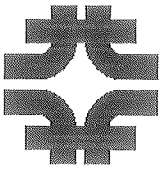


Fermilab

SSC DETECTOR SOLENOID DESIGN NOTE #104

TITLE: USC Magnet Working Group Report

AUTHOR: R. D. Kephart

DATE: December 18, 1989

ABSTRACT: This note consists of the viewgraphs presented at the Solenoid Detector Collaboration meeting at Fermilab on December 18, 1989.

R.D. KEPHART
Dec. 18, 1989

USC* Magnet Working Group Report

Group was Organized at ANL meeting Nov. 16-18,1989

PARTICIPANTS

ANL:	T. Field, S.H.KIM
Fermilab:	R. Fast, J. Grimson, R. Kephart,# J. Krebs, R. Wands.
LBL:	P. Eberhard, R. Kadel
Tsukuba:	S. Mori (Hitachi)
KEK:	T. Kondo#, A. Yamamoto
Adv. Cryogenics:	J. Purcell (paid consultant)

* USC :== Unnamed Solenoid Collaboration

= contact persons

Talk Outline

I ANL Meeting Summary (Nov 16-18, 1989)

II What have we done since

III Short Term Plans for the Group.

I ANL Meeting: what did we do?

1) Agree To work Together as a single group To explore various magnet options. (Focus = Thin, inside, indirectly cooled solenoids)

2) PLAN: Produce a single design report for both "Air core" and "Iron flux return" style magnets To serve as the basis for comparison.

Goals

1) Identify Elements common To both magnet designs. and Explore Them.
   eg: Conductor, Outer/Inner Vac shells, Radiation shields, Chimney, Power Supply, Quench Protection, Quench Detection, materials properties, Thermosiphon Cooling, ETC.

2) Identify Differences in Designs
   - AXIAL supports, AXIAL compressive forces, ETC.
   - Attempt To quantify difference in Physics Performance, (eg. material, field uniformity, etc)
   - COST, SCHEDULE, TECHNICAL RISK

Goals (cont)

3) Provide information for simulation studies:
   - Field Maps in Tracking Volume
   - Material distribution
   - Overall Geometry / CABLE Access
   - Scaling Laws vs R, L, B
   - Misc. detail: chimney, fringe field, etc

4) Develop an R+D plan that will allow more detail Engineering To start.

(MORE LATER ON THIS)

Details of ANL PLAN

(From T Kondo's summary)

FOR THE SAKE OF PHYSICS EVALUATIONS AND COST ESTIMATES, WE DESIGN SOLENOIDS OF

2 × { TYPE L : LONG SOLENOID WITH IRON FLUX RETURN
TYPE S : AIR CORE SOLENOID

WITH TWO DIFFERENT RADII,

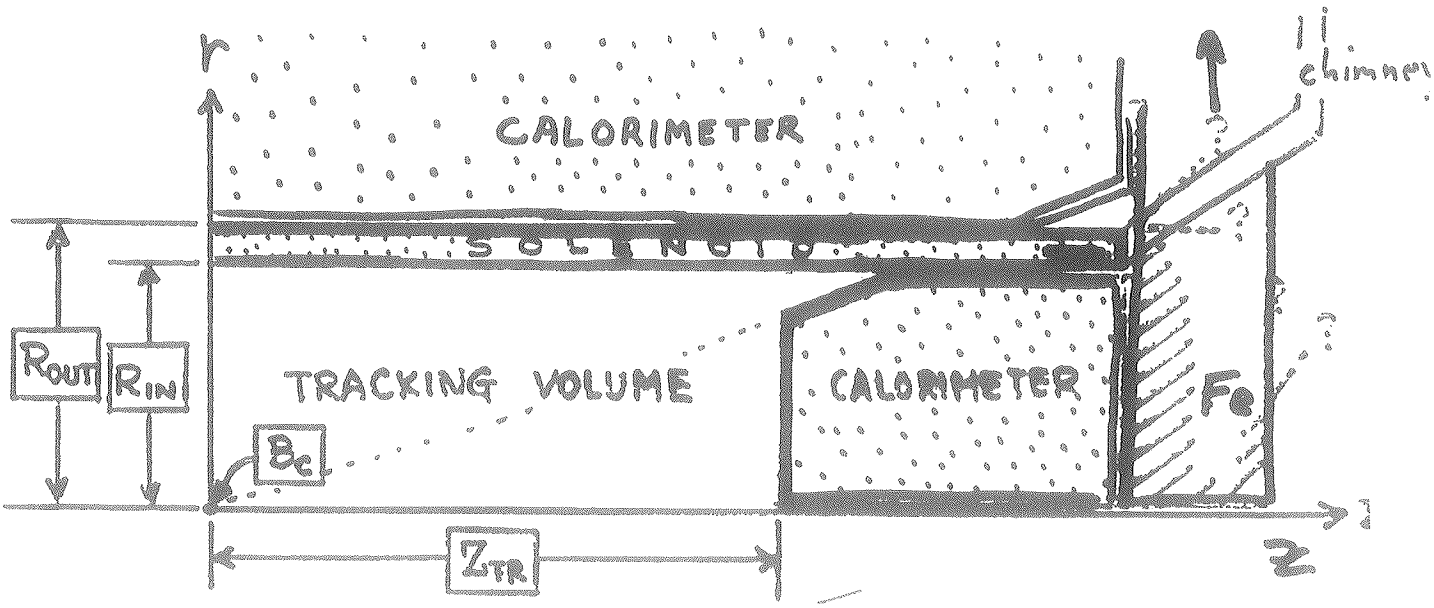
⇒ Look at ~4 Variants

PARAMETERS	SMALL	LARGE	
INNER RADIUS R_{IN} (USEFUL BORE)	170 CM	200 CM	
OUTER RADIUS R_{OUT}	200 CM	235 CM	
TRACKING VOLUME Z_{TR}	±400 CM	±450 CM	±500 for TYPE L
CENTRAL FIELD B_c	2.0 T	1.7 T	
RADIATION THICKNESS ($\theta = 90°$)	1.0 ~ 1.2 X_0	1.0 ~ 1.2 X_0	
$\int B \cdot dl$ (T-M)	3.4 - 3.5	3.4 - 3.5	

