the pulse coil concepts. Included here are requirements such as steady-state and transient power, cooldown, and in-use LN_2 refrigeration and helium boiloff due to eddy currents induced in components at 4 K. These comparisons are based on LN_2-cooled copper coils, but the relative values would be similar for water-cooled or even superconducting coils.

Table 1 summarizes the operating parameters for each concept, assuming the pulse cycle, geometry, and current density discussed earlier. The listing illustrates a clear advantage of the third concept in every category. The large eddy current losses[4] from the first two concepts are due to their inductive coupling with the bucking post and torque rings. Effective insulation of these structures to reduce the eddy current heating adequately would further increase the fabrication costs. The self-inductance of these two concepts is also high due to their size, causing proportionately high transient power requirements.

It should be noted here, though, that only one pair of coils is assumed for the third concept, so only one test coil is pulsed. If there were a requirement for pulsing all six test coils simultaneously, then six pairs of pulse coils would be necessary. All of the operating parameters would then be multiplied by a factor of six and the third concept would become less attractive. However, since there is presently no requirement to pulse all six test coils at once, there is no reason to pay for the extra costs incurred by doing so, as with the first two concepts. In addition, if any of the toroidal coils cannot withstand the pulse field, the ability to pulse selectively becomes necessary to avoid impacting the test plan.

3.3 SELECTION OF BEST CONCEPT

Based on the general criteria used in the foregoing comparisons, a pair of coils in the bore of a test coil is the most suitable concept

Table 1. Estimated operating parameters based on 0.14-T peak field magnitude

	I[a]	II[a]	III[a]
Current at peak field	2 × 1 MAT	0.8 MAT	2 × 1 MAT
Average length per turn	3000 cm	1841 cm	341 cm
Area of copper	2 × 450 cm^2	360 cm^2	2 × 445 cm^2
Resistance/$turns^2$	$1.33 \times 10^{-6}/2\Omega$	$1.02 \times 10^{-6}/\Omega$	$0.14 \times 10^{-6}/2\Omega$
Inductance/$turns^2$	2 × 28.5 μH	18.6 μH	1.2 μH
Stored energy ($Li^2/2$)	2 × 14.3 MJ	6.0 MJ	2 × 0.5 MJ
Maximum resistive power	2 × 1.33 MW	0.65 MW	2 × 0.14 MW
LN_2 vaporized	2 × 332 liters/pulse	164 liters/pulse	2 × 15 liters/pulse
Circulation rate for 80 K	2 × 8000 liters/hr	4000 liters/hr	2 × 365 liters/hr
Cooldown refrigeration (copper only, 300-80 K)	2822 MJ	693 MJ	295 MJ
Eddy current power at 4.2 K (Ref. 4)	325 W	56 W	∿5 W
Maximum inductive power	2 × 14.25 MW	9.30 MW	2 × 0.54 MW
Maximum total power	2 × 15.60 MW	9.86 MW	2 × 0.60 MW
Average total power	2 × 0.54 MW	0.26 MW	2 × 0.03 MW

[a]Numbers are for 1 set of coils.

for the LCP. As indicated, this concept is advantageous because it (1) provides the best match to the desired field distribution, (2) has a versatile configuration that can be built in the shop as a unit, and (3) requires the least power and refrigeration.

4. PRELIMINARY PULSE COIL DESIGN

Following the selection of the pulse coil concept, a more detailed conceptual design was undertaken. The effort was directed toward enhancing the versatility, simplifying the fabrication, and reducing the cost of operation.

The resulting pulse coil design and its location in the test stand[5] are shown in Fig. 14. Three pulse coils and three support segments are recommended so that three different test coil designs can be pulsed before rearranging the system. To facilitate rearrangement, each pulse coil is contained in a module which occupies a 60° arc so that the support segments and pulse coil modules are interchangeable. While the three-coil concept triples the cost of fabrication over a single-coil unit, it permits selective pulsing of test coils without warming up and relocation of the pulse coil — an advantage estimated to save more than six months of testing time.

The operating cost is highly dependent on the type of cooling supplied to the coils. The original concept called for cooling with forced flow liquid nitrogen, but this resulted in a high nitrogen refrigeration load. To reduce this load and thus lower the operating cost, a forced flow, water-cooled design was considered as an alternative. A comparison of these two systems is listed in Table 2. It is evident that the fabrication costs and refrigeration load would be substantially reduced using water as a coolant. Because the water is at room temperature, however, the coils must be shielded since only surfaces with temperatures of 80 K or lower are allowed to radiate to the test coil. This 80 K temperature limit is derived from a consideration in LCP to simulate the thermal loads that will occur in a tokamak reactor having a vacuum space with a thermal barrier such as the ORNL TNS concept of 1977. The final choice of coolant was based on considerations of LN_2

Table 2. Pulse coil coolant

		LN_2	Water
Conductor		1.75-cm square 0.93-cm hole	2.18-cm square 0.93-cm hole
Winding		624 turns 4 in hand 52 flow paths 12 turns/path	504 turns 2 in hand 24 flow paths 21 turns/path
Flow		18 liters LN_2/sec $\Delta p = 2$ atm	6.4 liters H_2O/sec $\Delta p = 3$ atm
Steady-state power		<60 kW/coil	<250 kW/coil
Minimum ramp time (2 × 0.6 MW P.S.)		2.4 sec	2.8 sec
Estimated direct cost, 1 pair of coils	Components inside vacuum tank	$750K	$550K
	Components outside vacuum tank (less P.S.)	$250K	$50K
	Total	$1000K	$600K

demand, its concomitant connected piping capacity, and complex system design requirements vs the relatively inexpensive water cooling system with its straightforward design approach and thermal shield. When preliminary calculations showed the relative ease with which insulation could be placed to isolate the pulse coils thermally, water was selected as the base reference design coolant.

Preliminary structural sizing has been performed to arrive at a welded plate construction for the coil module. In addition, a conceptual plan for the coil windings, coolant headers, and force cooled power leads has been devised. This design is illustrated in Fig. 15.

