EAGLE Internal Note
TECH-NO-002

Magnetic field calculations for the EAGLE-A solenoid

V.I.Klioukhine
IHEP, Protvino, Moscow reg., 142284, Russia
E-mail: KLIOUKHI@cernvm.cern.ch
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Introduction

The calculations based on CERN POISSON program package is done to compare three possible scenarios for the EAGLE-A solenoid magnetic field. All of them use a small solenoid coil of 1.231 m inner radius and of 2 cm thick in radial direction. One of the goals of this note is to compare magnetic field obtained for the "long" (7.6 m) and "short" (6.4 m) length coils. Another one is to compare the field obtained with the long coil as for a nonlaminated return yoke plate as for the laminated one. The laminated return yoke plate was taken as the collection of iron plates of 5 cm thick with air gaps of 1.5 cm between them. In addition to coil and return yoke plate the first layer of muon toroid is included into magnetic system. In all cases the values of total Ampere-turns are chosen in such way that the values of flux density in the center of the solenoid would be equal to 2.0 T.

Magnetic system parameters

The parameters of magnetic system for three sets of calculations are as follow:

Table 1

	SET 1	SET 2	SET 3
	(long coil)		(short)
- coil internal radius, m	1.231	1.231	1.231
- coil length, m	7.6	7.6	6.4
- conductor width, m	0.02	0.02	0.02
- total Ampere-turns, MAt	12.586	12.585	10.807
- return yoke plate:	laminated	nonlaminated	
inner radius, m	4.4	4.4	4.4
internal length, m	14.3	14.3	13.1
thickness, m	0.05*4	0.2	0.2
gaps, m	0.015*3	-	-
beam hole radius, m	0.789	0.789	0.723
- muon toroid first layer:			
inner radius, m	5.6	5.6	5.6
internal length, m	16.7	16.7	15.5
thickness, m			
for barrel	2.5	2.5	2.5
for end cups	2.0	2.0	2.0
beam hole radius, m	0.922	0.922	0.855

As boundary conditions, magnetic vector potential is equal to zero as on z-axis, as on a surface of cylinder with radius of 10 m and with $|z|$=10.75 m (10.15 m for SET 3).

Beam hole radii as for return yoke plate as for muon toroid are corresponding to pseudorapidity value equal to 2.9.

The geometries for three sets of the calculations is shown in Fig.1.

The description of iron magnetic properties

For the iron of the return yoke plate the B-H dependence used are presented in Table 2. It corresponds to the American 1010 steel magnetic properties.

Table 2

B, T	H, A/m	Permeability
0.0	0.0	0.0
0.4	149.0	2136.
0.8	244.0	2609.
1.0	328.0	2426.
1.2	470.0	2031.
1.4	820.0	1358.
1.5	1273.0	937.2
1.55	1751.0	704.2
1.6	2228.0	571.3
1.65	2984.0	439.9
1.7	4138.0	326.8
1.75	5730.0	243.0
1.8	7480.0	191.4
1.85	9550.0	154.1
1.9	12330.0	122.6
1.95	15920.0	97.45
2.0	19900.0	79.95
2.05	25470.0	64.03
2.1	33420.0	49.99
2.125	38200.0	44.26
2.15	43770.0	39.08
2.175	52520.0	32.94
2.2	66050.0	26.50
2.25	99480.0	18.00
2.275	119400.0	15.16
2.3	143200.0	12.78
2.35	171100.0	10.92
2.4	212500.0	8.982
2.5	286500.0	6.942
2.55	334200.0	6.070
2.675	429700.0	4.952
2.85	565000.0	4.013
3.2	843500.0	3.018
4.275	1695000.0	2.006
12.13	7958000.0	1.212

To describe the magnetic properties for the iron of the moun toroid it needs to take into account the saturation of that iron due to magnetic field produced by the muon toroid coils which give the phi component of the flux density approximately equal to 2 T. To obtain the new B-H table for this case the values of relative permeability for the flux density great than 2 T were used from Table 2, supposing that these flux densities are the absolute values of vector sum Bphi = 2 T and Brz. In such way the new dependence for H versus Brz presented in Table 3 were obtained.