Motivation:

No one is "locked in" {
1) Interest in US/JAPAN in both coil TYPES
2) MANY COMMON FEATURES
3) BY WORKING TOGETHER WE AVOID Duplication OF Effort + FACILITATE COMPARISONS

TYPE L : LONG SOLENOID



COIL LENGTH $\approx 2 \times (Z_{TR} +$ DEPTH OF FORWARD CALDRIMETR)

PLEASE GIVE US THIS.

CALORIMETER W.G.

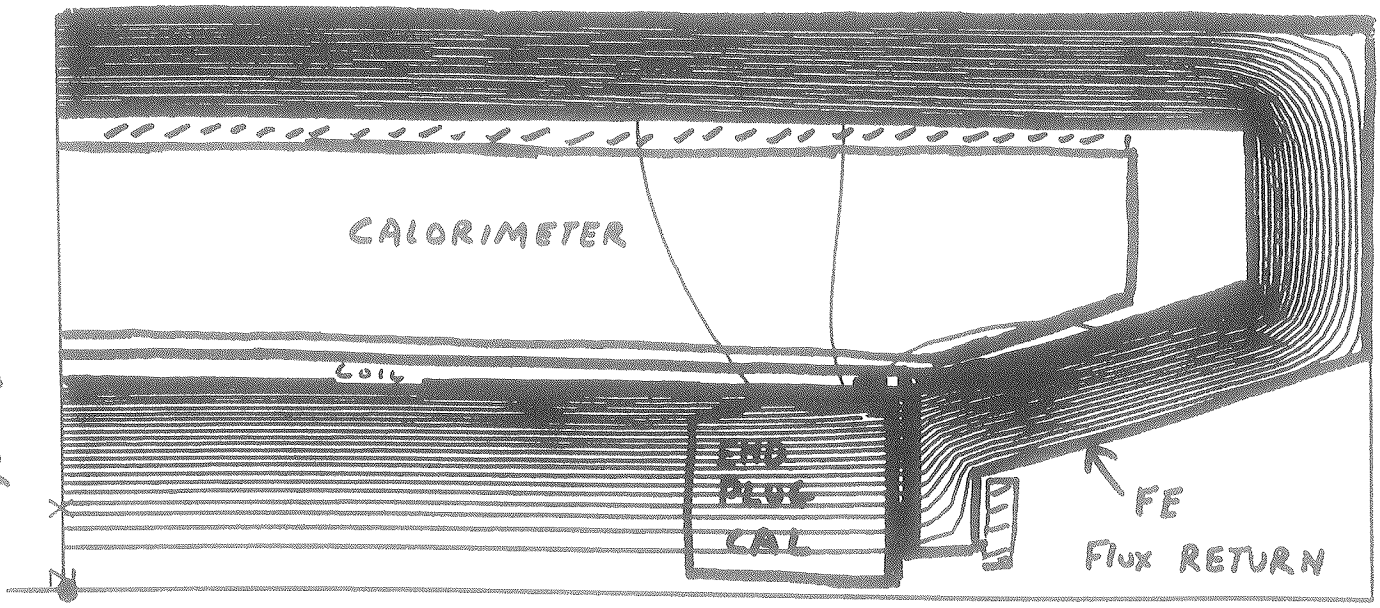
SHAPE & THICKNESS OF IRON FLUX RETURN ARE NOT SPECIFIED AT THIS STAGE, BUT PROBABLY