ACKNOWLEDGMENTS

The author wishes to thank P. B. Burn and P. B. Thompson for encouragement, guidance, and aid in conceptual design of pulse coils; J. N. Luton for help in testing credibility of coil design and calculations; J. R. Moore for assistance in magnetic field calculations; Y-K. M. Peng for TNS parameters; and H. T. Yeh for eddy current calculations.

REFERENCES

1. L. W. Nelms, P. B. Thompson, and T. L. Mann, *Large Coil Test Facility Conceptual Design Report*, ORNL/TM-6032, Oak Ridge, Tennessee (February 1978).
2. J. D. Callen et al., *Plasma Physics and Controlled Nuclear Fusion Research*, Vol. II, p. 369 (1976).
3. P. Komarek et al., "Some Additions to the Preliminary Definition of LCP," Kernforschungszenstrum Karlsruhe, Institut für Experimental Kernphysik.
4. H. T. Yeh (ORNL), private communication, January 1977.
5. P. S. Litherland (ORNL), private communication, January 1977.

FIGURES

<u>Figure</u>

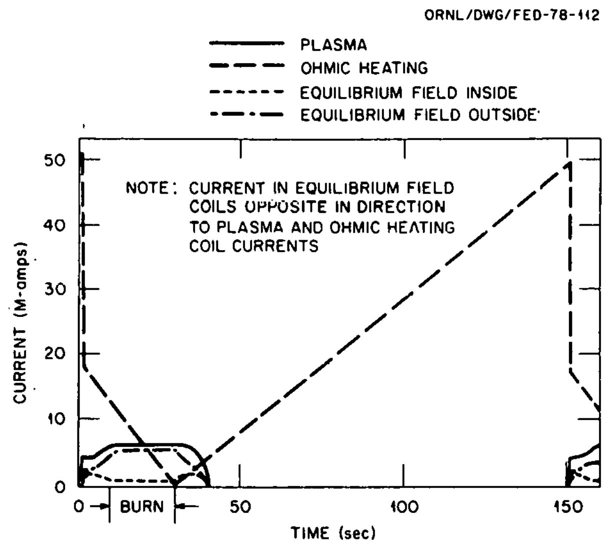

Fig. 1. TNS plasma history.

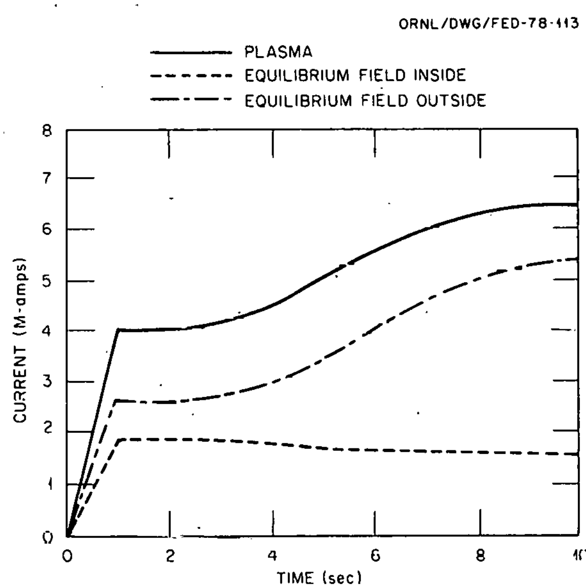

Fig. 2. First 10 sec of TNS plasma history.

