GEM TN-91-19

SSC GEM Magnetic Field Safety & Health Effects

R. P. Woolley
GEM Safety Coordinator
Experimental Facilities
Physics Research
SSCL

September 22, 1991

Abstract:

This report focuses upon the safety concerns associated with the fringe magnetic field, generated by the unshielded GEM Detector design. The report's purpose is to present the GEM Collaboration and SSC Directoral management with the regulatory requirements, and background information on human and equipment fringe field effects. Safety issues associated with the effects of the magnetic field upon personnel and equipment will be discussed, with the applicable regulatory requirements noted. The intent then is for SSC management to determine the nature and extent of application of the appropriate safeguarding, in mitigating the risk.

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R.P. Woolley

GEM Safety Coordinator
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Superconducting Super Collider Lab

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TABLE of CONTENTS

1.0	INTRODUCTION AND SCOPE	1
2.0	DETECTOR OVERVIEW	2
3.0	PROBLEM STATEMENT	3
4.0	MAGNETIC FIELD EFFECTS	4-5
5.0	REGULATORY STANDARDS	6
6.0	SUMMARY/DISCUSSION	7-8
7.0	REFERENCES	9
Fig. 1	Magnetic Fringe Field	10
Fig. 2	Magnetic Field (lateral view)	11
Fig. 3-4	Facilities Fringe Field Comparisons	12-13
Tab. 1	Magnetic Field Exposure Limits	14
Tab. 2	Sensitivity of Equipment and Component	15
Figs.5-10	Magnetic 'B' Contour Plots	16-21

1.0 INTRODUCTION AND SCOPE

This report focuses upon the safety concerns associated with the fringe magnetic field, generated by the unshielded GEM Detector design. The report's purpose is to present the GEM Collaboration and SSC Directoral management with the regulatory requirements, and background information on human and equipment fringe field effects. Safety issues associated with the effects of the magnetic field upon personnel and equipment will be discussed, with the applicable regulatory requirements noted. The intent then is for SSC management to determine the nature and extent of application of the appropriate safeguarding, in mitigating the risk.

2.0 DETECTOR OVERVIEW

The GEM Collaboration is proposing a large solenoidal detector for lepton, photon, and muon measurement/detection. To accomplish this objective, the detector will have hermetic electromagnetic and hadronic calorimetry and central tracking in a magnetic field. This field is generated from the proposed detector magnet system, and consists of a 16.6-meter bore and a 8,300 gauss single-coil (unshielded) superconducting solenoid oriented concentric to the beam axis. The coil has iron poles at both ends but no flux return (coils or iron) in the barrel region. Steel poles cover each end of the solenoid. Reductions in cost and manufacturing time result from elimination of the outer shield winding, however this produces a large external fringe field.

3.0 PROBLEM STATEMENT

Preliminary safety studies of the effect of the detector's external static magnetic field have been made. The personnel at risk from GEM's fringe magnetic field are those associated with implanted cardiac pacemakers, blood disorders (ex: sickle-cell anemia), or (at higher flux densities) implanted ferromagnetic medical devices, e.g., suture staples, aneurism clips, prostheses, etc.[2] These restrictions point toward prohibiting access of these personnel to surface buildings and surrounding areas, within the 5-10 gauss field boundary. Based upon recent human exposure data, limited potential exists for personnel health effects.

Indications are that there is a definite potential for interference with the normal electro-mechanical operation of 'magnetically sensitive' equipment, within the hall and on the surface. The high (8,300 gauss) magnetic field, generated at the muon and central tracking areas during conductor tests, is an uncommon safety and environmental risk caused by the large unshielded superconducting solenoid.

Significant stray fields will occur due to the absence of controlled flux return paths. Maps of this field are shown in Figures 1 & 2.[1] Based upon this data, shielding or design modifications will need to be applied to nullify any operational-interference effects upon hall and surface components. The fringe field level in the 'counting room' area of the Operations Center represents the worst-case stray dc field of ~ 25 gauss, with a transient time constant of 0.17 gauss/second (higher during 70 sec. quench) during a magnet discharge.[1] A < 40 gauss field would be present in the Operations Center, having a single-level basement.

Sensitive control and data processing equipment may require shielding or removal from the field, in order to nullify the adverse effects of magnetic flux densities > 5 gauss.

Existing regulatory magnetic field limits have incorporated a safety factor. It is management's decision to define a magnetic field exposure limit and the methodology of attaining compliance.

4.0 MAGNETIC FIELD EFFECTS

Field strength contour maps are shown in Figures 1 & 2. Recent U.S. epidemiological surveys have shown no significant health effects upon man associated with long term exposure to static magnetic fields. Available knowledge indicates the absence of any adverse health effects due to exposure to static magnetic fields up to 20,000 gauss[4]. One study inferred that the white blood cells of workers exposed to an average field of 76 gauss and a maximum of 146 gauss, were slightly changed (yet, still within the normal range). At a U.S. accelerator laboratory 792 employees worked in fields of 50 gauss for long durations and up to 20,000 gauss for periods of several hours. No significant change in 19 disease categories was found between the exposed and control groups[4]. The preliminary indication from limited experimental data is that short-term exposure to static fields > 50,000 gauss may produce significant adverse health effects, such as a ~7% reduction in aortic blood flow velocity[4].

A survey is required to verify that all equipment or components in the detector, underground hall and some surface buildings, are suitably shielded or designed to avoid the operationally disruptive influence of the field (See Table 2). Techniques for accomplishing this have been successfully applied in other high field unshielded magnet facilities[1]. Equipment and components that could cause injury or major detector damage, if field influenced, must be protected. The magnetic field affects dc motors (their armatures, commutators, and brushes) and other magnetically-coupled devices. The dc magnetic field strength is ~ 1,000 (R) and 2,000 (Z) gauss immediately external to the operating detector's support structure[3]. Comparisons of existing unshielded magnet facilities to GEM, are presented in Figs. 3-4. Fringe field strength decreases with the cube of the distance from the source. Field strength contours of constant 'B' are illustrated in Figures 5-10,[6] where 'Z' is the beam axis and 'R' is the vertical axis.

At a level of ≥ 100 gauss ferrous tools may begin to be transported[4]. This indictates that an interlock system should power-down the magnet prior to personnel access of the underground hall, and patrols of the hall wil be required to ensure that all personnel and loose magnetic materials are removed.

The U/G hall and surface operations building(s) (especially the Counting Room) will require that their magnetically-sensitive safety systems, components and instrumentation (ex: fire detection, computers, monitors, software, etc.) have iron shielding or field shaping coils. The shielding, to attenuate the fringe 'B' (magnetic) field to 5-10 gauss, is currently being reviewed as to thickness, magnetic saturation, permeability, and cost. Shielding to a ≤ 10 gauss level meets the current regulatory pacemaker requirement. Fences and barriers with pacemaker-warning signs could be located just beyond the 10 gauss (OSHA) field line, and inside and outside of any buildings within this field to notify and warn personnel. A site survey should be done and general access restricted during the first full-field operation.