IRON THICKNESS $\gtrsim$ 1 M

ANSYS 4.4
DEC 15 1989
10:05:16
PLOT NO. 2
POST1 STRESS
STEP=2
ITER=10
MAG
SMX =3.281

ZV =1
DIST=6.16
XF =2.523
YF =-5.6
EDGE

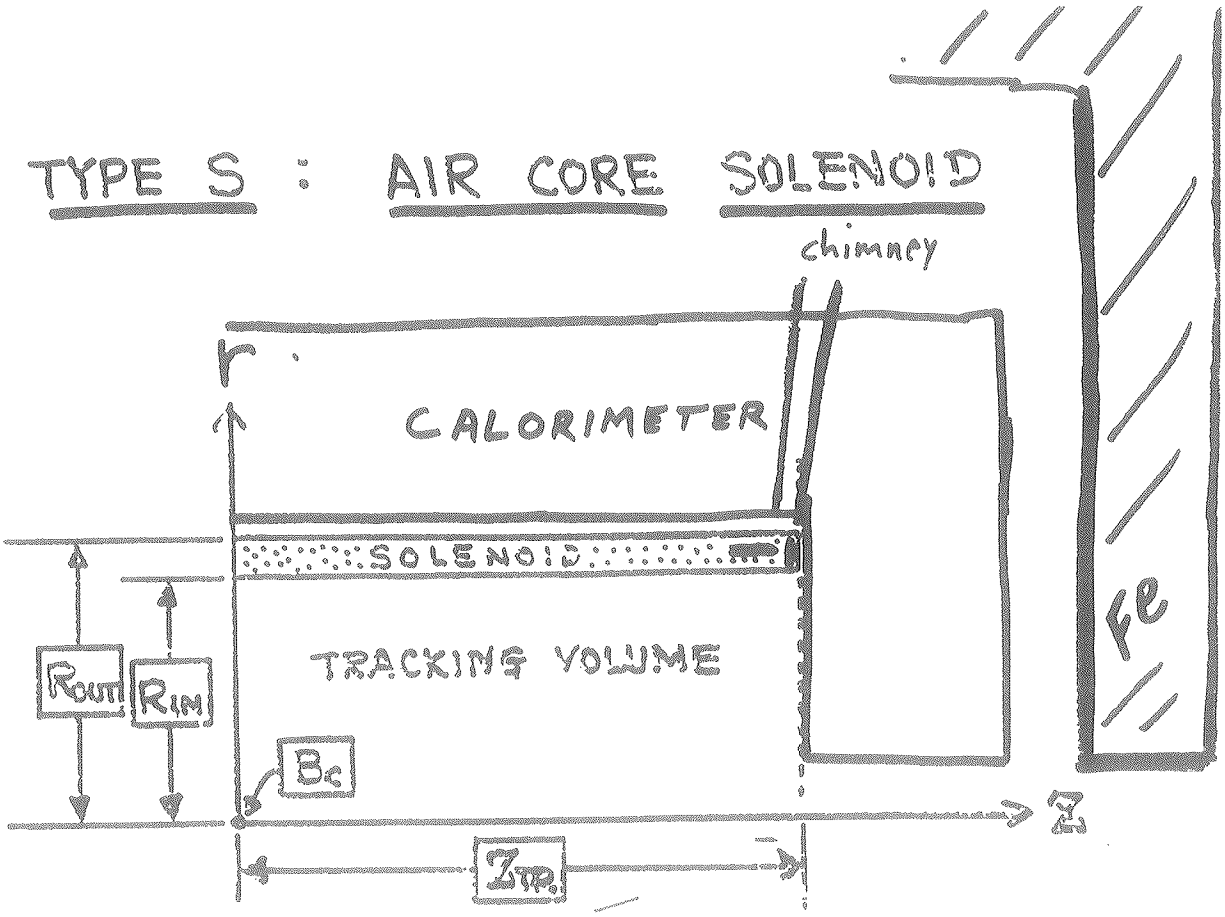
TYPE L: Long Solenoid (with Flux Return)



Features:

1) ENDPLUG ⇒ "CRACK" IN CALORIMETRY
2) "Small" compressive force on coil, Larger decentering forces
3) SUPPORTS + ENDS "hidden" by calorimetry
4) longer Tracking Volume with UNIFORM $\vec{B}$
5) small Fringe fields

