Title
MAGNETIC FIELD EFFECTS ON HUMANS: EPIDEMIOLOGICAL STUDY DESIGN PART II

Author
Colonias, J.S.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Physics, Computer Science & Mathematics Division

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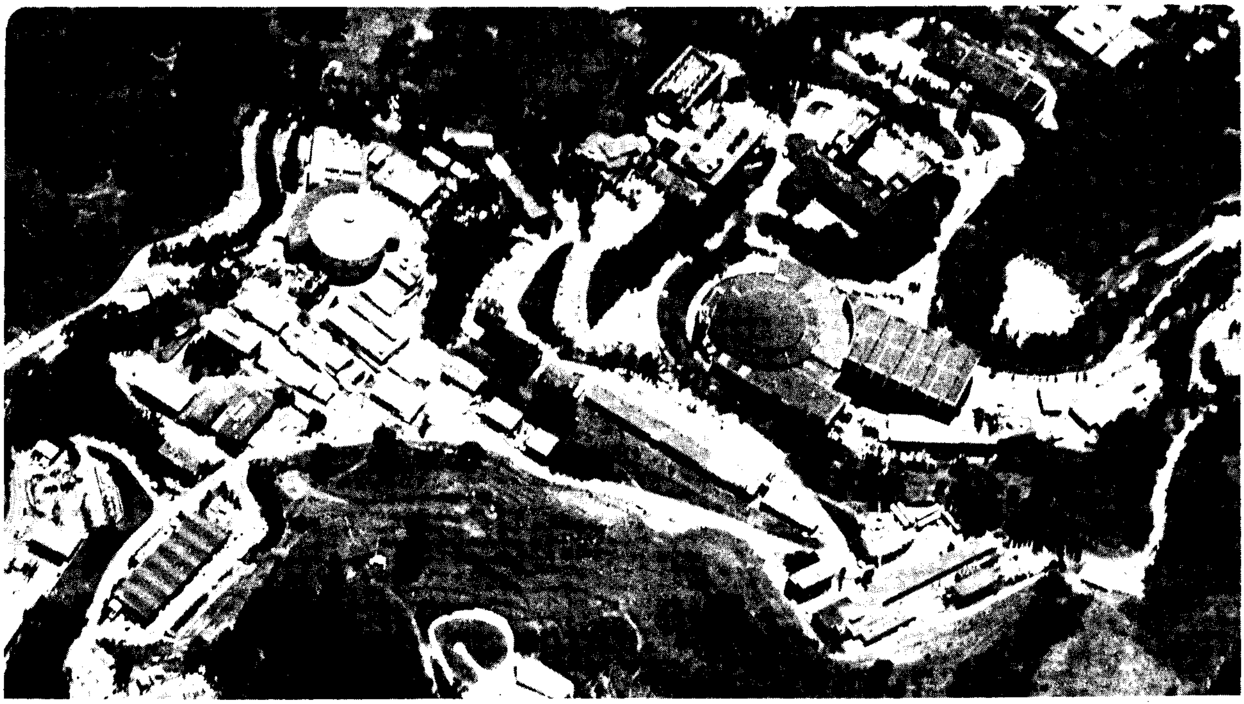

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MAGNETIC FIELD EFFECTS ON HUMANS:
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John S. Colonias
Computer Science and Applied Mathematics
Lawrence Berkeley Laboratory
Berkeley, California

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Magnetic Field Effects on Humans:

Epidemiological Study Design

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John S. Colonias
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
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I. ABSTRACT

In a previous paper, (see LBL-8349) the authors described the overall details of a study, designed to investigate the epidemiological health effects, if any, resulting from occupational exposure produced by various nuclear instruments such as cyclotrons, bubble chambers, spectrometers, etc.

In this paper we describe the methodology involved in determining the magnetic field exposure to such instruments.

II. INTRODUCTION

Presently, the biological consequences of magnetic fields on humans has not been substantiated by any systematic experiments, even though the literature abounds with studies on biological effects, some of which can neither be reproduced or certified. However, the purpose, of this design study is not to ascertain the validity of the above, but rather to attempt to perform a statistical study designed to evaluate potential health effects in groups of scientists and industrial workers who have been occupationally exposed to high magnetic fields. An end-product of this study might be the establishment of limits of exposure for industrial workers which at the present time are set quite arbitrarily.

The specific purpose of this paper, however, is to outline the methodology that we used in assessing the fringe magnetic field for the various instruments analyzed and to show the degree of reliability of our magnetic field exposure estimates.

A block diagram showing the various stages of this study is shown in Fig. 1. The part outlined in this report is enclosed with dashed lines.

III. FACILITY CLASSIFICATION

In this study, we anticipate to correlate a population of approximately 1000 exposed subjects with 1000 matched controls. The size of this sample necessitates the cooperation of laboratories other than our own, and the classification of nuclear instruments, and apparatus as far as magnetic properties are concerned, in a fashion meaningful to this study. For this purpose we classified these instruments in two broad types:

a) DC Type (or very slow time varying)

- I. Circular accelerators
- II. Bubble Chambers
- III. Magnetic spectrometers
- IV. Magnets, (conventional or superconducting)

b) Pulsed Fields (sharp rise, short duration)

Magnetic fields of this type are encountered in fusion experimental facilities. Many of these facilities rely on strong magnetic fields to contain high temperature plasmas, with little or no-iron shield. For example in tokamak type

fusion devices it is not unusual for the toroidal field to be in excess of 20 kG with a high fringing field value at distances up to 500 meters.

Fields of this type have been coded for possible future use, and are mentioned here only for the purpose of completeness of this report.

IV. ANALYSIS AND EVALUATION OF MAGNETIC FIELDS

The variety of nuclear instruments listed in Table I, the large number of subjects to be included in the study, as well as, geographical distances that separate each cite, necessitated the careful classification of all nuclear instruments, as far as magnetic field properties are concerned, into categories, so that a comprehensive program of magnetic exposure history could be obtained.