The FAA currently has no regulations for static magnetic fields. Of primary concern is the field's influence upon aircraft that would penetrate the above-ground magnetic field 'bubble'. The FAA indicated that a significantly stronger and higher (than GEM's) elevation field, would be required before being considered a potential air-traffic hazard[7]. The FAA suggested that after the field is surveyed and measured, SSC should inform them of the field strength/gradient characteristics in order for FAA to decide upon navigational map inclusion.

Additional areas of concern are electromagnetic interference and compatibility with transmission and communication systems within the field of influence. Also, SSC Management should anticipate the public's reaction to knowledge of this field.

Static magnetic fields are not within the jurisdiction of the Federal Communications Commission (FCC), the Environmental Protection Agency (EPA), and the Texas Department of Health, Radiation Control (TDHRC).

5.0 REGULATORY STANDARDS

Following are currently accepted magnetic fields exposure guidelines, based upon the best available data from several official sources[4,9] :

Maximum Exposure: Workers must never be exposed to fields > 20,000 Gauss, regardless of the duration of the exposure or the body part exposed.

Fields > 5,000 G: If the peak exposure is > 5,000 G, workers should be exposed to a daily maximum average field strength of ≤ 600 G (measured at the torso) or 6,000 G (measured at the extremities).

Fields < 5,000 G: If the peak field to which workers are exposed is < 5,000 G, personnel may be exposed to a week-long maximum average field strength of ≤ 600 G (measured at the torso) or 6,000 G (measured at the extremities)[2].

Medical Restrictions: Personnel with medical electronic implants (such as artificial cardiac pacemakers) and metallic prosthetic implants cannot be exposed to fields > 10 G.* Personnel with sickle-cell anemia or similar hemoglobin-related conditions (but not carriers) cannot be exposed to fields > 500 G.

* The 10 G level is from the American Conference of Governmental Industrial Hygienists (ACGIH), a standards-setting group recognized by OSHA.

Agencies involved with the regulation or standard-setting of magnetic field radiation include:

- Department of Energy (DOE)
- Occupational Safety & Health Administration (OSHA)
- Food and Drug Administration- Center for Devices and Radiological Health (FDA)
- Environmental Protection Agency (EPA)
- Federal Aeronautics Administration (FAA)
- National Institute of Safety & Health (NIOSH)
- Texas Department of Health, Radiation Control (TDHRC)
- Amer. Conf. of Gov't. Ind. Hygienists (ACGIH)
- Electric Power Research Institute (EPRI)
- World Health Organization (WHO) - EHC 69

Table 1 provides a summary of all applicable regulatory agency's magnetic field exposure limits.

6.0 SUMMARY/DISCUSSION

The FDA's field exposure limit of 5 gauss only applies to cardiac pacemaker manufacturers, while the FNAL[8], ACGIH and OSHA have determined that their pacemaker safety limit is 10 gauss. This is certainly several orders of magnitude below the level at which health may begin to be affected. Some data acquisition systems (computers, monitors, software) are influenced at the 5-10 gauss level, so consideration should be given to shielding or relocation. Additional consideration must be given to aircraft instrumentation affectation. The initial indication from two sources is that magnetically-sensitive instrumentation CAN be disrupted at ≥ ~5 gauss, however, no pertinent regulation currently exists.

The FDA regulation requires controlled access to all areas with > 5 gauss. New-design pacemakers can be affected at 15-17 gauss[5]. The FDA was cautious and incorporated a large safety factor, due to the liability aspect and questionable confidence levels on input from pacemaker manufacturers. For SSC and consortium personnel, a questionnaire on body metal content and a written legal warning should effectively screen those affected from controlled access areas.

The unshielded single-coil magnet is significantly less expensive than either the two-coil or iron-shielded systems. If surface shielding is considered, the Final Supplemental Environmental Impact Statement (FSEIS) won't allow SSC to pave a large (hectares) area with steel plate, without reopening the environmental impact assessment process. For access protection of the field perimeter, fencing or even hedges with proper warning signs is acceptable.

No applicable magnetic field data was contained within the following sources:

- TRNLC/URA Contract - DEAR 970.5704-2
- SEIS for SSC-Main Report, 12/90
- FCC - OST Bulletin #65, 10/85
- Texas Regulations for Control of Radiation-Part 35, 9/88
- PPPL - Practices and Procedures RF and Microwave, Sec.4, 1/82
- SSC ES&H Manual
- FNAL Radiation Guide
- Various SSC Radiation TaskForce Reports,1/86-11/88
- LBL Safety Manual
- TU Electric - Safety Policy
- Microwave News-Report on Non-Ionizing Radiation-89-91.

The preliminary indication from the FAA is that SSCL would need to notify them, when the actual field size and strength is measured, to allow the FAA to determine if flight navigation maps require revision. A draft is being prepared that would advise them of our GEM intentions.

Operational experience from several unshielded dc magnet systems indicates that an effective personnel safety protocol can be established[1]. These safe-operation facilities include bubble chambers, magnetic fusion confinement devices, and many MRI[10] hospital installations:

- HFTF at LLNL
- MFTF at LLNL
- FENIX at LLNL
- LCT (ISMTF) at ORNL
- 15-ft. Bubble Chamber[11]/CCM at FNAL
- ALCATOR C-MOD at MIT Francis Bitter Magnet Laboratory
- MRI Solenoid at the MIT F.B.M.L.

Please refer to Figures 3 & 4 for simple quantitative comparisons between GEM and these existing facilities. Although the extent of GEM's 10 gauss field is ~3.5x that of LLNL-MFTF, their safety considerations are the same. No new safety issues are represented by GEM's sizeable fringe field. A significant number of safe, successful years of operation have been logged, by existing unshielded magnet facilities, with no indication of accidents or injuries. The larger GEM fringe field will probably necessitate additional localized equipment shielding, to maintain operability.

7.0 REFERENCES

[1] *Shielding Scheme for the SSC SC Magnet Stray Field Environment*, Shen, Patrick, Heim, & Chaplin (7/91).

[2] *Threshold Limit Values for Chemical Substances and Physical Agents - 1990-1991*, ACGIH, ('90).

[3] *An Expression of Interest to Construct a Major SSC Detector*, SSC EOI-0020, Barish & Willis, (7/91).

[4] *Environmental Health Criteria 69 - Magnetic Fields*, UN, WHO, & IRPA, (1987).

[5] *DC Magnetic Field Limits*(memo), Jay Benesch, (8/14/91).

[6] *Magnetic Contours of Constant B*, Peter Marston, MIT, (8/16/91).