TYPE S : AIR CORE SOLENOID



SOLENOID LENGTH = $2 \times Z_{TR}$

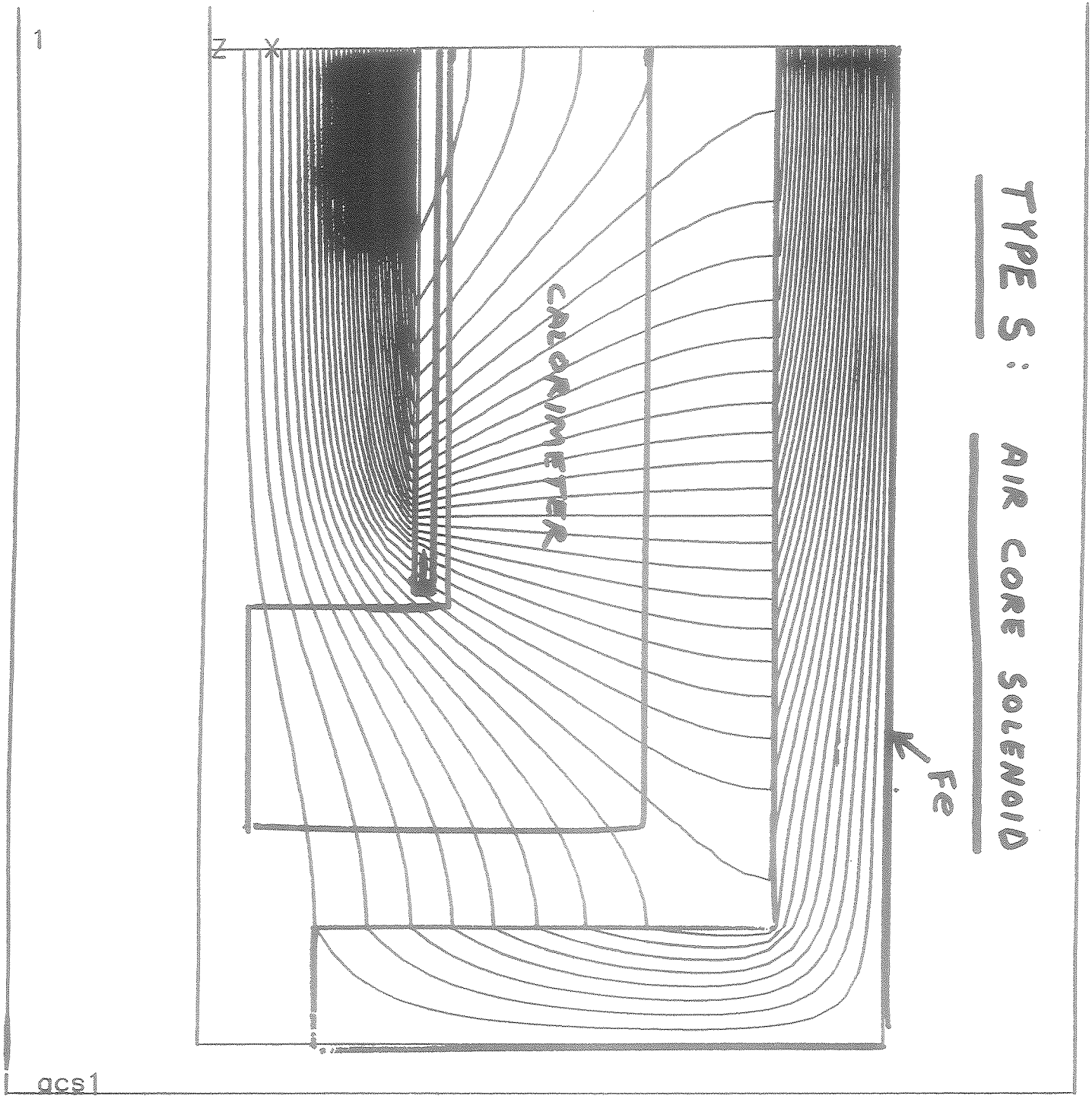
Features

0) No Major Calorimeter Crack (but coil ENDS + chimney are problems

1) large compressive force on coil + small decentering forces

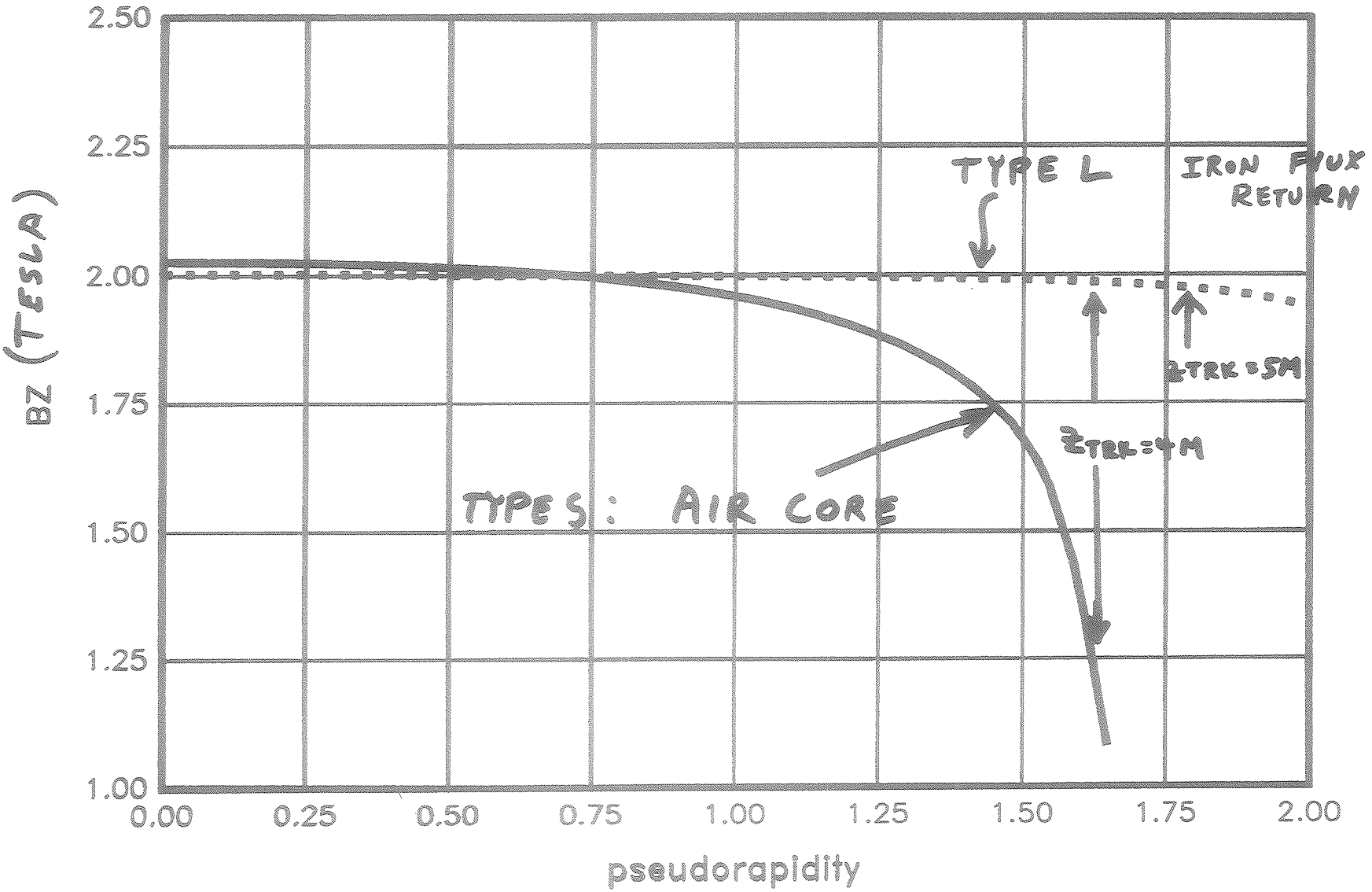
2) Non-Uniform $\vec{B}$ + fringe fields

3) CAN BE fully TESTED without Yoke.