ORNL/DWG/FED-78-114

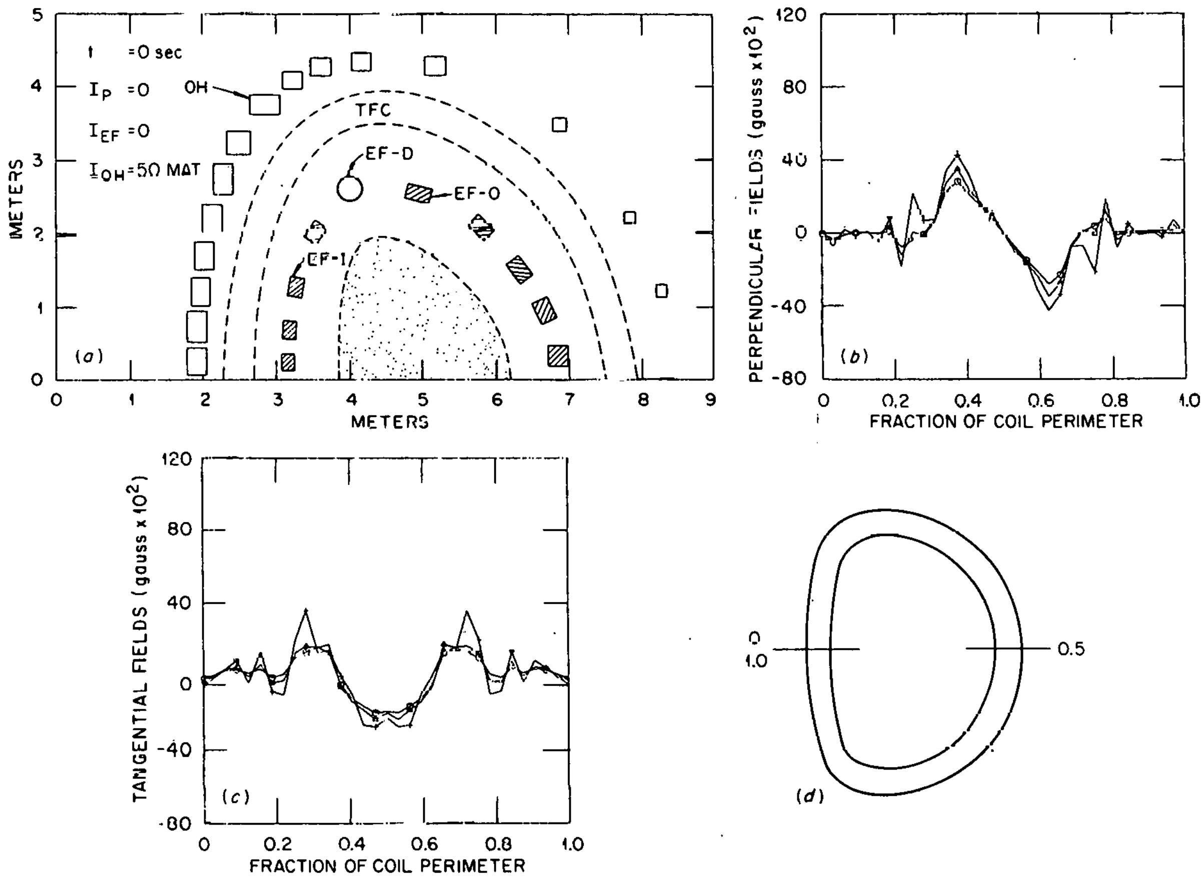

Fig. 3. TNS parameters at t = 0 sec. (a) plasma current density contours and PF coil currents, (b) distribution of transient fields in TF coils perpendicular to windings, (c) distribution of transient fields in TF coils parallel to windings, (d) fractional division of TF coil perimeter. (Here OH is ohmic heating, EF is equilibrium field, I is inner, O is outer, and D is divertor.)

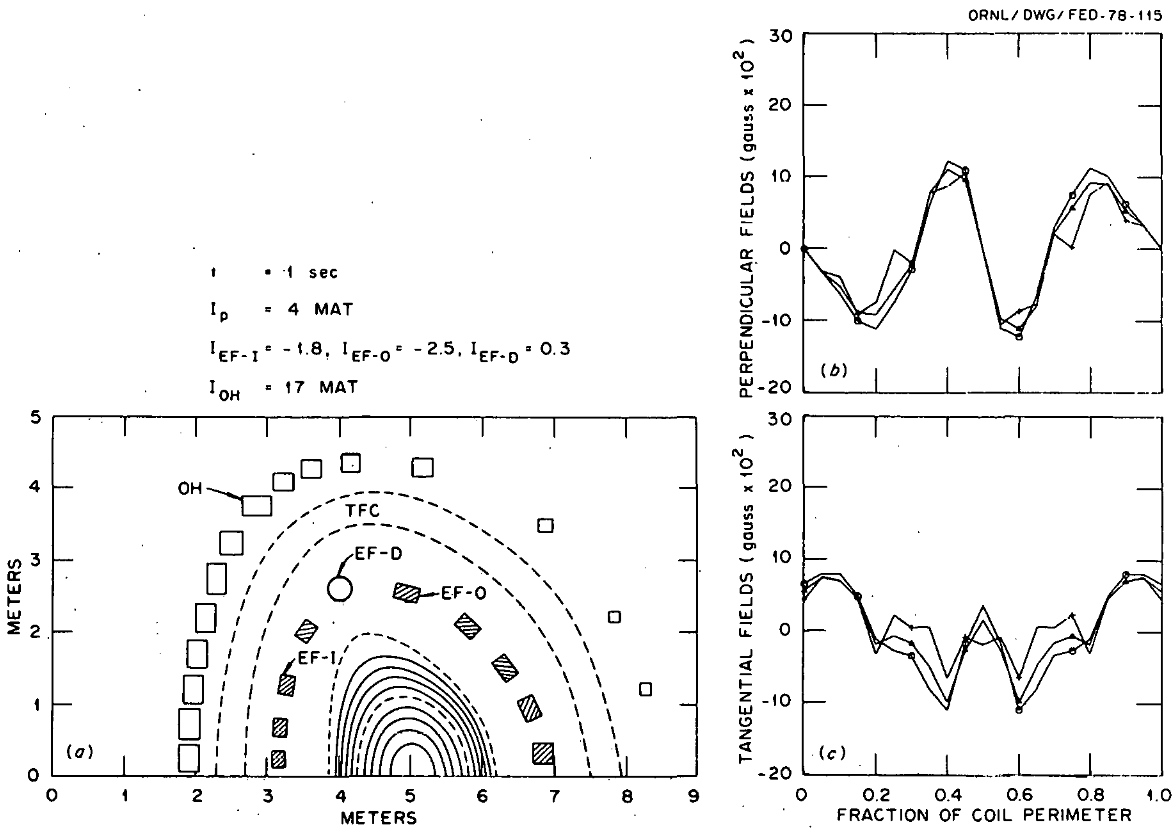

Fig. 4. TNS parameters at t = 1 sec. (a) plasma current density contours and PF coil currents, (b) transient fields in TF coil perpendicular to windings, (c) transient fields in TF coil parallel to windings.