[7] *Private telcon with Dick Kirsch at FAA*, (8/14/91)

[8] *Fermilab ES&H Manual, Static Magnetic Fields* - 5062.2, (11/87).

[9] *LLNL Health & Safety Manual*, Supplement 26.12, "Working in Magnetic Fields," ('85)

[10] *Ferromagnetic Screening Around a Superconducting Magnetic Resonance Imager*, Health Physics Vol.51, No. 4 (Oct.'86), pp 545-550.

[11] *Magnetic Field Measurements Around Bubble Chambers*. Memo from L. Coulson dated 7-30-91.

FIELD ON THE SURFACE IR 1 _ IR 8

IR 1 : BEAM 46.9 m /surface

IR 8 : BEAM 48.1 m /surface

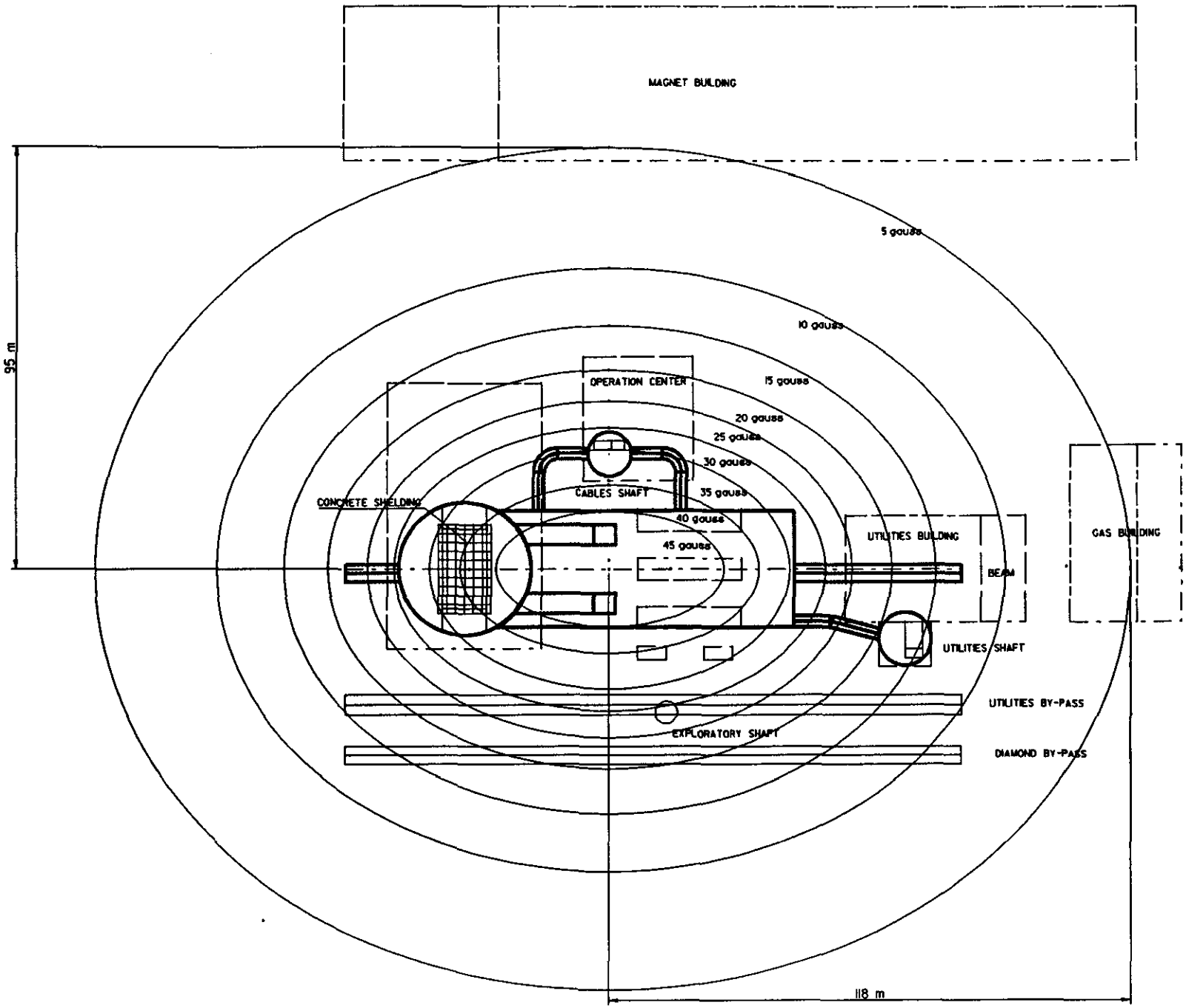


FIGURE 1

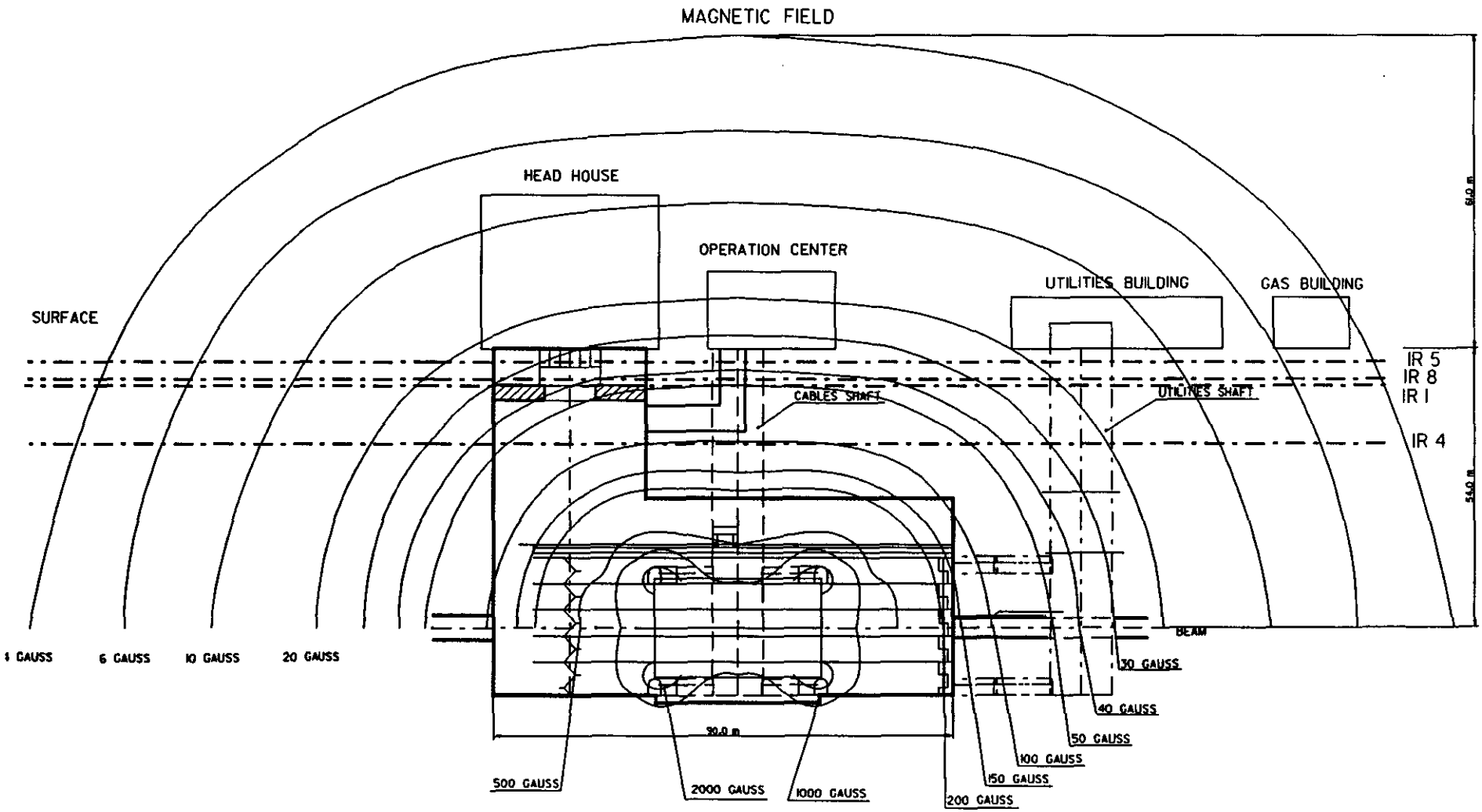

MAGNETIC FIELD
HEAD HOUSE
OPERATION CENTER
UTILITIES BUILDING
GAS BUILDING
SURFACE
IR 5
IR 8
IR I
IR 4
CABLES SHAFT
UTILITIES SHAFT
BEAM
1 GAUSS
6 GAUSS
10 GAUSS
20 GAUSS
30 GAUSS
40 GAUSS
50 GAUSS
100 GAUSS
150 GAUSS
200 GAUSS