Specifically, we concentrated our efforts in the following tasks:

A. Classification of instruments according to similarity of magnetic field behavior

B. Locating magnetic measurements of existing installations (if such measurements have been made and are available)

C. Measuring magnetic fields (with magnetometers), for those installations that exist, but measurements were not available.

D. Simulating mathematically, those instruments which have been retired from service or for those that measurements are not available.

The above items will be discussed in detail in the following paragraphs.

A. Classification of Nuclear Instruments

Table I, presents a preliminary attempt to classify some of the nuclear instruments (investigated as of now), into categories, so that an assessment could be made of the magnitude of the effort required to obtain the necessary data for the study. Figure 2 shows the geographical location of these instruments.

Many of these facilities have been visited by members of this study group, so that first hand information could be obtained regarding operational characteristics of these instruments, and to gather information relating to their operation, shut down times, existence of magnetic field measurements etc.

B. Existing Magnetic Measurements

In some instances, magnetic field measurements at large distances from the center of the machines were available and in such cases these measurements were used exclusively, and no attempt was made to reproduce them. An example of such measured magnetic field is shown in Fig. 3 which displays the measured field in the vicinity of the 7 ft. Bubble Chamber located at Brookhaven National Laboratory. Based on such information we were able to estimate magnetic field exposures, for subjects whose daily duties bring them in the vicinity of these machines.

Members of this group have been eager in locating such measurements, particularly for instruments that are no longer in operation.

C. Measurements Made on Existing Machines

In cases where measured data were difficult to locate members of the study group visited the installation under consideration and measured the remanent magnetic field at various distances from the center of the machine.

For purposes of illustration, Fig. 4 shows such a measured magnetic field map corresponding to the 184" fixed frequency cyclotron located at Lawrence Berkeley Laboratory, while Fig. 5 shows a similar map at the MPS facility at the Brookhaven National Laboratory.

Similar maps have been prepared for those facilities which are listed in Table I and are still in operation.

D. Simulation of Remanent Magnetic Field

In those cases where the nuclear instrument did no longer exist or measurements were not available, we computed the remanent magnetic field by simulating the magnet geometry mathematically.

There are some excellent computer programs that do this job and, in our case we used a computer program called TRIM , which transformes a Poisson type equation (Eq. 1)

$$\nabla \cdot \left(\frac{1}{\mu} \nabla \cdot \vec{A}\right) = 4\pi \vec{J} \qquad \text{Eq. 1}$$

where μ = permeability of material

$\vec{A}$ = vector potential

$\vec{J}$ = Current density

to its finite difference approximation equivalent (Eq.2). The resulting equations are solved by some overrelaxation scheme.

$$\sum_{i=1}^{6} w_i(A_i - A) + 4\pi J = 0 \qquad \text{Eq. 2}$$

w = weights associated with grid points

A = vector potential

The procedure for such simulation involves the following steps.

1. A triangular non-uniform grid is used, on which the magnetic geometry is outlined. This grid may have up to 10,000 points.

2. Once this grid has been prepared, program TRIM uses that grid to compute the magnetic field at any location inside this grid space. The maximum dimensions of the grid space must be sufficiently large to insure that the appropriate boundary conditions imposed (that is $\vec{A} = 0$ on the boundary) are valid.

One has to exercise caution in interpreting the results produced by such simulation, since the results are a two dimensional approximation of the real situation. This means that in the Cartesian coordinate space, the magnet geometry is assumed to be infinitely long in the z- direction (see Fig. 6) and we are only computing the magnetic field in a two-dimensional cross-sectional cut.

In the cylindrical coordinate system we assume that the magnet under consideration is that which would be obtained if the geometry was rotated around the z-axis (see Fig. 7)

The magnetic field is obtained from the curl of the vector potential (Eq. 3).

$$\vec{B} = \nabla X \vec{A} \qquad \text{Eq. 3}$$

Since $\vec{A}$ has only one non-zero component in two dimensions, the components of B in the Cartesian coordinate system are:

$$B_x = \frac{\partial A}{\partial y} \qquad \text{Eq. 4}$$

$$B_y = - \frac{\partial A}{\partial x} \qquad \text{Eq. 5}$$

Similarly in the case of axial symmetry

$$B_z = \frac{1}{r} \frac{\partial (rA)}{\partial z} \qquad \text{Eq. 6}$$

$$B_r = - \frac{1}{r} \frac{\partial (rA)}{\partial r} \qquad \text{Eq. 7}$$

1. Illustrative example

Perhaps, the best way of illustrating the procedure involved in this type of simulation is through an example:

Consider the 90" Cyclotron magnet shown in Fig 8. This fixed frequency cyclotron was built around 1954 at Lawrence Livermore Laboratory to accelerate protons, deuterons and tritons, through a wide range of energies obtained by tuning the frequency and increasing the magnetic field from 2000 to 9000 gauss.

The simulation of this magnet following the outline discussed above produced the mesh shown in Fig. 9 and the resulting flux distribution shown in Fig. 10, while a plot of the computed magnetic field as a function of distance away from the center of the magnet is shown in Fig. 11. Such simulations produce accurate results, however, these results must be carefully interpreted since as it was mentioned earlier they represent a two dimensional approximation of a three dimensional field.

V Evaluation of Results

The methodology described above has been sufficient to provide us with magnetic field exposure estimates of a high degree of confidence. There are, however, cases where such simulations are neither possible nor do they produce reliable results. For example the 184" Cyclotron magnet at Berkeley, a sketch of which is shown in Fig. 12, requires azimuthal as well as Cartesian symmetry in order to be simulated mathematically. That is, while the pole face of the magnet is cylindrical the return yoke is rectangular.

For such magnets, we use a cylindrical version of program TRIM and we adjust the return yoke area to produce an area equal to that in cylindrical geometry (See Fig. 13). This artifice is very successful, if one is interested in results confined in the vicinity of the magnet pole face, however, for results outside the magnet, which are of importance in this study, the results are erroneous because the return yoke was adjusted for cylindrical symmetry, which means that the return yoke surrounds the magnet. If we assume that the magnet has Cartesian symmetry, the results are worst, since then the magnet is assumed to be infinitely long in the z direction (as shown in Fig. 6).