Table 3
Brz-H dependence for Bphi = 2 T

|B|, T	MU	MUabs*10E6	Brz, T	H, A/m
2.0	79.95	100.5	0.0	0.0
2.0001	79.92	100.46	0.020	199.1
2.05	64.03	80.49	0.4500	5591.0
2.1	49.99	62.84	0.6403	10190.0
2.125	44.26	55.63	0.7181	12910.0
2.15	39.08	49.12	0.7890	16060.0
2.175	32.94	41.41	0.8548	20640.0
2.2	26.5	33.31	0.9165	27510.0
2.25	18.00	22.62	1.031	45580.0
2.275	15.16	19.05	1.084	56900.0
2.3	12.78	16.06	1.136	70730.0
2.35	10.92	13.73	1.234	89880.0
2.4	8.982	11.29	1.327	117530.0
2.5	6.942	8.726	1.500	171900.0
2.55	6.070	7.630	1.582	207300.0
2.675	4.952	6.225	1.776	285300.0
2.85	4.013	5.044	2.030	402460.0
3.2	3.018	3.794	2.498	658400.0
4.275	2.006	2.522	3.778	1498000.0
12.13	1.212	1.524	11.96	7848000.0

The uniformity of magnetic field

Table 4 contains the values of the field ununiformity which are reached at two values of radius (0.5 m and 1.0 m) for different values of |z| inside the solenoid coil. The ununiformity is calculated in percents for z component of flux density like

$$(Bzi-Bz0)/Bz0*100\%.$$

Table 4

set \ |z|, m		0.0	1.0	2.0	3.2	3.8
SET 1	r=0.5 m	0.114	-0.833	-4.800	-	-47.880
	r=1.0 m	0.450	-0.324	-3.352	-	-47.851
SET 2	r=0.5 m	0.114	-0.833	-4.799	-	-47.867
	r=1.0 m	0.450	-0.324	-3.352	-	-47.837
SET 3	r=0.5 m	0.207	-1.514	-9.378	-47.049	-
	r=1.0 m	0.791	-0.531	-6.045	-47.052	-

From this table one can see that there is no difference between SET 1 (laminated return yoke plate) and SET 2 (unlaminated return yoke plate). The situation at the ends of the long and short coils is the same too. Inside the short coil the ununiformity of the field is in two times higher then in the case of long coil, but not so dramatic as at the ends of the coils.

The field Br and Bz components' behaviour inside the coils versus z- and r-coordinates is shown in Figs. 2 and 3, respectively.

The values of magnetic field in the hadronic calorimeter, return yoke, and muon chamber regions

Two tables, 5 and 6, give presentation for the typical values of magnetic field (in Gausses) in the calorimeter and muon chamber regions. The maximum values of flux density in the return yoke plate are as follow:

- laminated plate: 1.23-1.40 T (barrel) and 1.08 T (end cups);
- nonlaminated plate: 1.34 T (barrel) and 0.45 T (end cups) for long (7.6 m) coil; 1.28 T (barrel) and 0.45 T (end cups) for short (6.4 m) coil.

The behaviour of the field components in all this regions are presented in Figs. 4 and 5.

Table 5

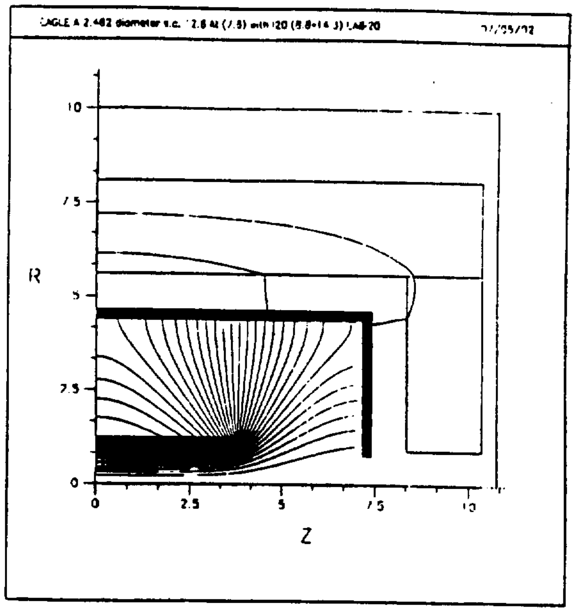
set \ r, m	calorimeter 2.5	calorimeter 4.0	muon chambers 5.0	muon chambers 5.5
1 ($0<\|z\|<6.9$)	395-1416	79-573	4-26	13-25
2 ($0<\|z\|<6.9$)	393-1414	77-571	5-26	10-24
3 ($0<\|z\|<6.3$)	531-1420	96-562	4-22	10-20