1
Z
X
CALORIMETER
Fe
TYPE S: AIR CORE SOLENOID
ANSYS 4.4
DEC 15 1989
10:00:38
PLOT NO. 1
POST1 STRESS
STEP=2
ITER=10
MAG
SMX =3.301
ZV =1
*DIST=4.675
*XF =3
*YF =-4.25
EDGE
gcs1

BZ versus Pseudorapidity at r=1.5 m

(B = 2.0 TESLA
R = 1.7 M)

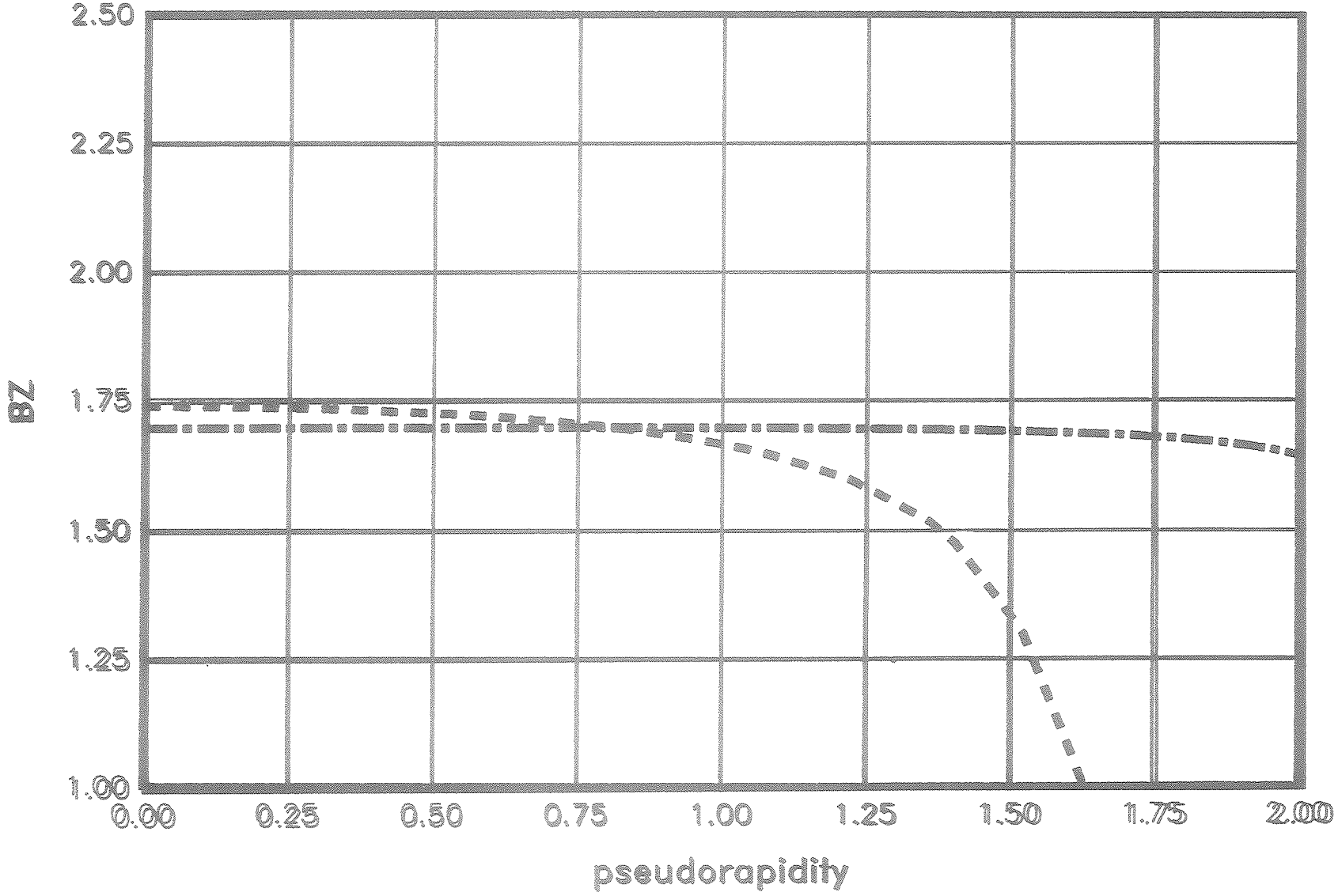


SKIP?