In the case of the 184" cyclotron magnet and at radial distances greater than 40 ft. on the gap midplane, the magnet looks like a point magnetic dipole of strength M and a magnitude of:

$$H = M/r^3$$

where r = distance from the point to the dipole and M is estimated by:

M = (NI)(area)

Similar observations can be made for other magnets for which no measurements are available or simulations are difficult to perform.

Some of the old type bubble chamber magnets posses this dual symmetry and care should be exercised in interpreting simulation results. Bubble chamber magnets operate at very high magnetic fields with very large gaps, and human beings do enter the fringe fields of these magnets periodically for such purposes as film changing, surveillance and maintenance. Therefore such magnets are the best candidates for a biomagnetic study.

VI. Conclusions

Even though this study has not been completed and the results not published, the effort that relates to the estimation of the magnetic field exposure has been completed and some general comments are in order:

1. From the beginning, we have been plagued by the lack of reliable magnetic field data.

2. Much of the old nuclear apparatus has been retired from service and the difficulty of un-earthing data has been enormous.

3. Much of the new nuclear apparatus has been designed with the expressed concern of lack of understanding of biomagnetic effects of fringe fields on humans, however, no pertinent instrumentation has been or is being designed to aid future experimenters in evaluating potential hazards of such fields.

It would, therefore, be appropriate to begin thinking seriously, the type of instrumentation needed so that their implementation would aid future researchers in securing reliable data for various studies.

It would be very easy to install "recording magnetometers" at strategic places in various nuclear installations to monitor magnetic field levels, or perhaps a pocket magnetic "dosimeter" might not be a far fetched idea as it could have been a few years ago.

Even though there is no indication that exposure to magnetic fields is a potential health hazard, the fact thatfuture societies will depend more and more for their energy needs on devices that make use of magnetic fields, is enough indication to accelerate our efforts to design the appropriate tools to facilitate our understanding of their effects.

BIBLIOGRAPHY

1. T.F. Budinger et all, Magnetic Field Effects on Humans: Epidemiological Study Design -- LBL-8319

2. J.S. Colonias, Particle Accelerator Design - Computer Programs, Academic Press - 1974

3. J.S. Colonias, Calculation of Magnetic Fields for Engineering Devices-- International Joint MMM-Intermag. Conf., June 1976, LBL-4805

4. B.H. Smith, A 90-inch Cyclotron with an Adjustable-Energy External Beam, June 1954 (UCRL-2620)

5. A.C. Paul, J.S. Colonias, Magnetic Field Calculations for the 184" Synchrocylotron, February 1970, UCRL-18882

TABLE I

NUCLEAR INSTRUMENT CLASSIFICATION

CHART

INSTRUMENT	LOCATION	TYPE	Magnet GAP (Average) inches	Central Field kG	Measurements Available
FERMI	Fermi Lab	AGS		9.0	
COSMOTRON	BNL	P.S	8.6	13.8	Yes
AGS	BNL	P.S	2.2	13	Yes
ZGS	ANL	P.S	5.75	12.7	
Bevatron	LBL	P.S.	11.8	15.5	Yes
184" Cyclotron	LBL	F.M.	14	23.3	Yes
90" Cyclotron	LLL	F.F.	12.0	9	No
88" Cyclotron	LBL	F.F.	9.645	17.0	Yes
86" Cyclotron	Oak Ridge	F.F.	17.5	9	Yes
60" Cyclotron	ANL	F.F.	11.87	16.35	No
60" Cyclotron	BNL	F.F.	12.5	14.6	No
76" Cyclotron	Davis	F.F.	17.7	17.7	Yes
42" Cyclotron	LASL	F.M.	4.2-5.25	18-6kG	
83" Cyclotron	Univ. of Mich.	C.W.	11.25	15	
76" Cyclotron	ORNL	C.W.	Variable	12-22	
50" Cyclotron	Univ. of Mich.	F.F.	5.75	15	
43" Cyclotron	Univ. of Ill.	F.F.	6.25	17	
95" Cyclotron	Harvard	F.M.	11.7	19.0	
64" Cyclotron	Michigan St. U.	F.F.	6.6	18.0	
<u>Bubble Chambers</u>					
15 ft	Fermi Lab			30	
12 ft	ANL			18	
7 ft	BNL			28.5	
80"	BNL			17	
72"	SLAC			16	
40"	SLAC			26	
31"	BNL				
30"	BNL				No
25"	LBL				No
20"	BNL				No
15"	SLAC				No