Table 6

set \ z, m	calorimeter 0.0	calorimeter end of coil	muon chambers 7.5(6.9)	muon chambers 8.3(7.7)
1 ($1.5<\|r\|<4.0$)	625- 79	523-574	46-54	75-53
2 ($1.5<\|r\|<4.0$)	623- 77	523-573	25-27	54-27
3 ($1.5<\|r\|<4.0$)	896- 96	537-562	22-23	25-21

Conclusions

From the point of view of the magnetic field behaviour there is no essential difference between long (7.6 m) and short (6.4 m) solenoid coils. The return yoke plate of 20 cm thick sufficiently well protects the muon chambers from the muon field and could be done as laminated return yoke to serve simultaneously as finished part of the hadronic calorimeter.



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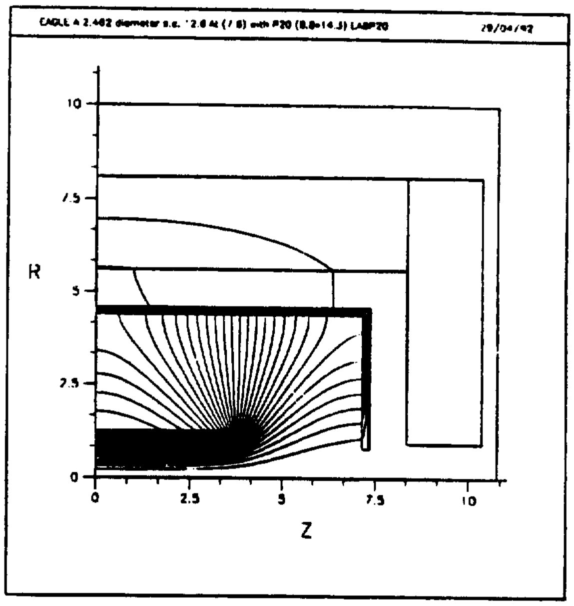

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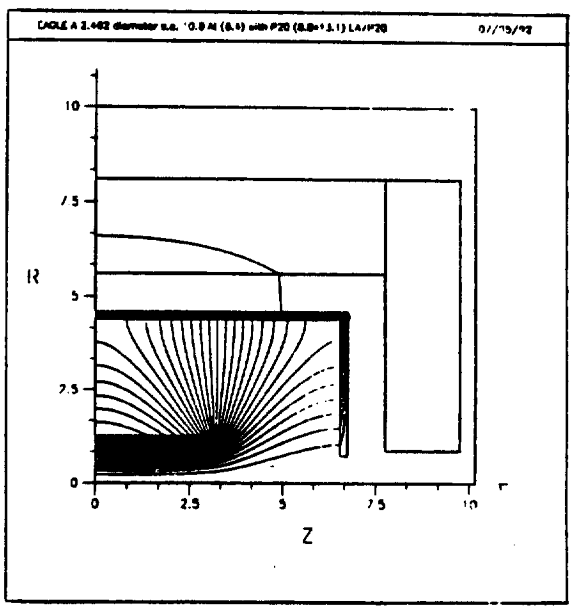
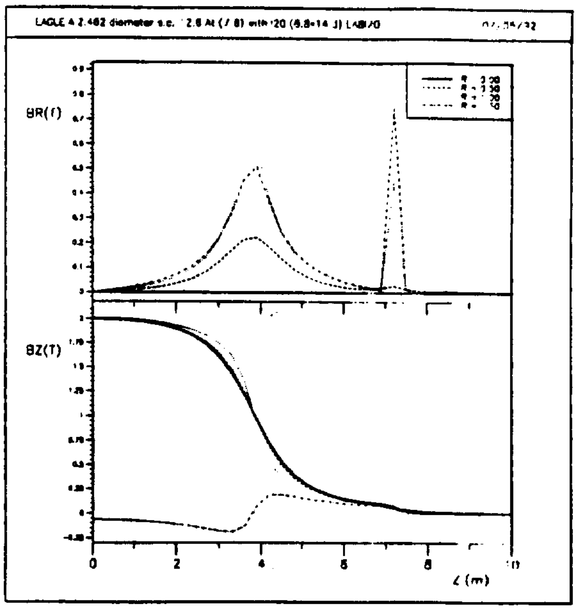