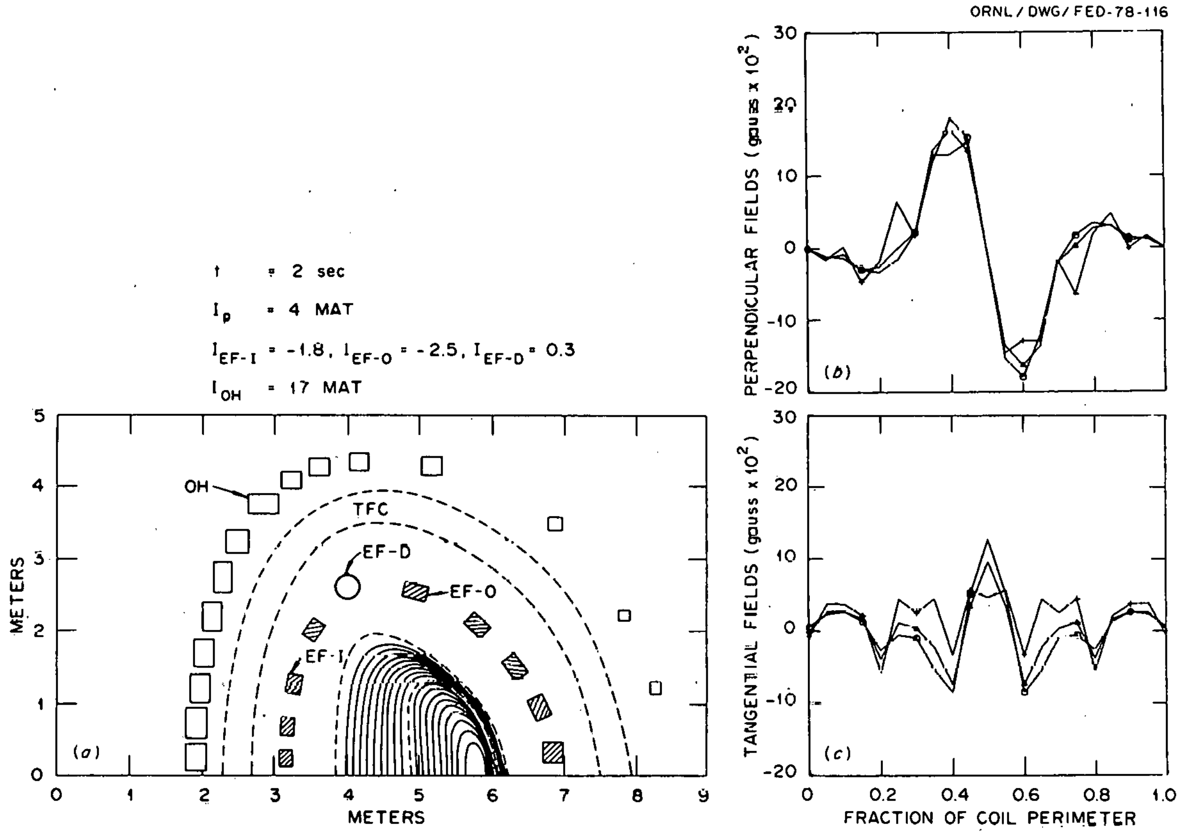

Fig. 5. TNS parameters at t = 2 sec. (a) plasma current density contours and PF coil currents, (b) transient fields in TF coils perpendicular to windings, (c) transient fields in TF coils parallel to windings.

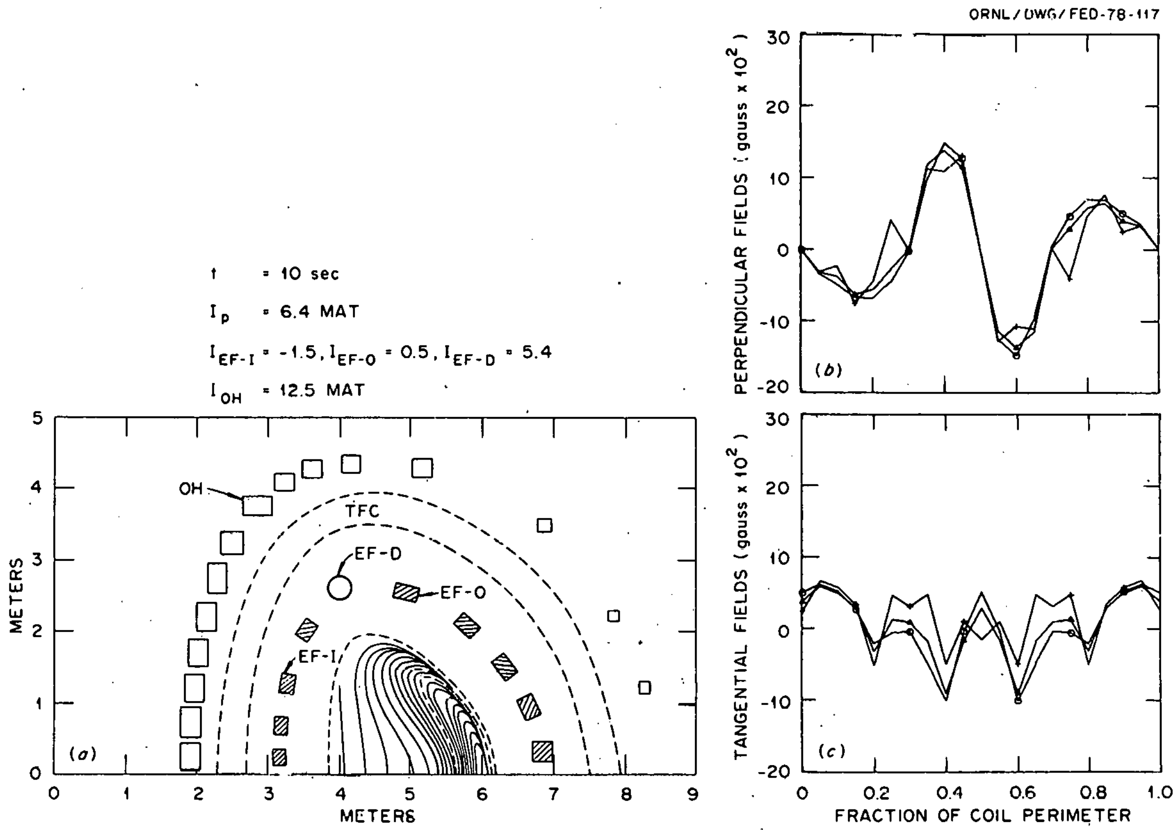

Fig. 6. TNS parameters at t = 10 sec. (a) plasma current density contours and PF coil currents, (b) transient fields in TF coils perpendicular to windings, (c) transient fields in TF coils parallel to windings.

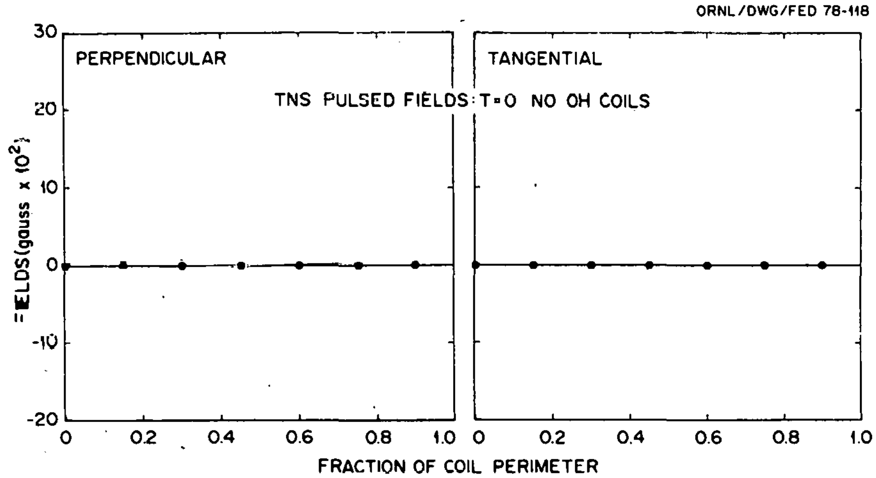

Fig. 7. Transient fields in TNS TF coils at t = 0 sec with no contribution from OH system.