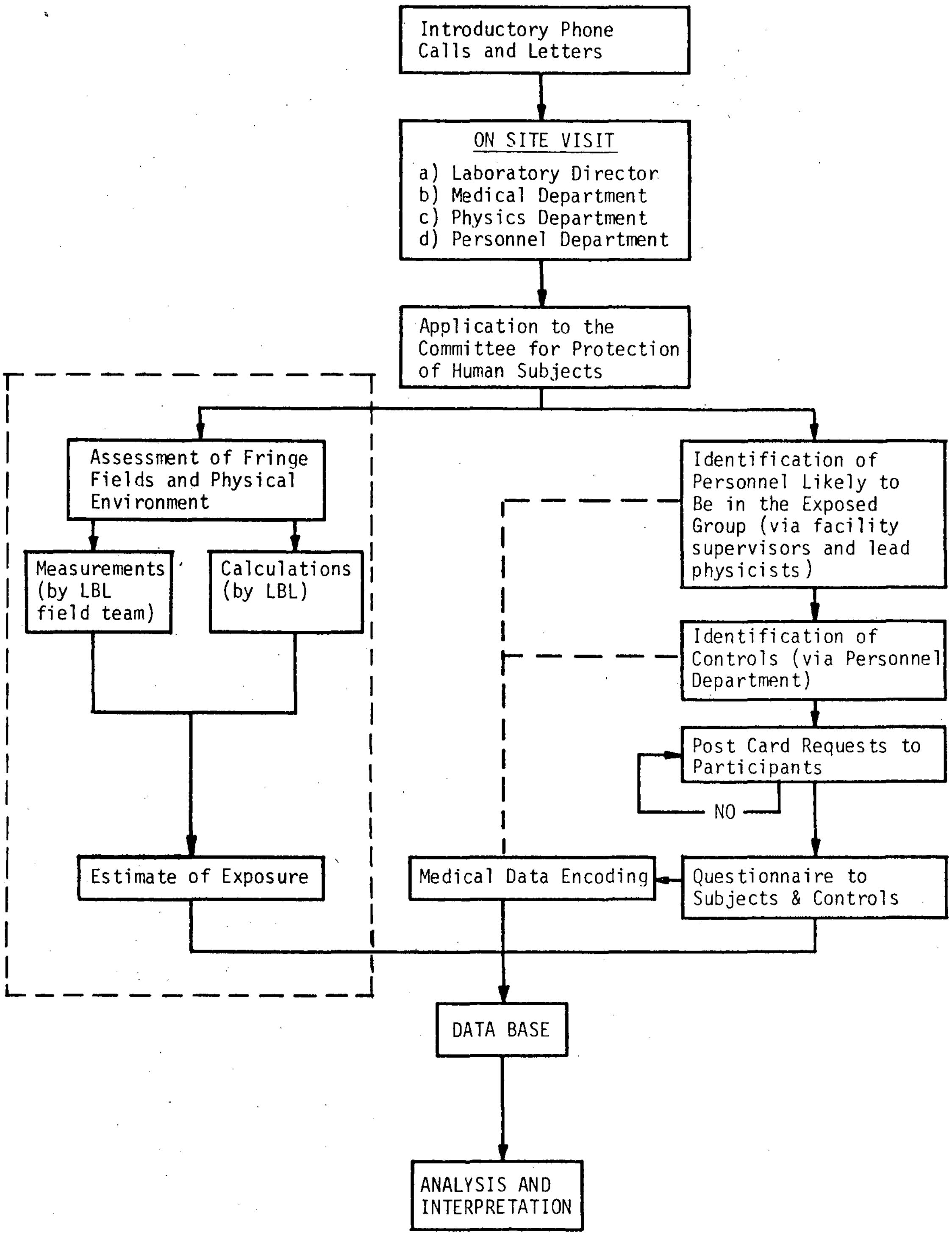

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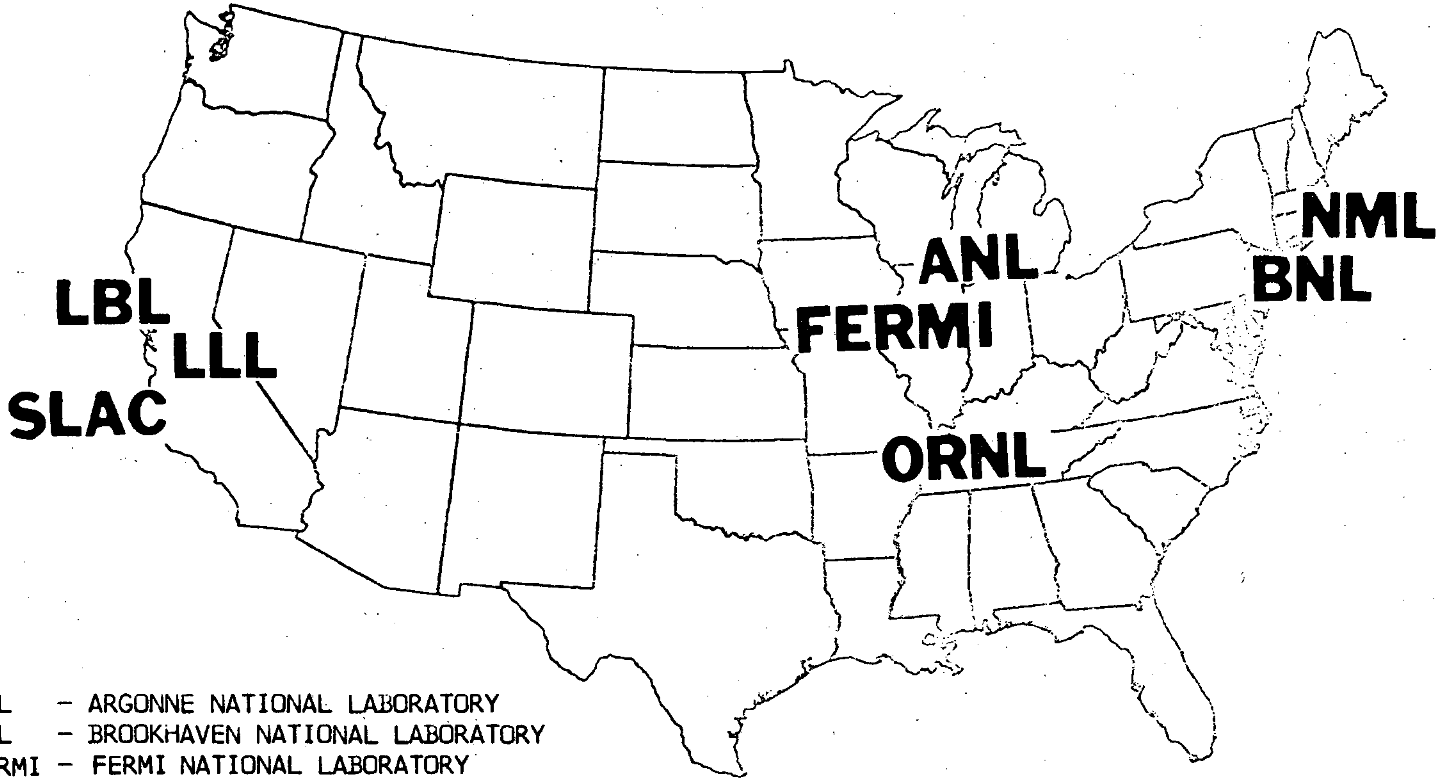
Fig. 1. Block diagram showing the various stages of this study. Blocks surrounded by dotted lines are outlined in this paper.