SET 3

Fig. 1



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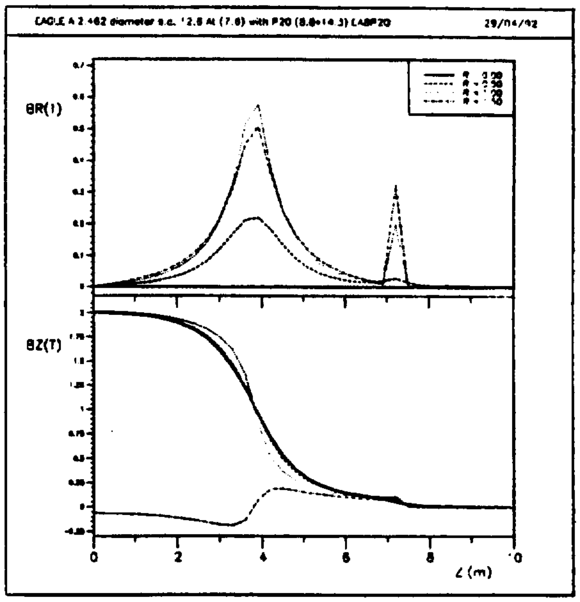

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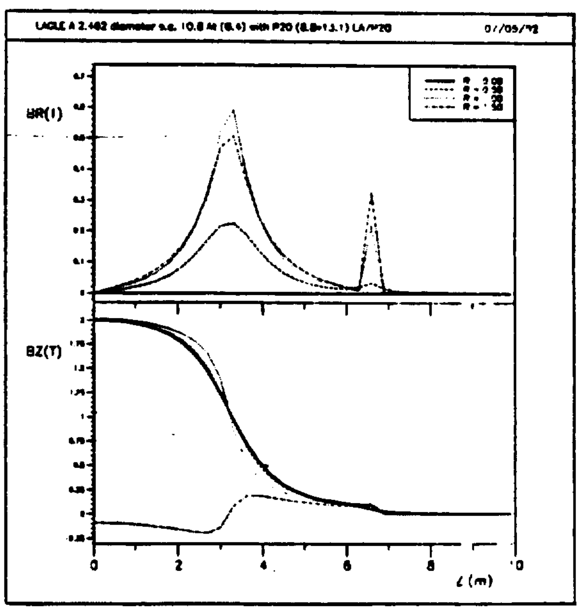
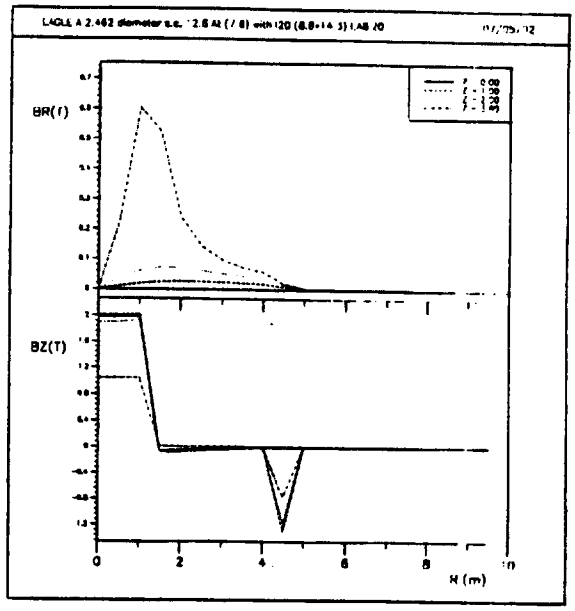


SET 3

Fig. 2

SET 1



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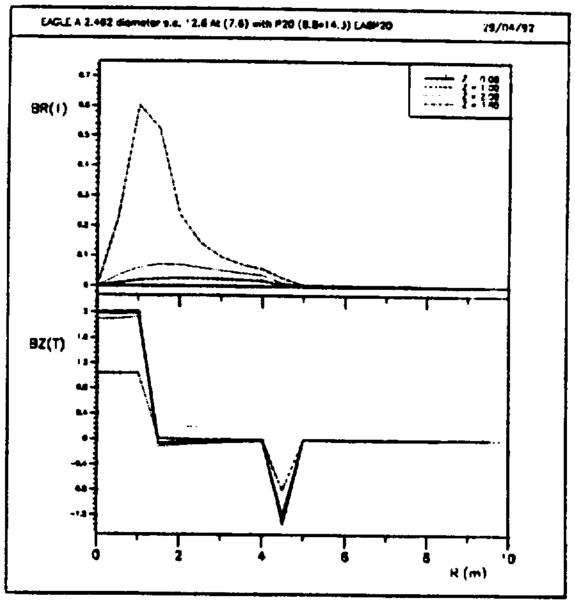