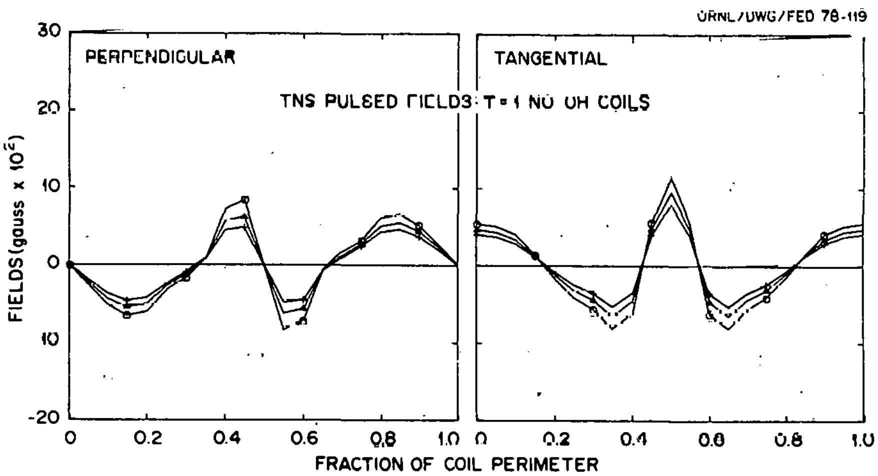

Fig. 8. Transient fields in TNS TF coils at t = 1 sec with no contribution from OH system.

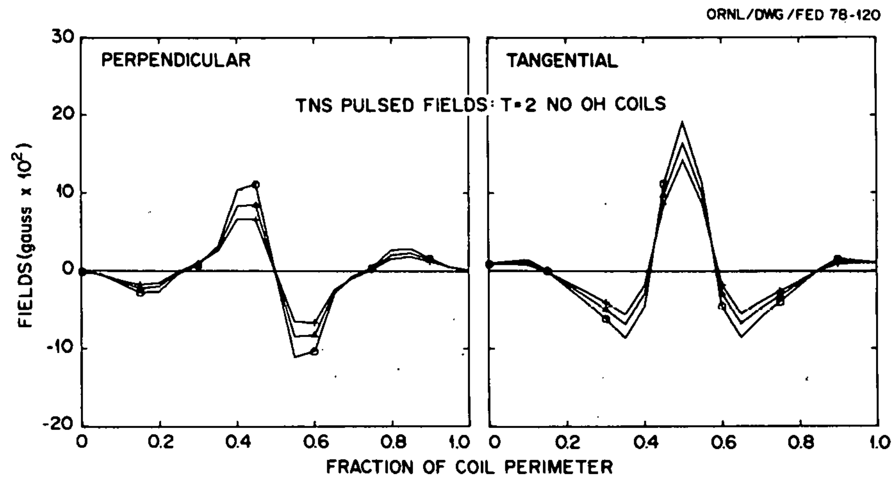

Fig. 9. Transient fields in TNS TF coils at t = 2 sec with no contribution from OH system.

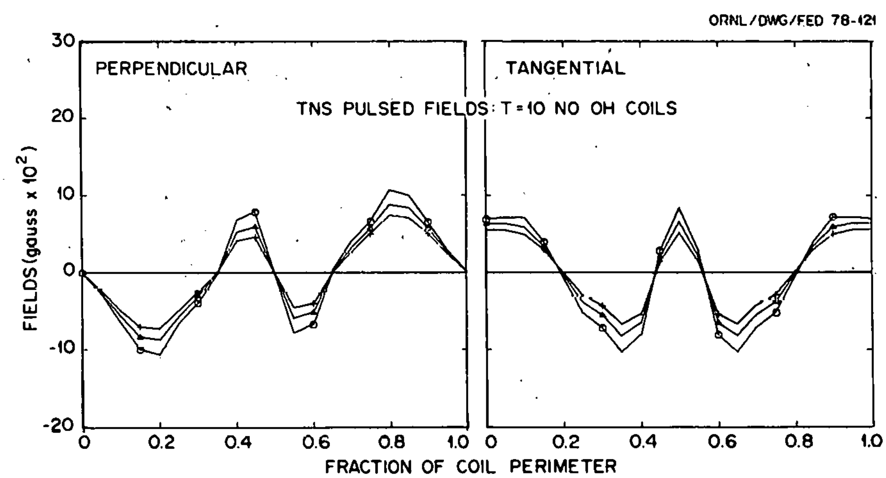

Fig. 10. Transient fields in TNS TF coils at t = 10 sec with no contribution from OH system.

ORNL/DWG/FED 78-122

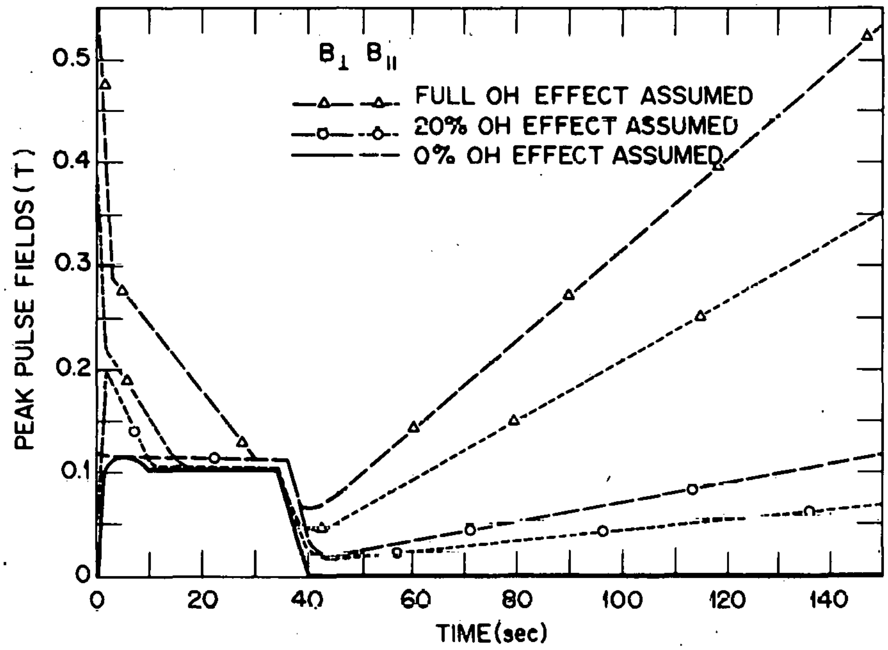

Fig. 11. Peak transient fields vs time in TNS TF coils for different assumed contributions from OH system.