ANL - ARGONNE NATIONAL LABORATORY
BNL - BROOKHAVEN NATIONAL LABORATORY
FERMI - FERMI NATIONAL LABORATORY
LBL - LAWRENCE BERKELEY LABORATORY
LLL - LAWRENCE LIVERMORE LABORATORY
NML - NATIONAL MAGNET LABORATORY
ORNL - OAK RIDGE NATIONAL LABORATORY
SLAC - STANFORD LINEAR ACCELERATOR CENTER

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Fig. 2. Map showing geographical location of laboratories participating in this study.

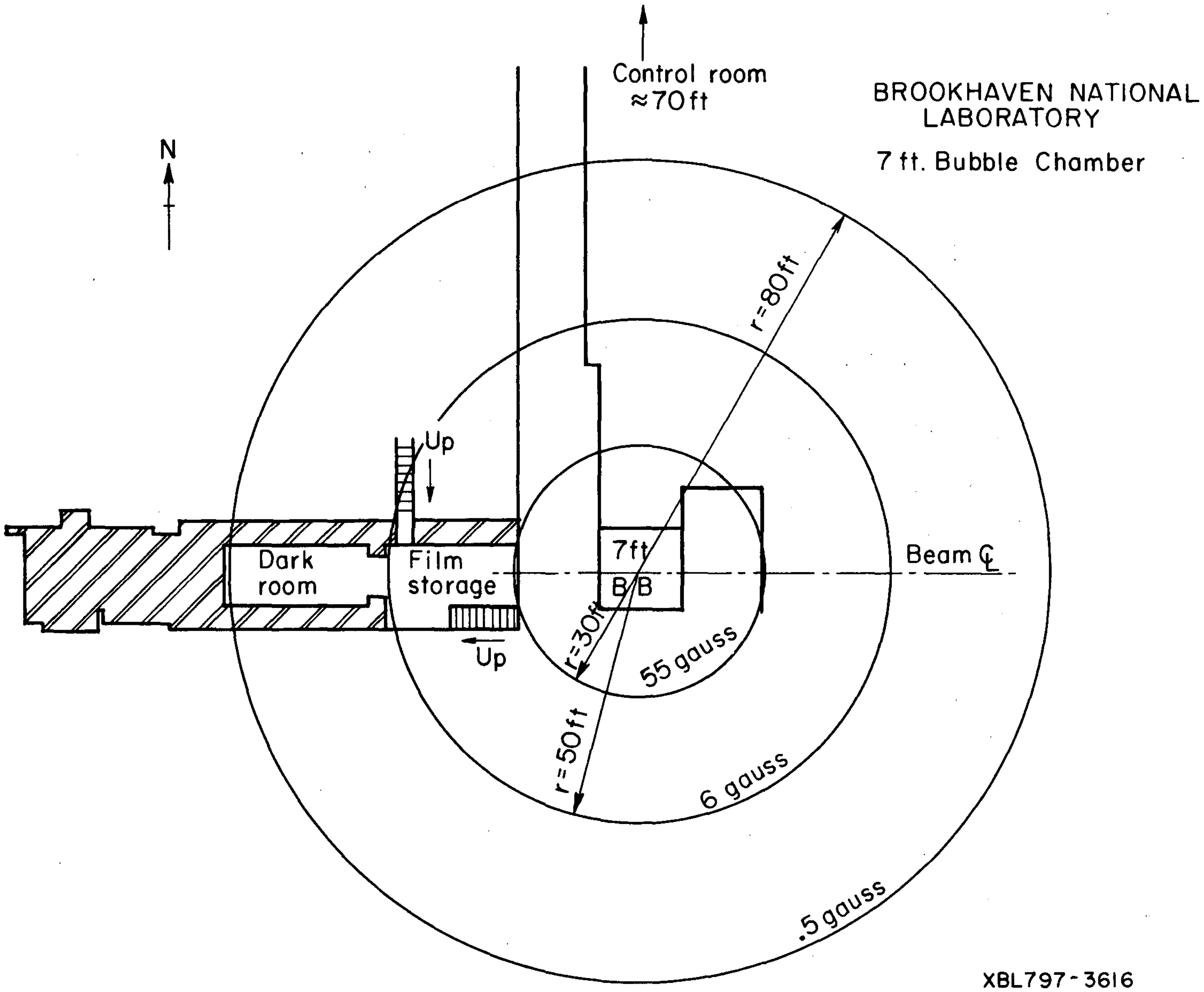

Fig. 3. Magnetic field map of the 7ft.
bubble chamber magnet at Brookhaven National Laboratory.