500 GAUSS
2000 GAUSS
1000 GAUSS
90.0 m

FIGURE 2

FACILITIES FRINGE FIELDS COMPARISON

Date: September 23, 1991 - R. Woolley

	LAB FACILITY	Years In Operation	Magnet Strength	Altitude of 5 gauss Field	Magnet Elevation	Surface Area 10 gauss (pacemaker)	Surface Area 5 gauss (instrumentation sensitivity)	Health Effects Reported
1	SSC - GEM	New	0.8 T	71m	<47m>	~26,800m2	~43,000m2	n/a
2	LLNL - FENIX	~0.5	14.0 T	23m	<3 m>	4,976m2	6,464m2	none
3	LLNL - HFTF	~10	~11 T	16m	<2 m>	452m2	804m2	none
4	LLNL - MFTF	<1 week	~ 7 T	50m	~3.5 m	7,350m2	~13,000m2	none
5	15'BBL.CH-FNAL	15	~3.2 T	~40m	2 m	2,463m2	~5,000m2	one suture move
6	LCT - ORNL	2	8 T	n/a	3m	n/a	n/a	no verifiable
7	Tohoku/Chicago Sync.-FNAL	~20-25	~ 3.0 T ea.	?	?	?	?	?

FIGURE 3

SURFACE FIELD SIZE COMPARISON

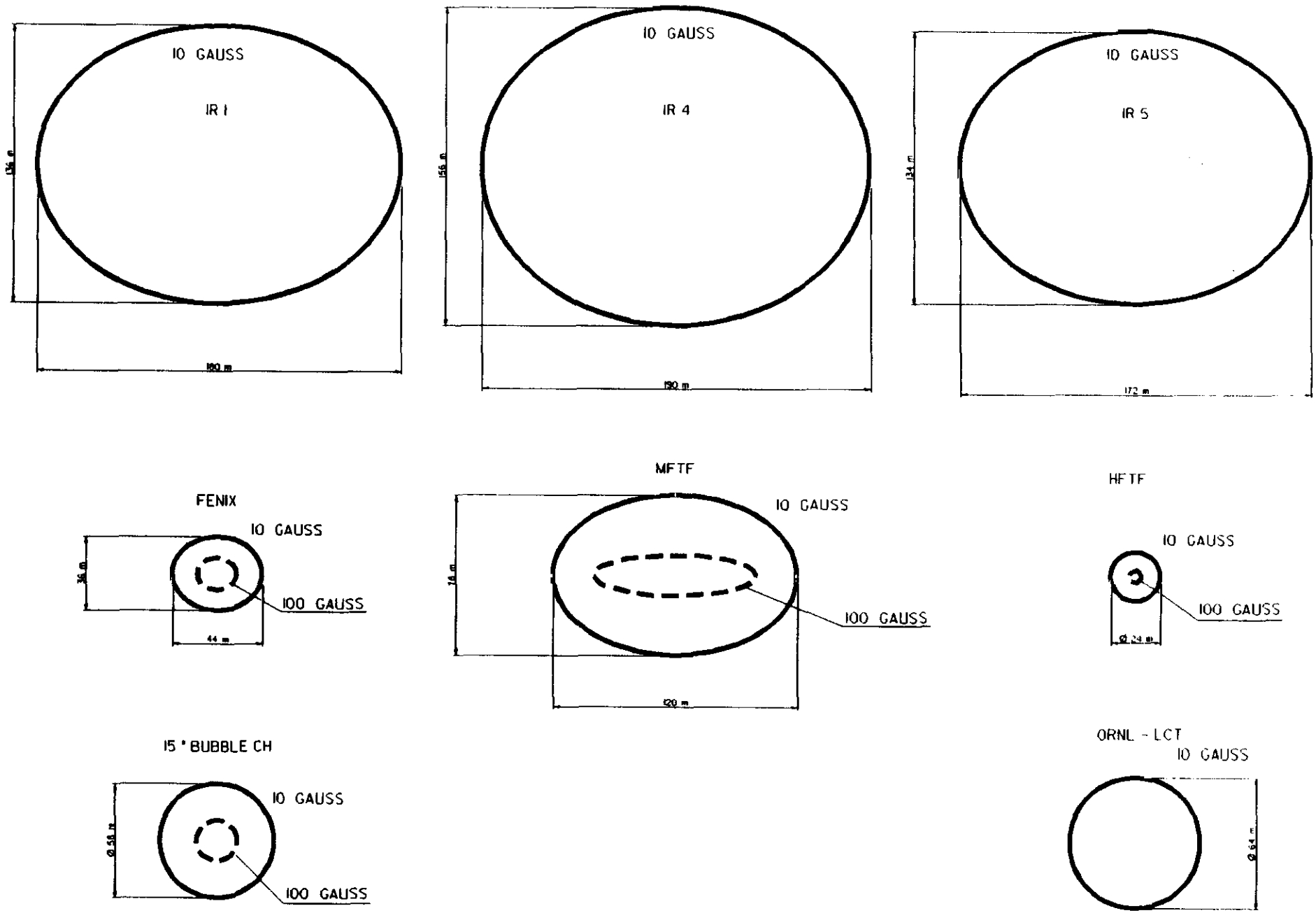


FIGURE 4

Table 1. Magnetic Field Exposure Limits[4]