BZ versus Pseudorapidity at r=1.5 m

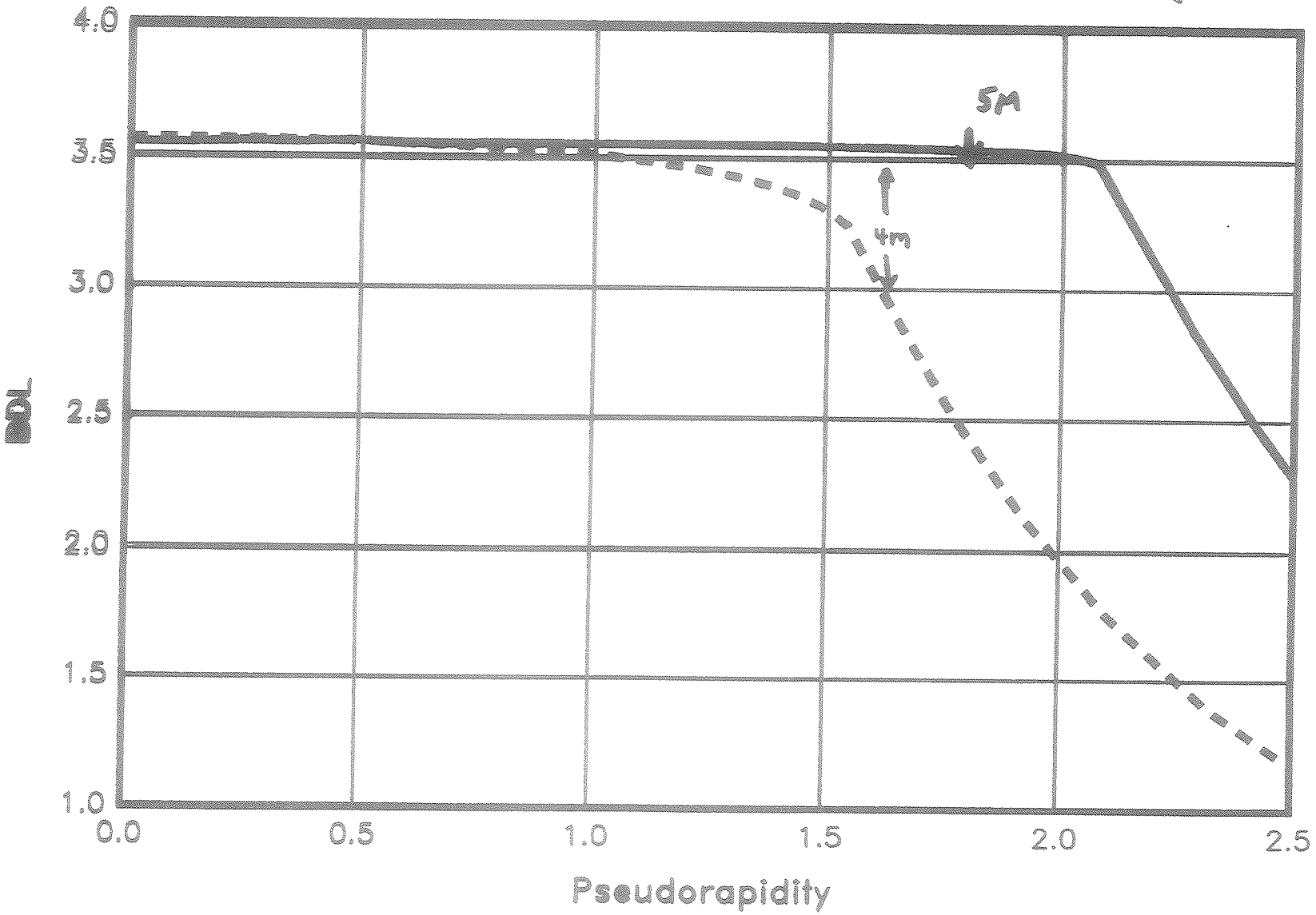
Air Return Solenoid, r = 2.1, BZ = 1.8

R = 2.0 M
B = 1.8 Tesla



$\int B \cdot dL$ Versus Pseudorapidity

Iron Return Solenoid, $r = 3.8$, $B_z = 2.0$ ($B = 2.0\,T$, $R = 1.7\,M$)