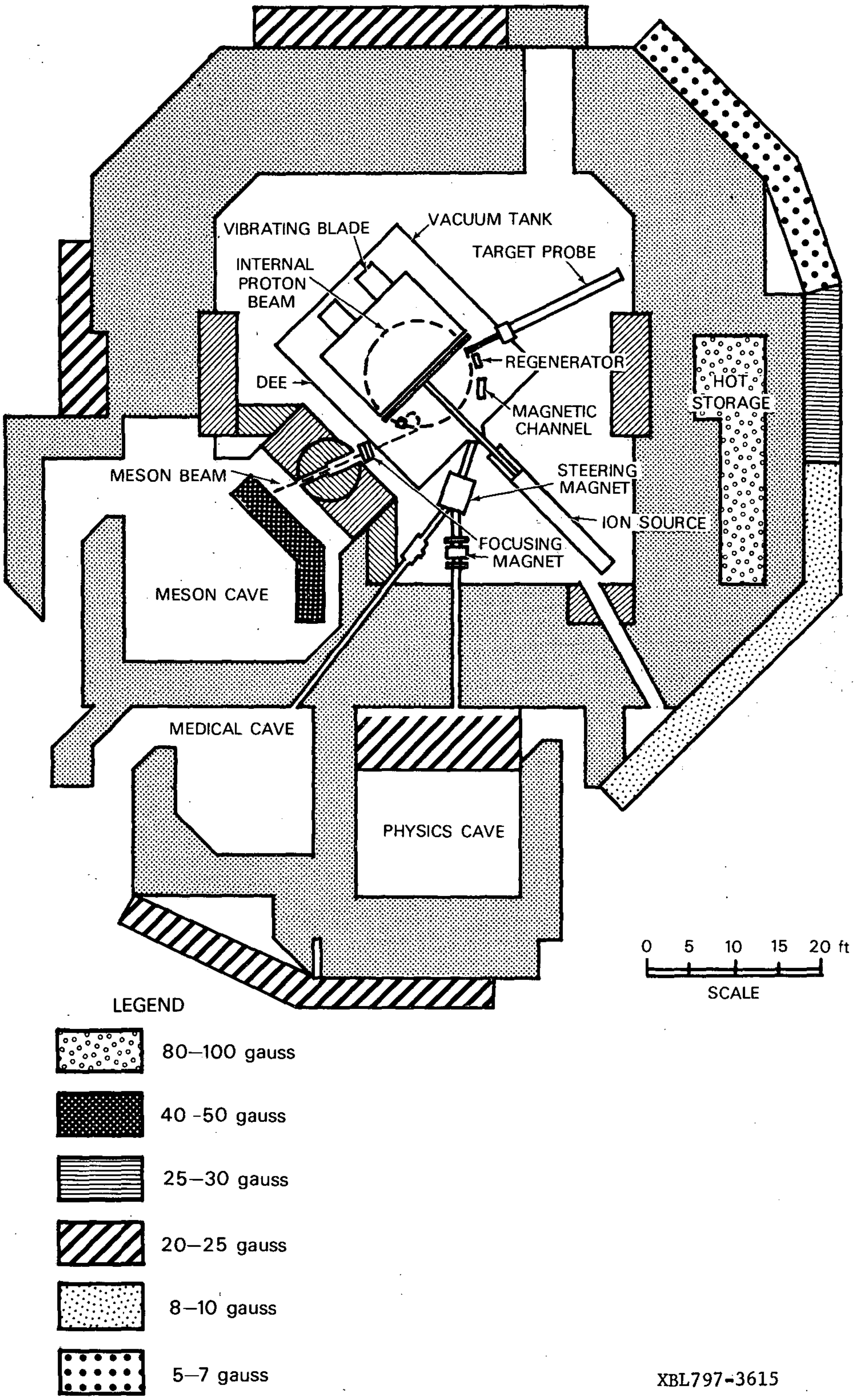

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Fig. 4. Sketch of the 184" Synchrocyclotron at LBL showing measured magnetic fields.

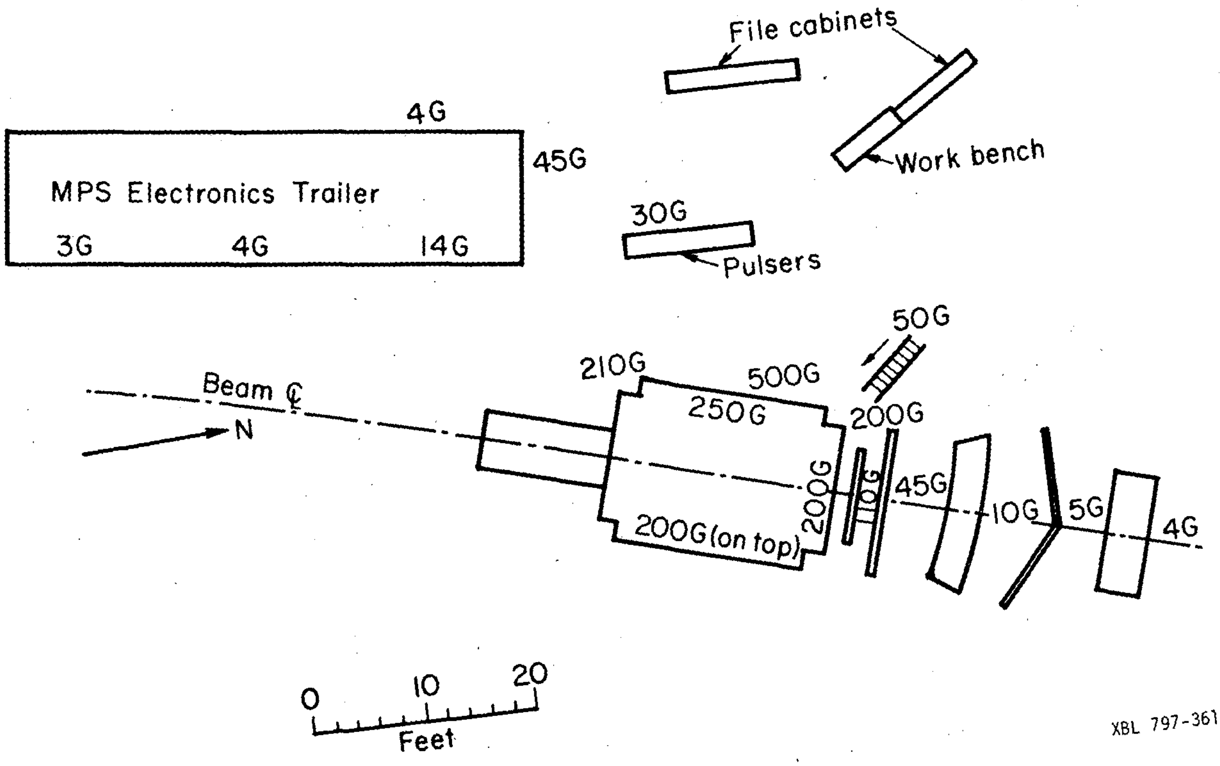

Fig. 5. Magnetic Field measurements at the MPS facility at Brookhaven National Laboratory.