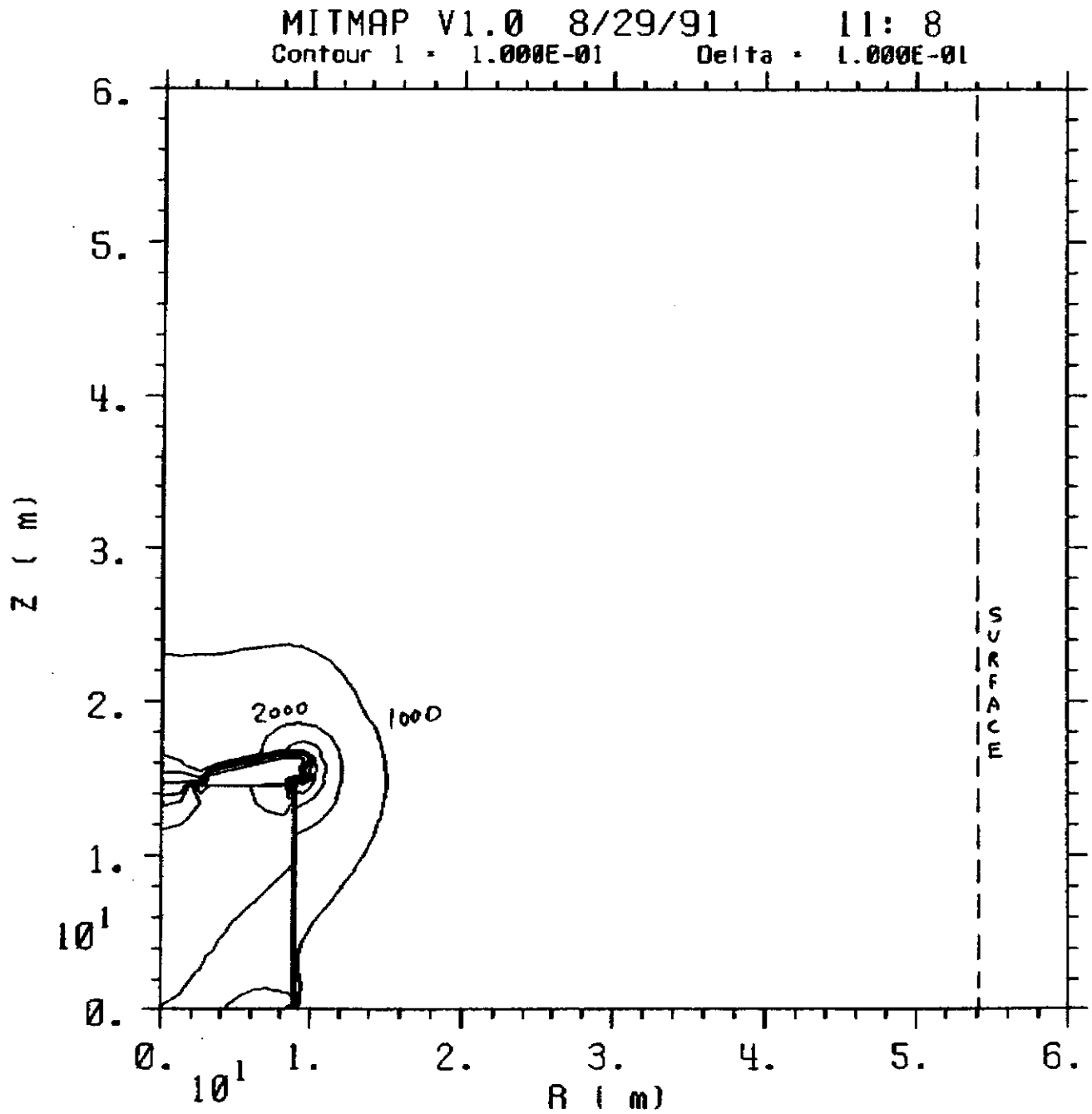
Agency	Field	Exposure Time	Body Region	Comments
SLAC (1970)	200 G	extended (h)	whole body	unofficial, occupational
	2,000 G	short (min.)	whole body	
	2,000 G	extended (h)	arms, hands	
	20,000 G	short (min.)	arms, hands	
USSR (1978)	100 G	8 hours	whole body	regulation issued by Ministry of Health
DOE (Alpen, 1979)	100 G	8 hours	whole body	recommended to DOE contractors
	1,000 G	<= 1 hour	whole body	
	5,000 G	<= 10 min.	whole body	
FDA (1980)	5 G	none	pacemaker	limit is dictated by pacemaker mnfr. only
CERN (NRPB, 1981)	2,000 G	minutes	whole body	recommended practice
	20,000 G	short	hands, arms, feet	
LLNL (1985)	600 G	day	torso	max. ave./day in peak field > 5 kG
	600 G	day	torso	max. ave./week in peak field < 5 kG
	6,000 G	day	extremities	max. ave./wk. (<5kG) max. ave./day (>5kG)
	20,000 G	short (min.)	whole body	peak exposure limit
ACGIH (1990)	10 G	none	pacemaker	current 15-17G limit of mech. interference
	600 G	8 hours	whole body	time-weighted average
	6,000 G	8 hours	extremities	time-weighted average
	20,000 G	ceiling limit	whole body	never exceed