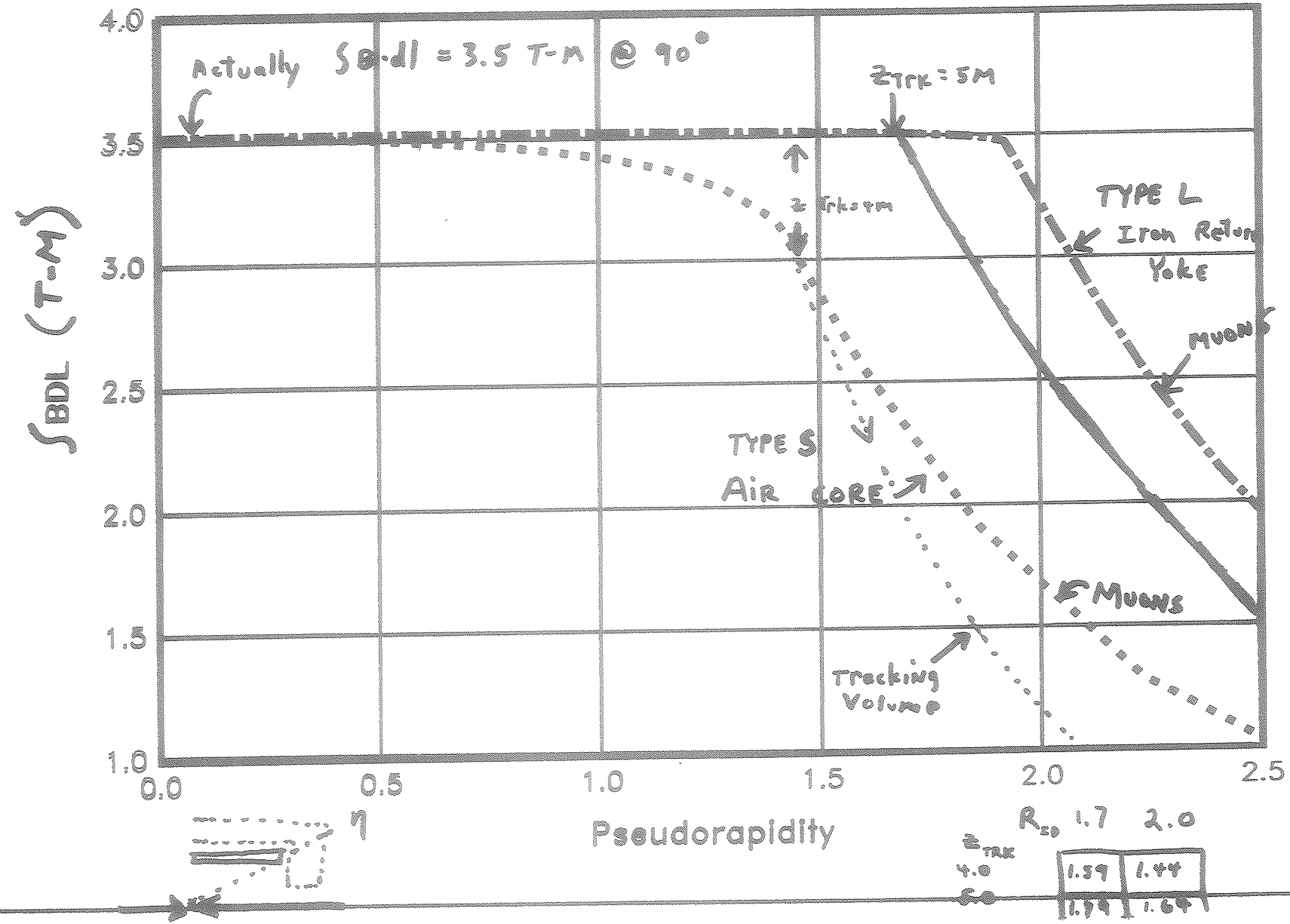


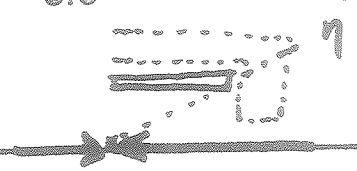
∫B·DL versus Pseudorapidity

Iron Return Solenoid, r = 2.1, BZ = 1.8

Air Core Solenoid, r = 2.1, BZ = 1.8

(B = 1.7, R = 2.0)