ORNL/DWG/FED-78-124

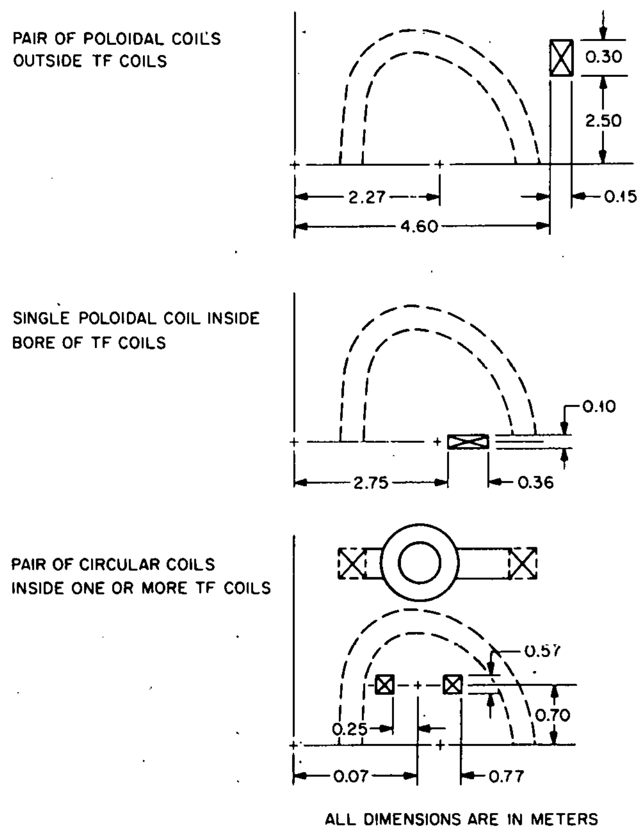

Fig. 12. Pulse coil concept geometries.

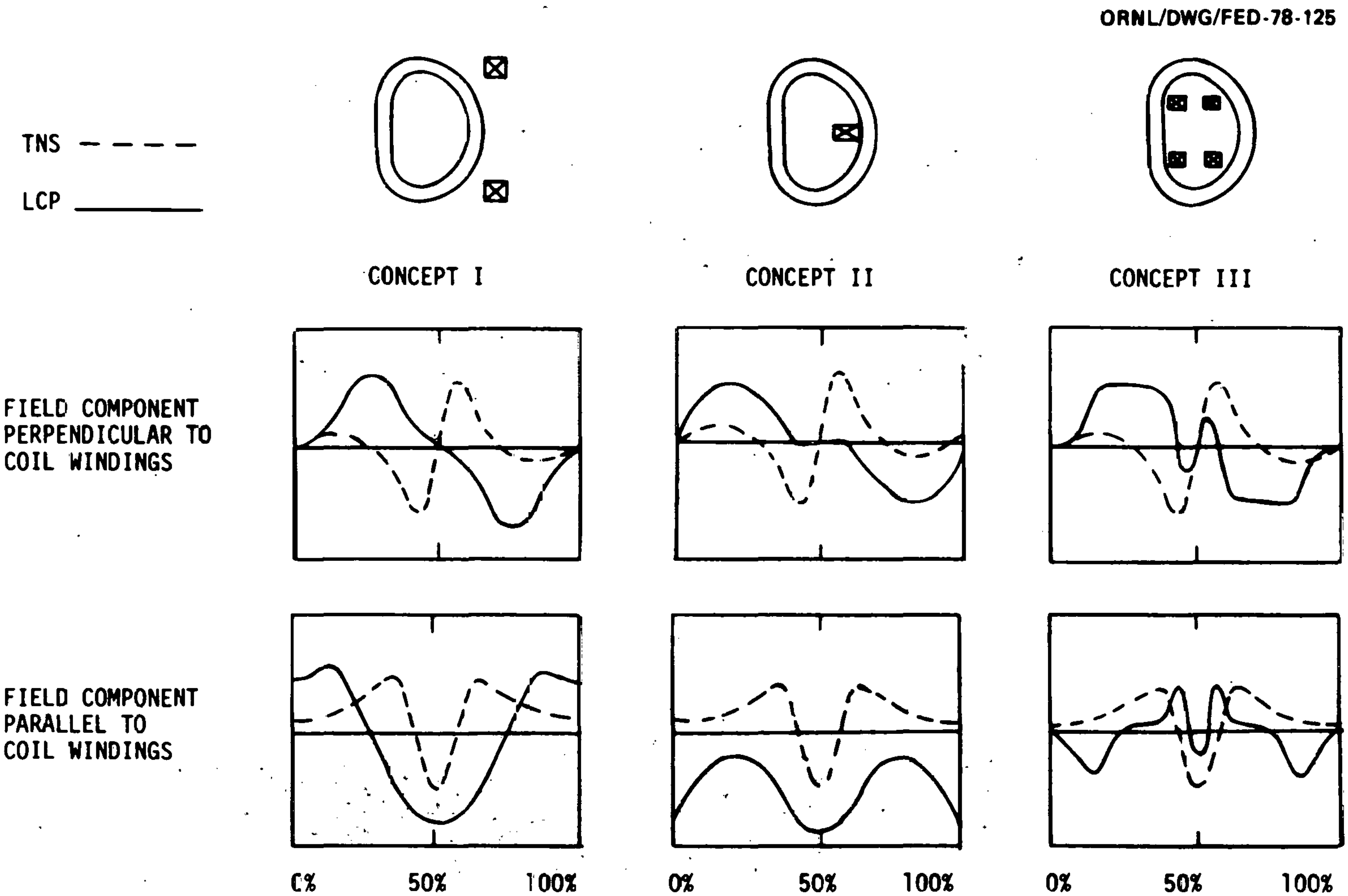

Fig. 13. Distribution of transient fields around TF coil perimeter.