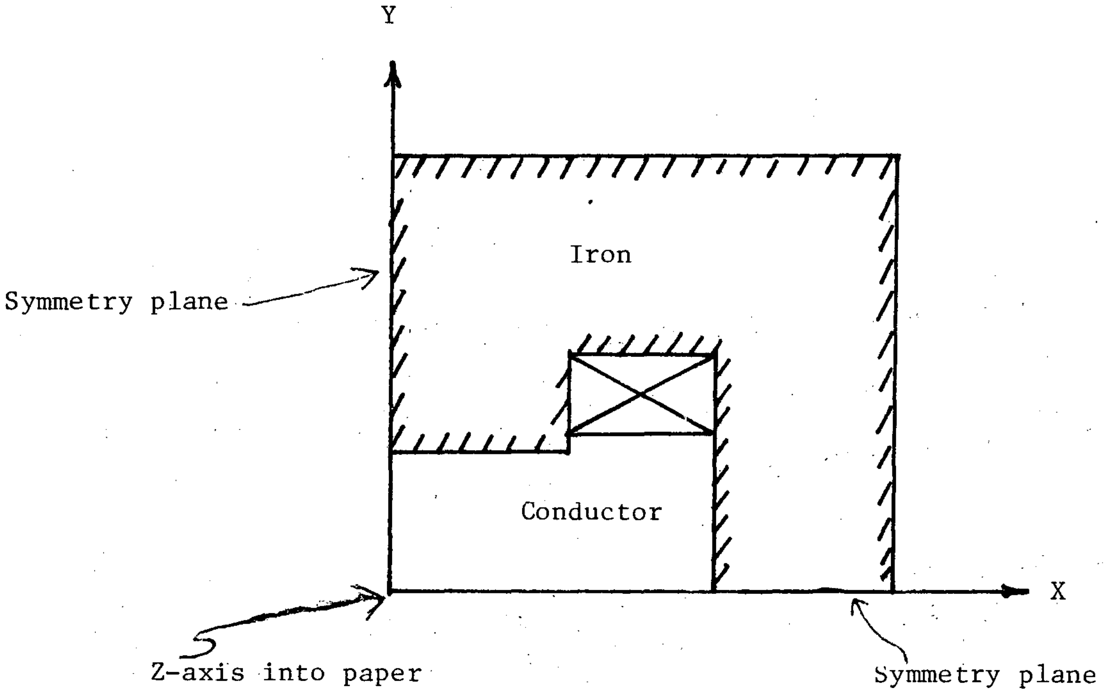

Fig. 6 Cartesian coordinate system

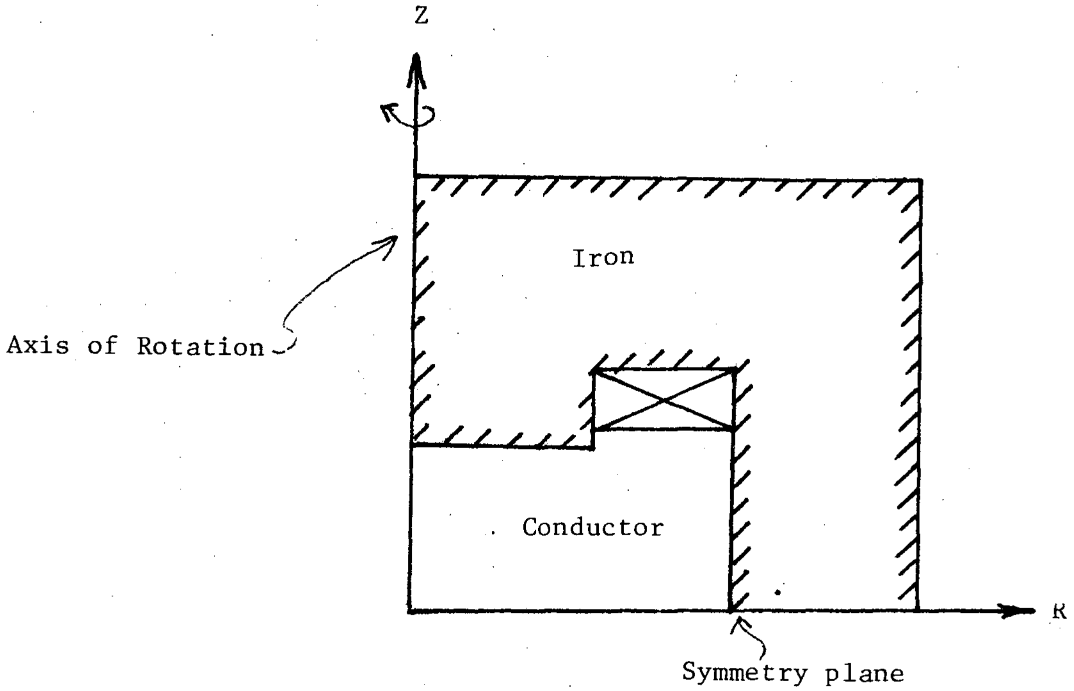

Fig. 7 Axial or Cylindrical Coordinate System

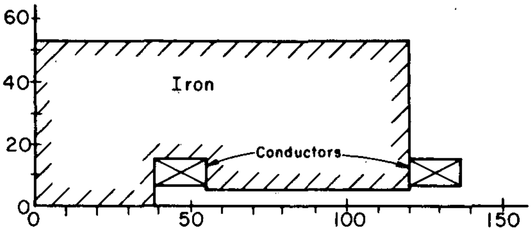

Fig. 8. Sketch of 90-inch cyclotron magnet (dimensions in inches).