Table 2. Sensitivity of Equipment and Component

	>5 G	>10 G	>100 G	>1000 G
Data Acquisition System				
Computer	x			
Monitors				
Black & white		x		
Color	x			
Instrumentation & Control				
Relay			x	
Solid-state device			x	
Magnetic solenoids, valves			x	
Safety device				x
Analog display			x	
Vacuum & Refrigerator				
Mechanical pump			x	
Turbo pump			x	
Electric motors			x	
Ferro-fluidic seals				x

x: shielding is needed

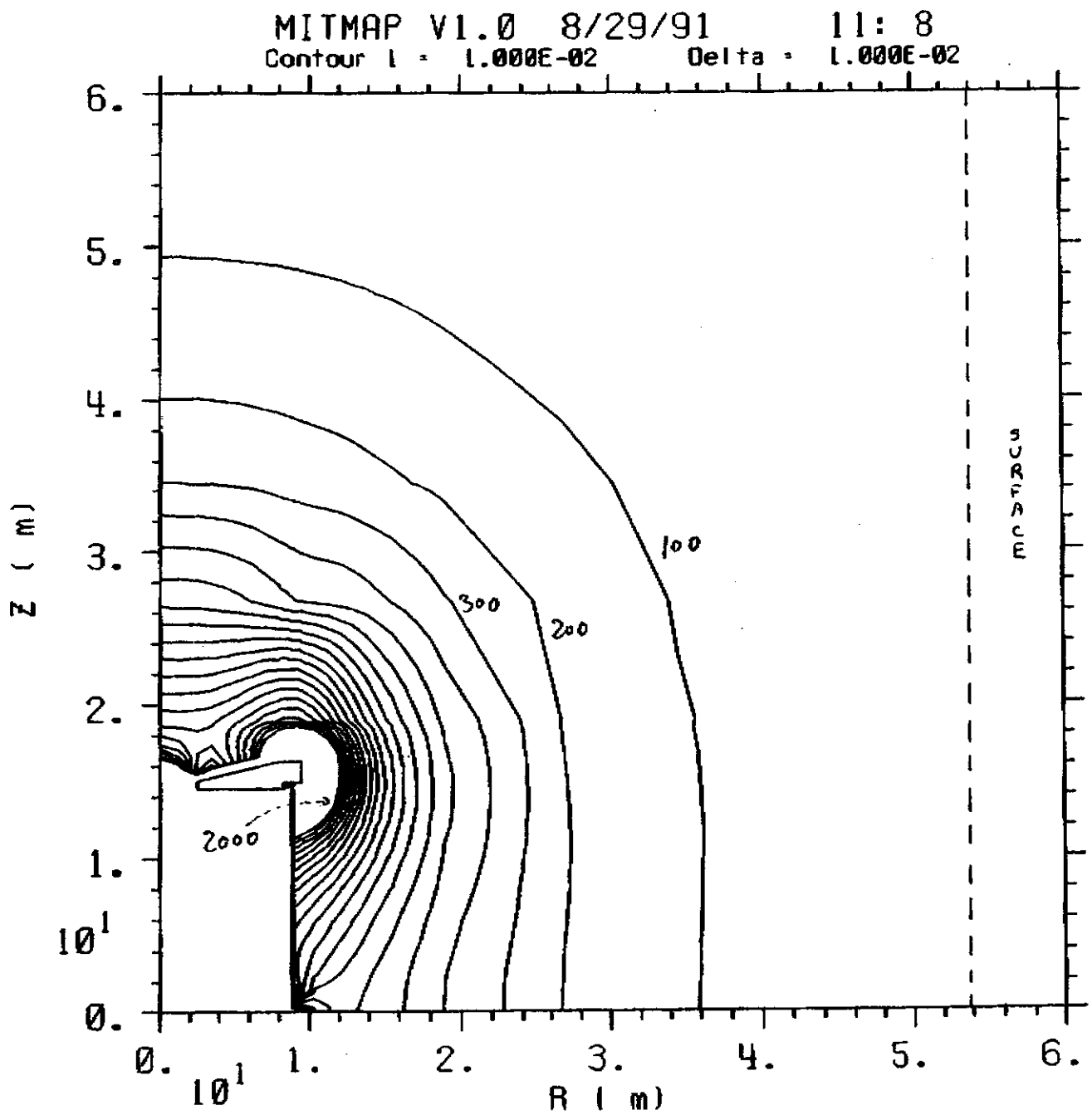
GEM 1 --- Baseline with Full Pole



CONTOURS OF CONSTANT B

FIGURE 5