ORNL/DWG/FED-77-601R

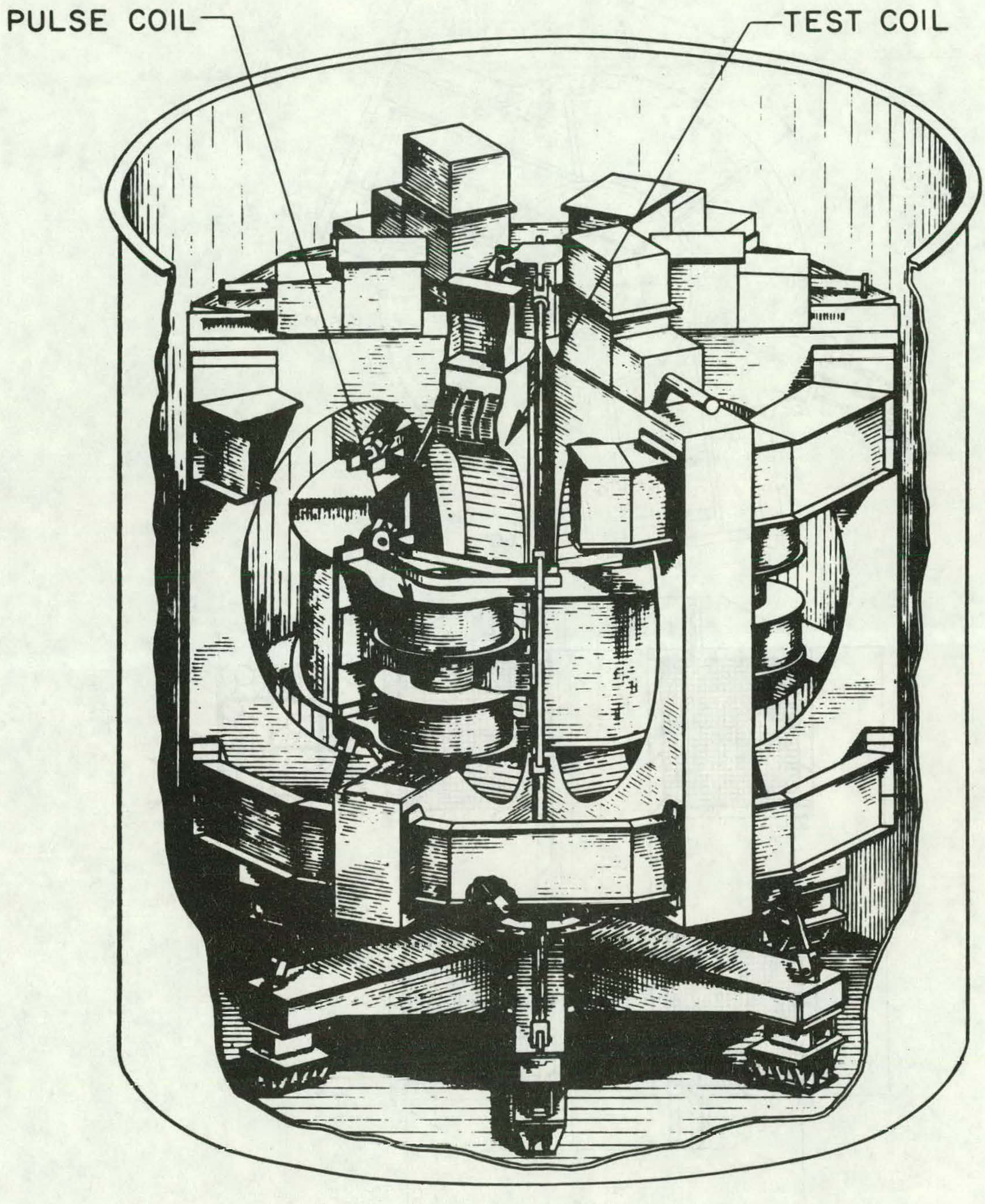

Fig. 14. Location of pulse coil in Large Coil Facility.