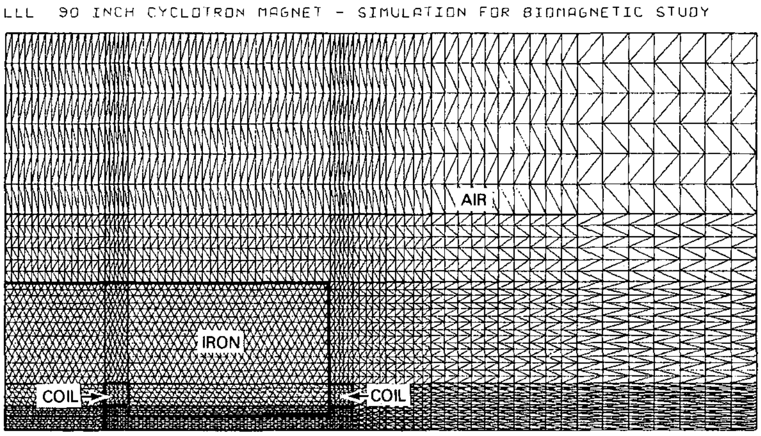

Fig. 9. Triangular mesh for the 90-inch cyclotron magnet

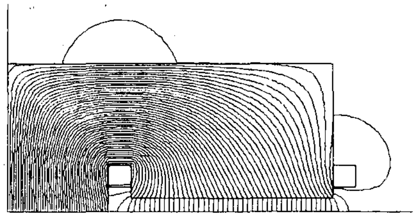

Fig. 10. Computer generated Plux distribution for the 90-inch cyclotron magnet

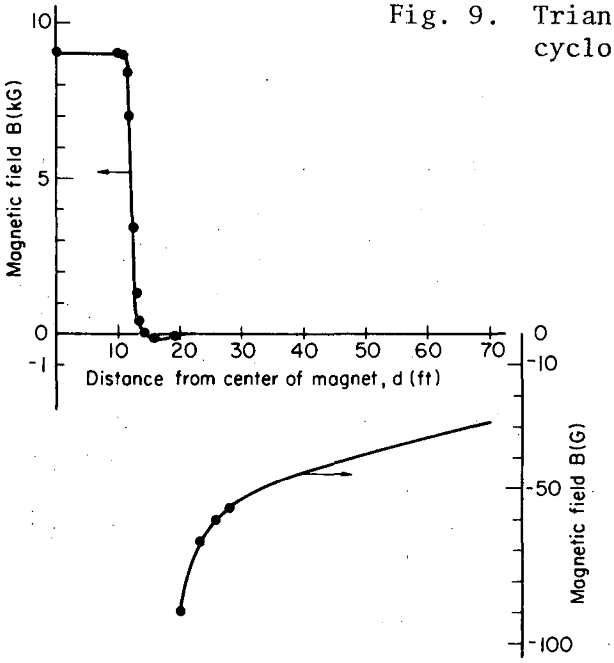

Fig. 11. Plot showing distribution of magnetic field on a function of distance.

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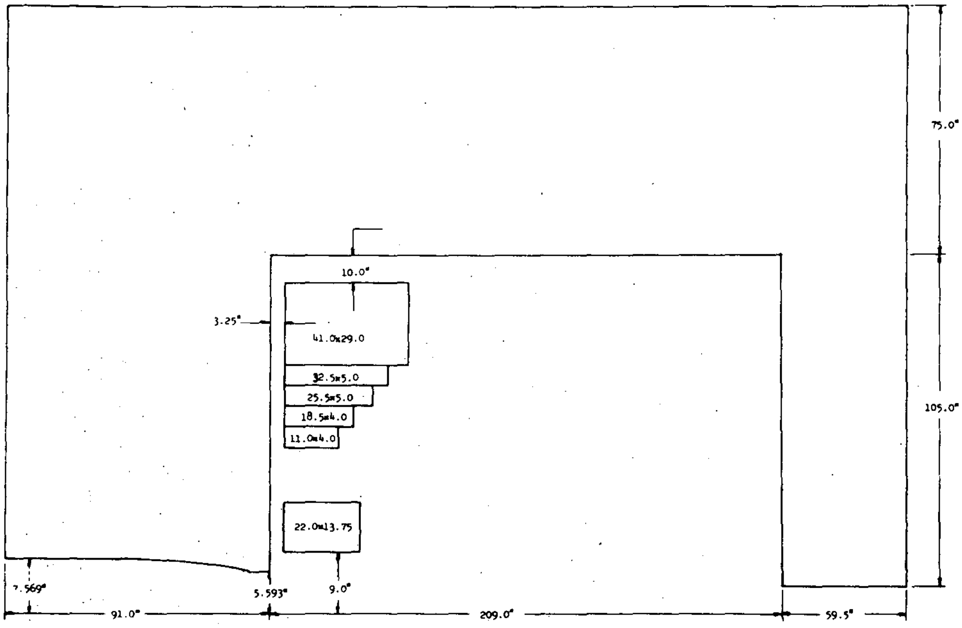

Fig. 12. The 184-inch cyclotron magnet.

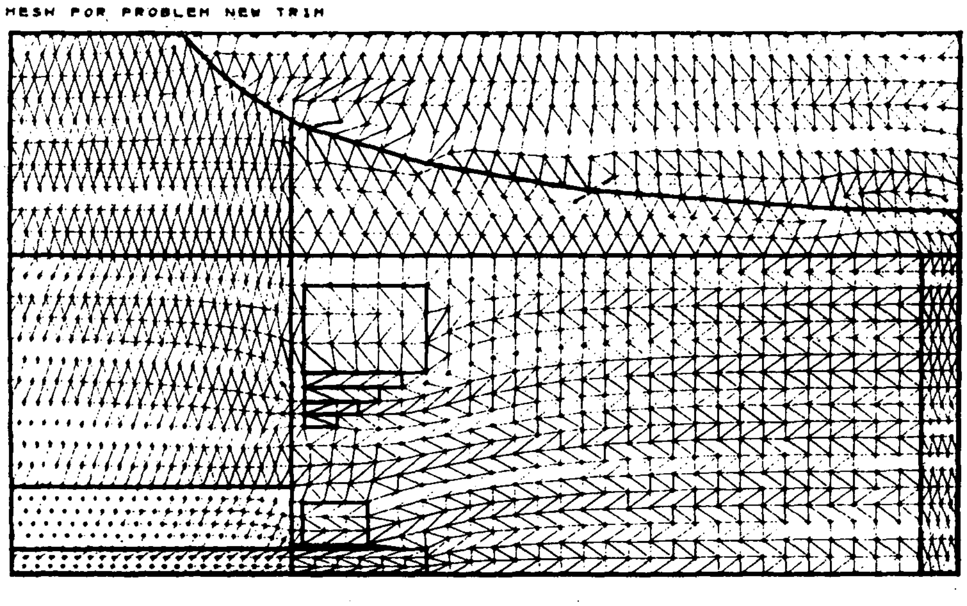

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Fig. 13. Triangular mesh generated by TRIM, for the 184" Cyclotron magnet with adjustment for cylindrical symmetry.

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720