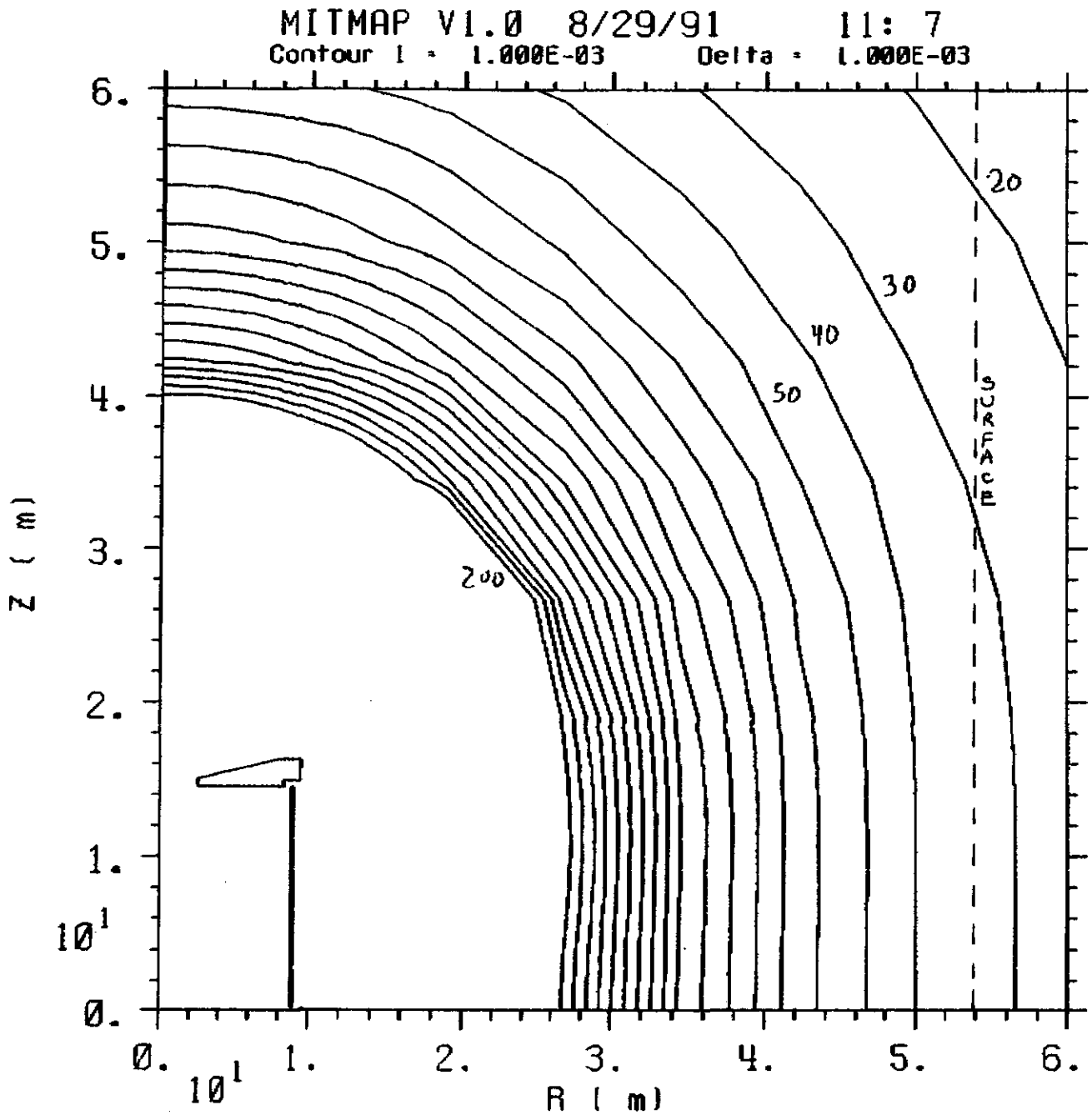
GEM 1 --- Baseline with Full Pole



CONTOURS OF CONSTANT B

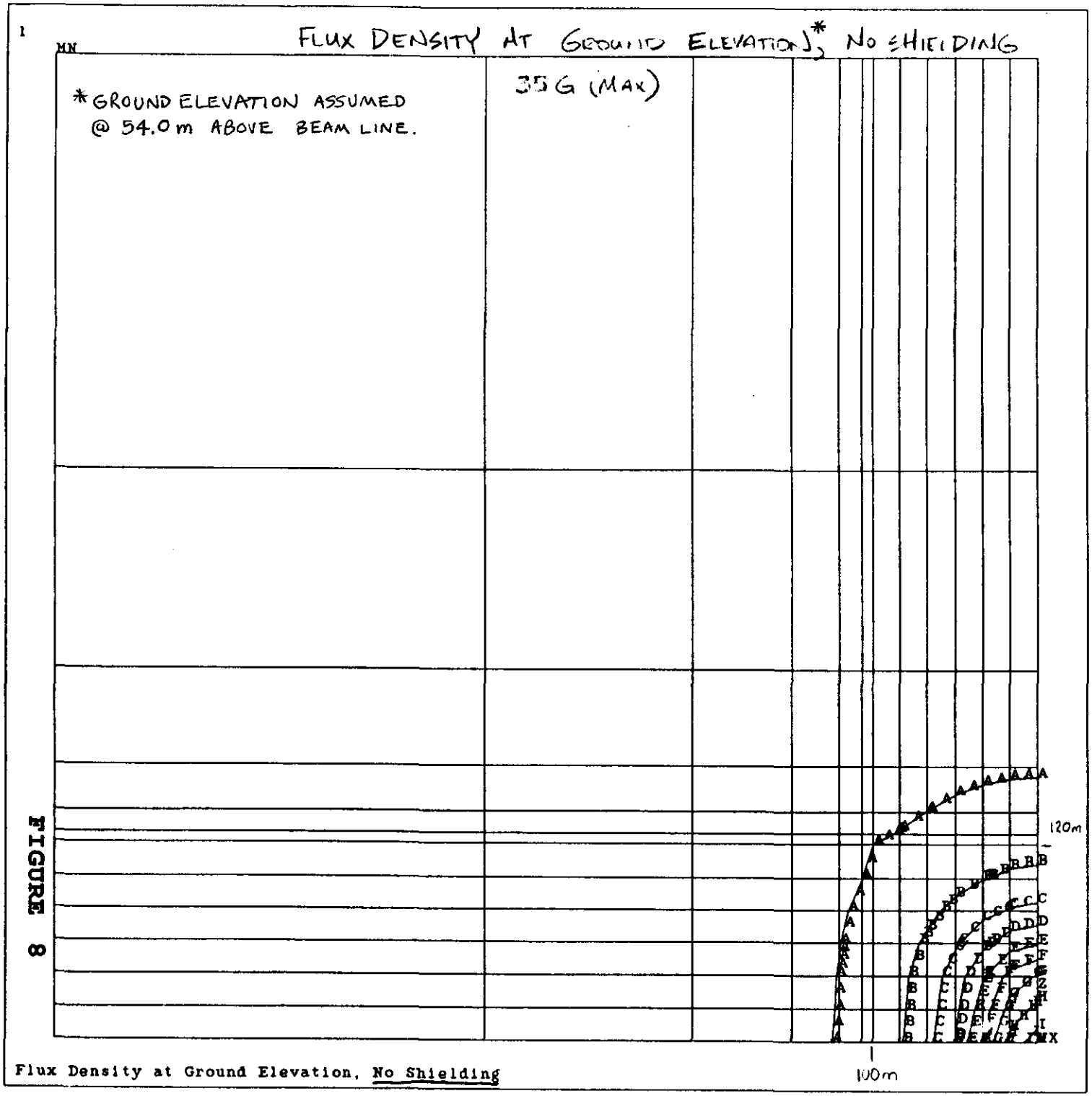
FIGURE 6

GEM 1 --- Baseline with Full Pole



CONTOURS OF CONSTANT B

FIGURE 7



ANSYS 4.4A
AUG 28 1991
14:30:37
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
BSUM (AVG)
SMN =0.300E-05
SMX =0.003976

YV =1
DIST=330
XF =300
ZF =300
VUP =Z
A =0.224E-03 [T]
B =0.665E-03
C =0.001107
D =0.001548
E =0.00199
F =0.002431
G =0.002873
H =0.003314
I =0.003755

PROPOSED PIT SIZE.
200m WIDE
×
240m LONG
×
THK
(TO BE DETERMINED)