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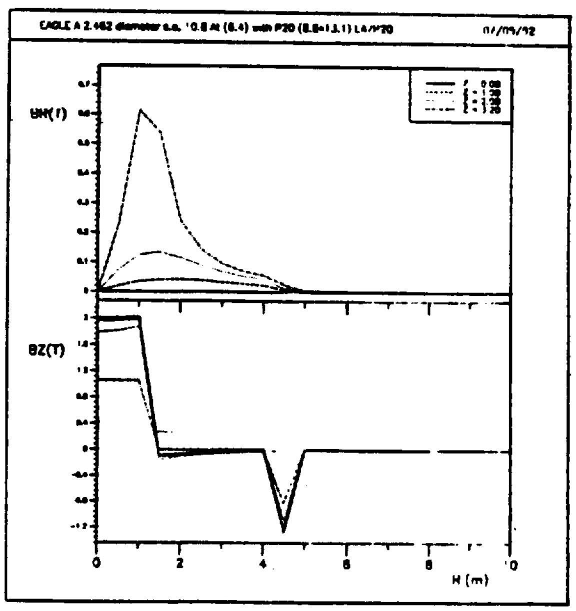
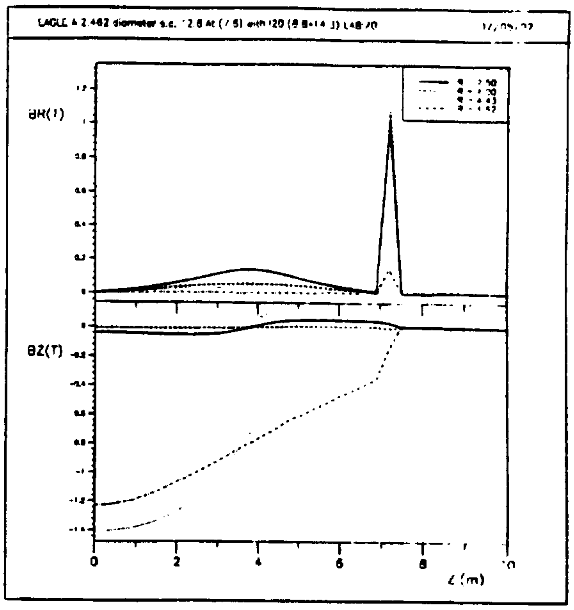


Fig. 3

SET 1



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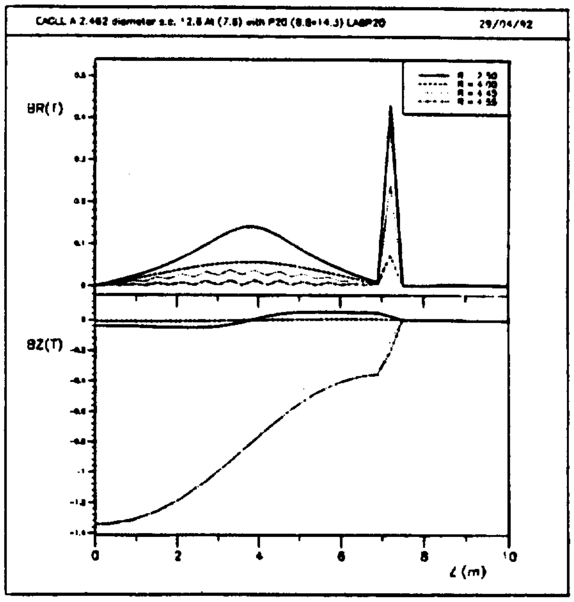