ORNL/DWG/FED-78-127

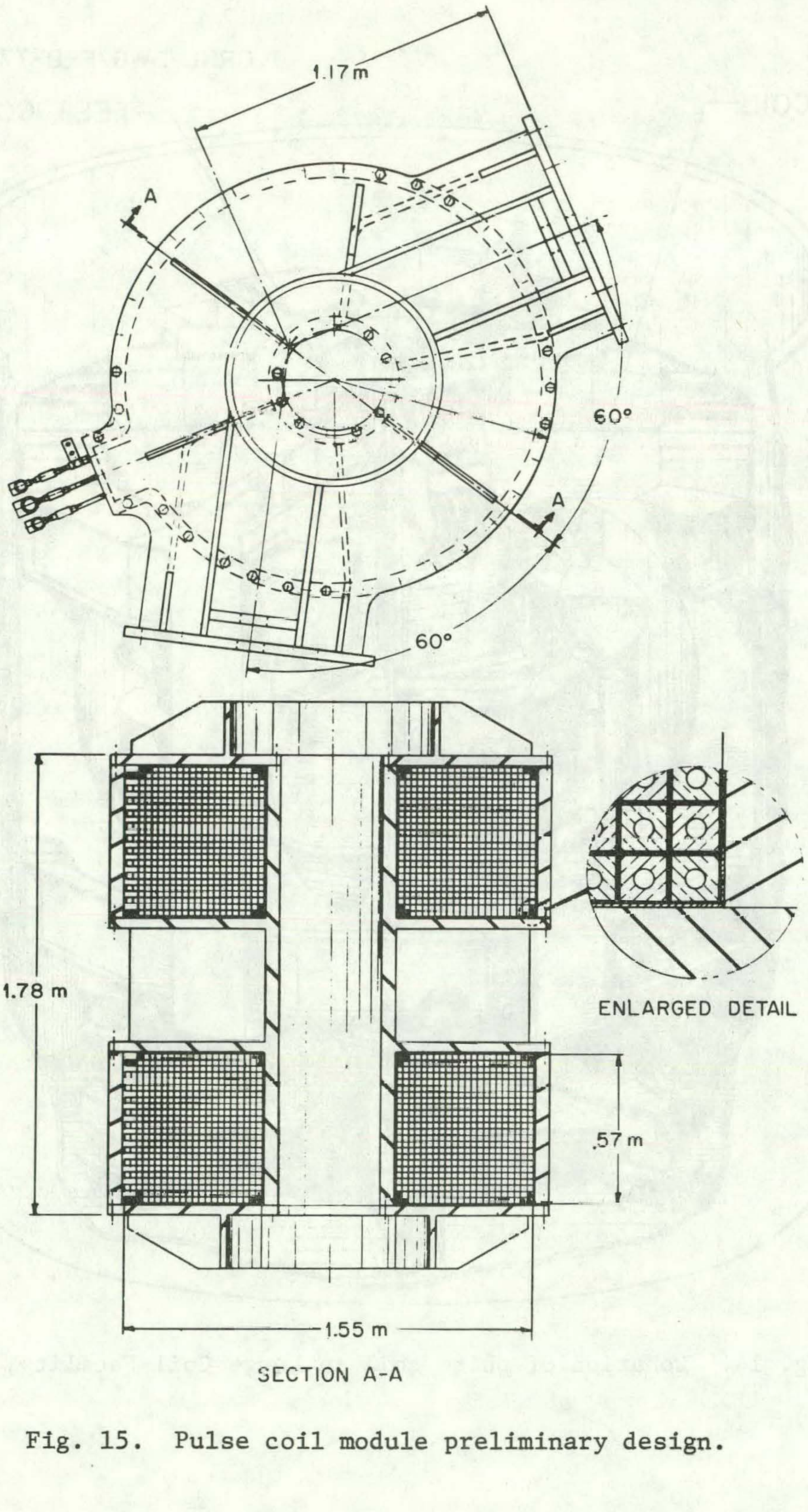

Fig. 15. Pulse coil module preliminary design.

ORNL/TM-6197
Dist. Category UC-20 b

INTERNAL DISTRIBUTION

1. J. K. Ballou
2. W. Becraft
3. M. Bender
4. L. A. Berry
5. R. L. Brown
6. E. H. Bryant
7. P. B. Burn
8. J. D. Callen
9. D. D. Cannon
10. R. A. Dandl
11. L. Dresner
12. W. A. Fietz
13. W. M. Fletcher
14. J. S. Goddard
15. H. H. Haselton
16. P. N. Haubenreich
17. R. E. Hill
18. R. M. Hill
19. G. R. Jasny
20. R. P. Jernigan
21. T. C. Jernigan
22. G. G. Kelley
23. J. P. Kois
24. P. S. Litherland
25. J. W. Lue
26. J. N. Luton
27. T. L. Mann
28. W. E. Manrod
29. J. R. May
30. H. C. McCurdy
31. J. R. McGuffey
32. J. R. Miller
33. O. B. Morgan
34. J. R. Moore
35. D. R. Norris
36. L. W. Nelms
37-46. B. E. Nelson
47. Y-K. M. Peng
48. M. Roberts
49. M. W. Rosenthal
50. T. L. Ryan
51. R. E. Schwall
52. J. L. Scott
53. T. E. Shannon
54. J. Sheffield
55. S. S. Shen
56. R. E. Stamps
57. R. C. Stewart
58. D. Steiner
59. W. C. T. Stoddart
60. P. B. Thompson
61. P. L. Walstrom
62. E. R. Wells
63. H. T. Yeh
64. ORNL Patent Office
65-66. Central Research Library
67. Document Reference Section
68-69. Laboratory Records Department
70. Laboratory Records, ORNL-RC
71. Fusion Energy Division Communications Center
72. Fusion Energy Division Library

EXTERNAL DISTRIBUTION

73. D. S. Beard, OFE, DOE, Washington, DC 20545
74. F. E. Coffman, OFE, DOE, Washington, DC 20545
75. R. W. Conn, Department of Nuclear Engineering, University of Wisconsin, Madison, WI 53706
76. J. J. Ferrante, General Electric Co., Schenectady, NY 12345
77. J. File, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08540
78. Harold K. Forsen, Vice President, General Manager, Laser Enrichment Department, Exxon Nuclear Company, Inc., 777-106th Ave., NE, C-00777, Bellevue, WA 98009
79. Harold P. Furth, Co-Head Experimental Division, Plasma Physics Laboratory, Princeton University, P.O. Box 451, Princeton, NJ 08540

80. Roy W. Gould, California Institute of Technology, Mail Stop 116-81, Pasadena, CA 91125
81. D. S. Hackley, General Dynamics, Convair Division, P.O. Box 80847, San Diego, CA 92138
82. C. D. Henning, Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550
83. Robert L. Hirsch, Exxon Research and Engineering Co., P.O. Box 101, Florham Park, NJ 07932
84. Ray Huse, Chairman, EPRI Fusion Program Committee, Public Service Electric and Gas Co., 80 Park Place, Newark, NJ 07101
85. Robert B. Jacobs, 1942 Broadway, Suite 207, Boulder, CO 80302
86. J. O. Neff, OFE, DOE, Washington, DC 20545
87. David J. Rose, Department of Nuclear Engineering, Room 24-210, Massachusetts Institute of Technology, Cambridge, MA 02139
88. Susan S. Waddle, DOE-ORO, Oak Ridge, TN 37830
89. J. L. Young, Westinghouse Electric Corp., P.O. Box 10864, Pittsburgh, PA 15236
90. E. J. Ziurys, OFE, DOE, Washington, DC 20545
91. Director, Research and Technical Support Division, DOE-ORO, Oak Ridge, TN 37830

92-242. Given distribution as shown in TID-4500, Magnetic Fusion Energy (Distribution Category UC-20 b, Magnetic Systems)