FIGURE 8

Flux Density at Ground Elevation, No Shielding

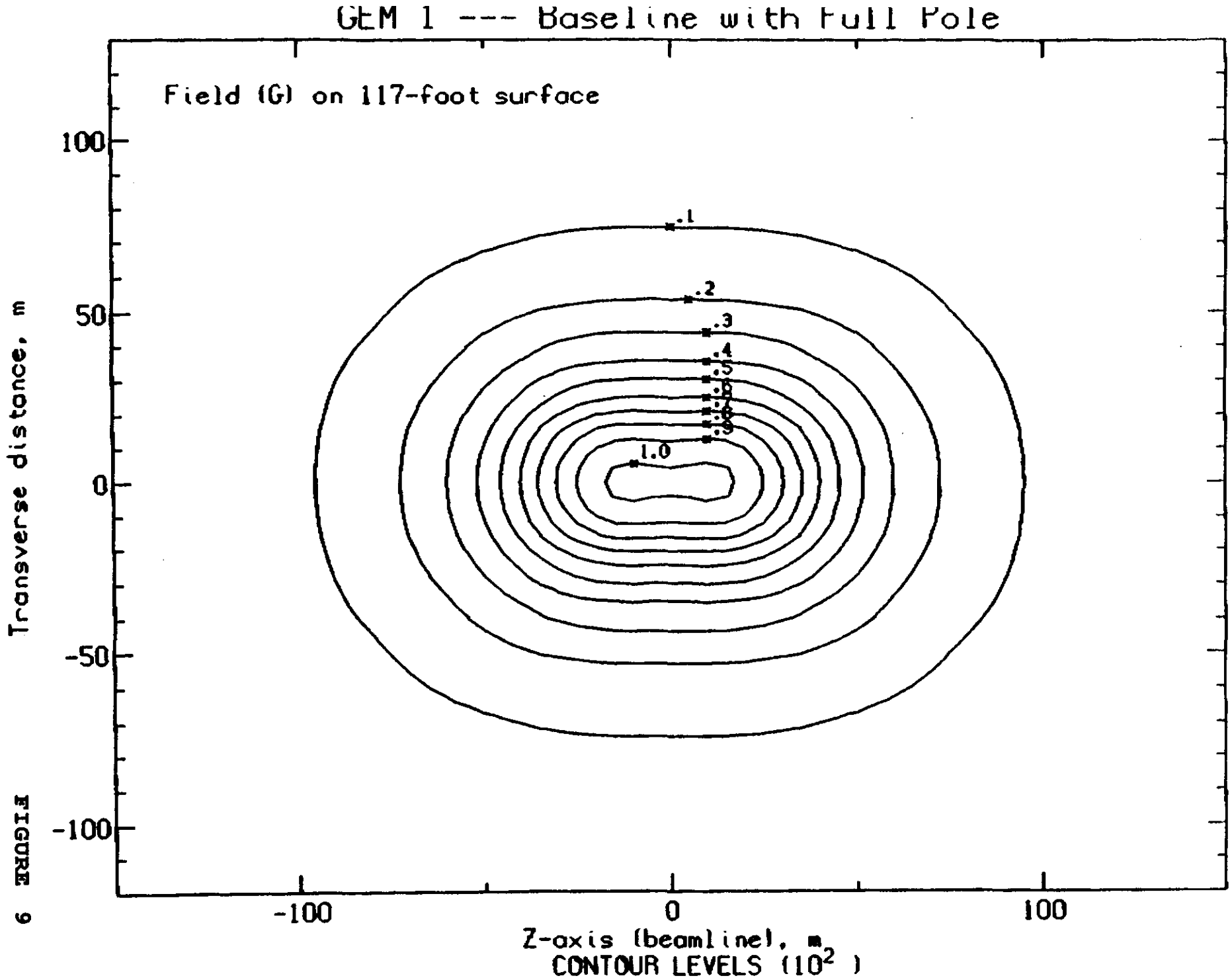

GEM 1 --- Baseline with Full Pole
Field (G) on 117-foot surface
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
100
50
0
-50
-100
Transverse distance, m
-100
0
100
Z-axis (beamline), m
CONTOUR LEVELS (10^2)

FIGURE 9

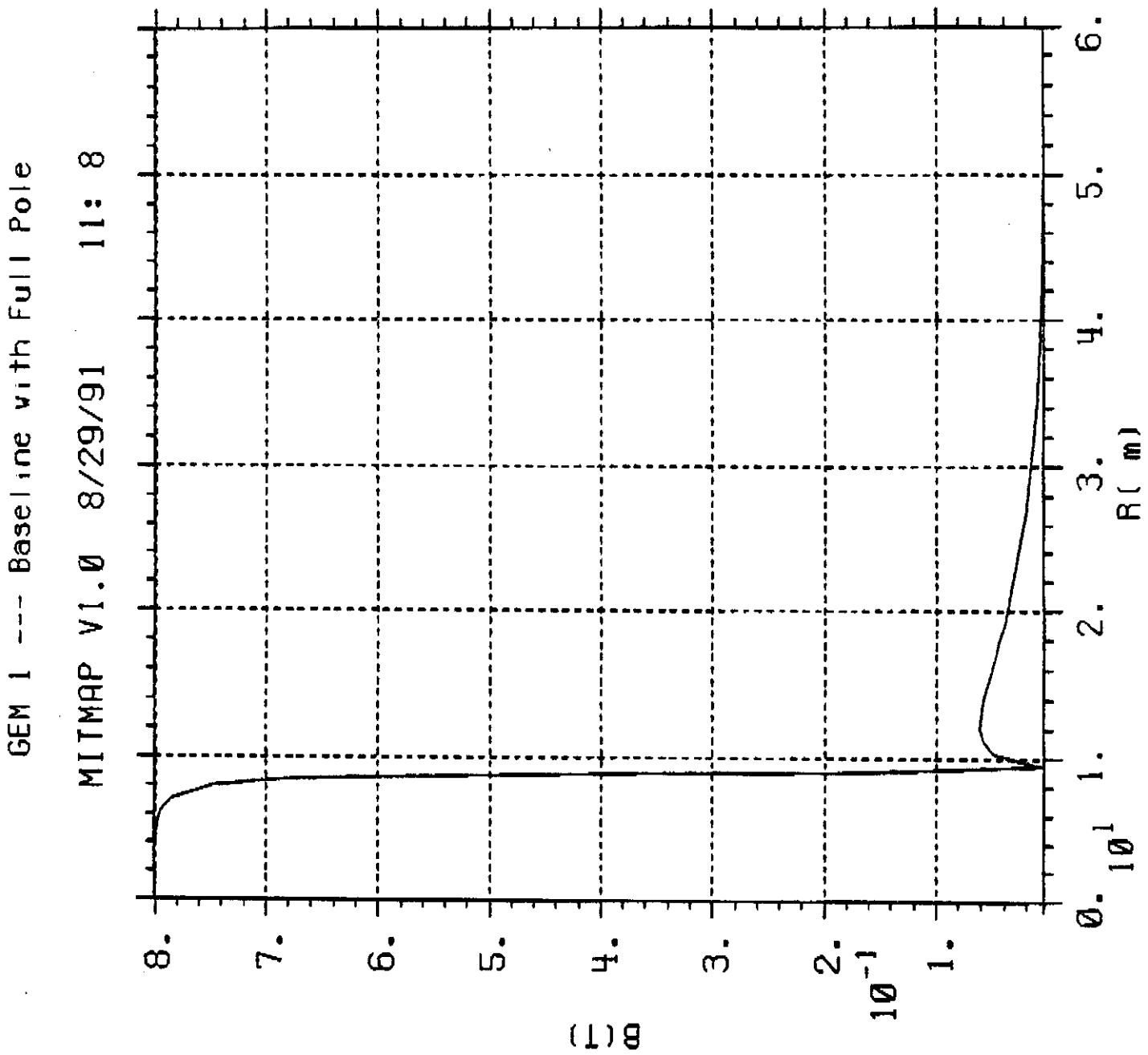

GEM 1 --- Baseline with Full Pole
MITMAP V1.0 8/29/91 11: 8
B(T)
8.
7.
6.
5.
4.
3.
2.
1.
10^{-1}
0.
1.
2.
3.
4.
5.
6.
10^{1}
R(m)

FIGURE 10