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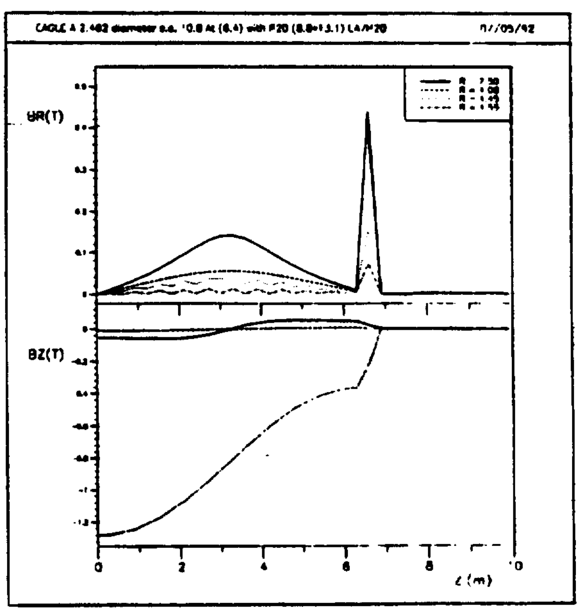
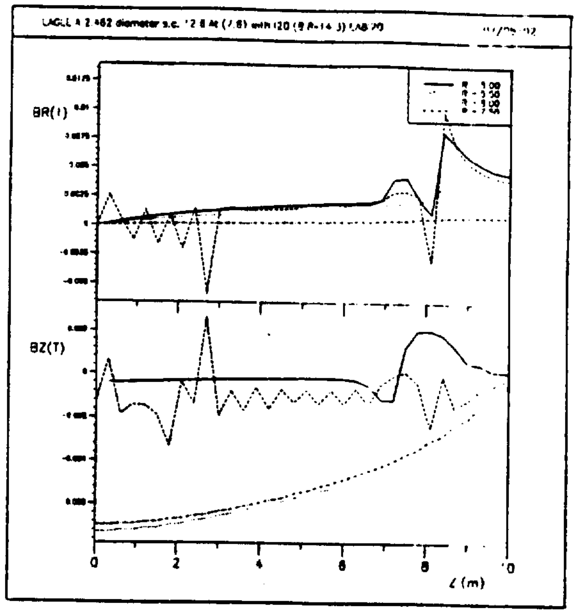


Fig. 4



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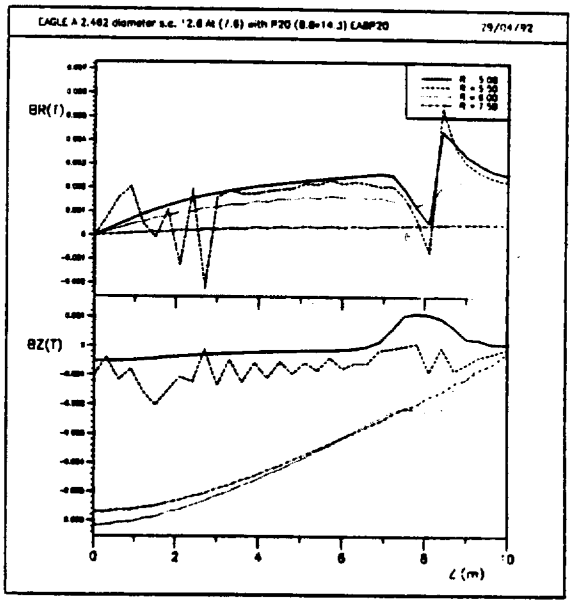

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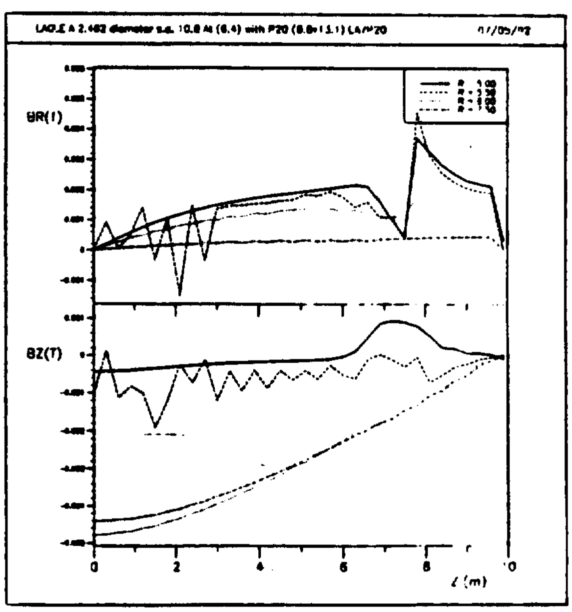

SET 3

Fig. 5