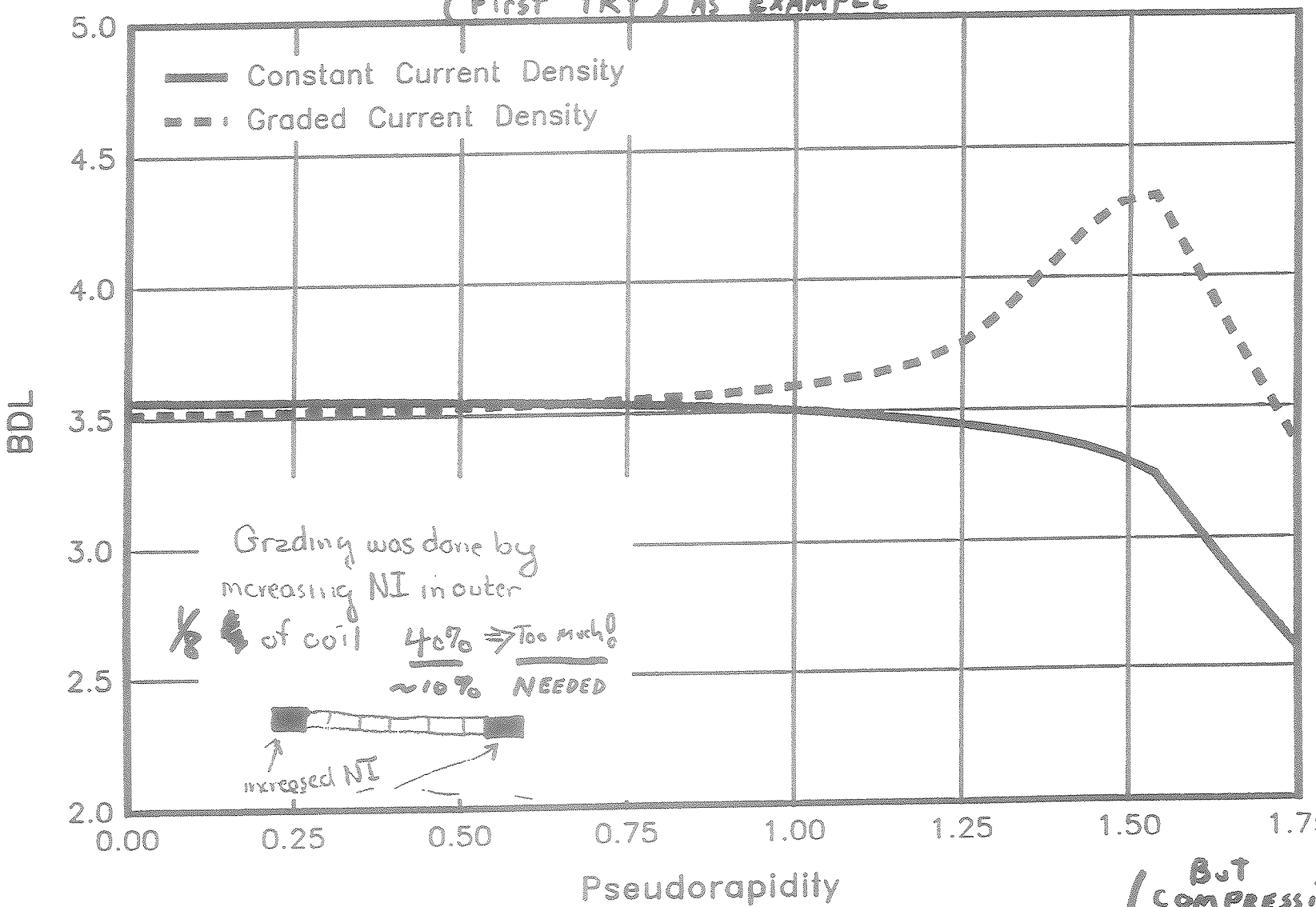


z_{TRK}	R_{ID} 1.7	2.0
4.0	1.59	1.44
5.0	1.79	1.64

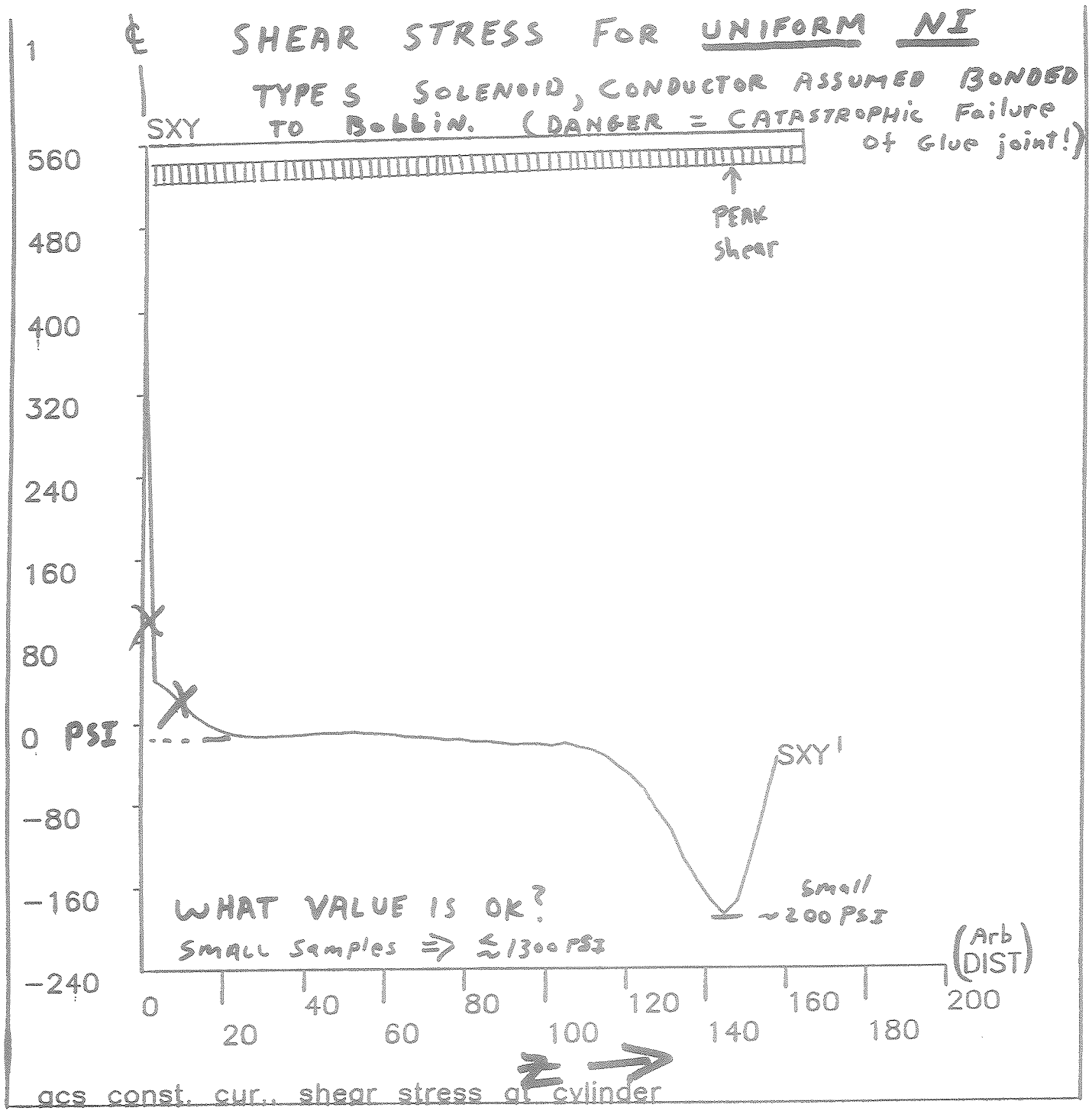
CAN WE "TUNE UP" The $\int B \cdot dl$ IN TYPE 5 Coils? YES

BDL versus Pseudorapidity

Comparison of ACS w/Constant and Graded Cur. Dens.
(FIRST TRY) AS EXAMPLE



ADJUST LENGTH + NI To flatten $\int B \cdot dl$ curve. (But COMPRESSIVE Forces are worse)



ANSYS 4.4
DEC 15 1989
11:22:24
PLOT NO. 1
POST1
STEP=1
ITER=1
PATH PLOT
NOD1=2
NOD2=4
SXY
STRESS GLOBAL

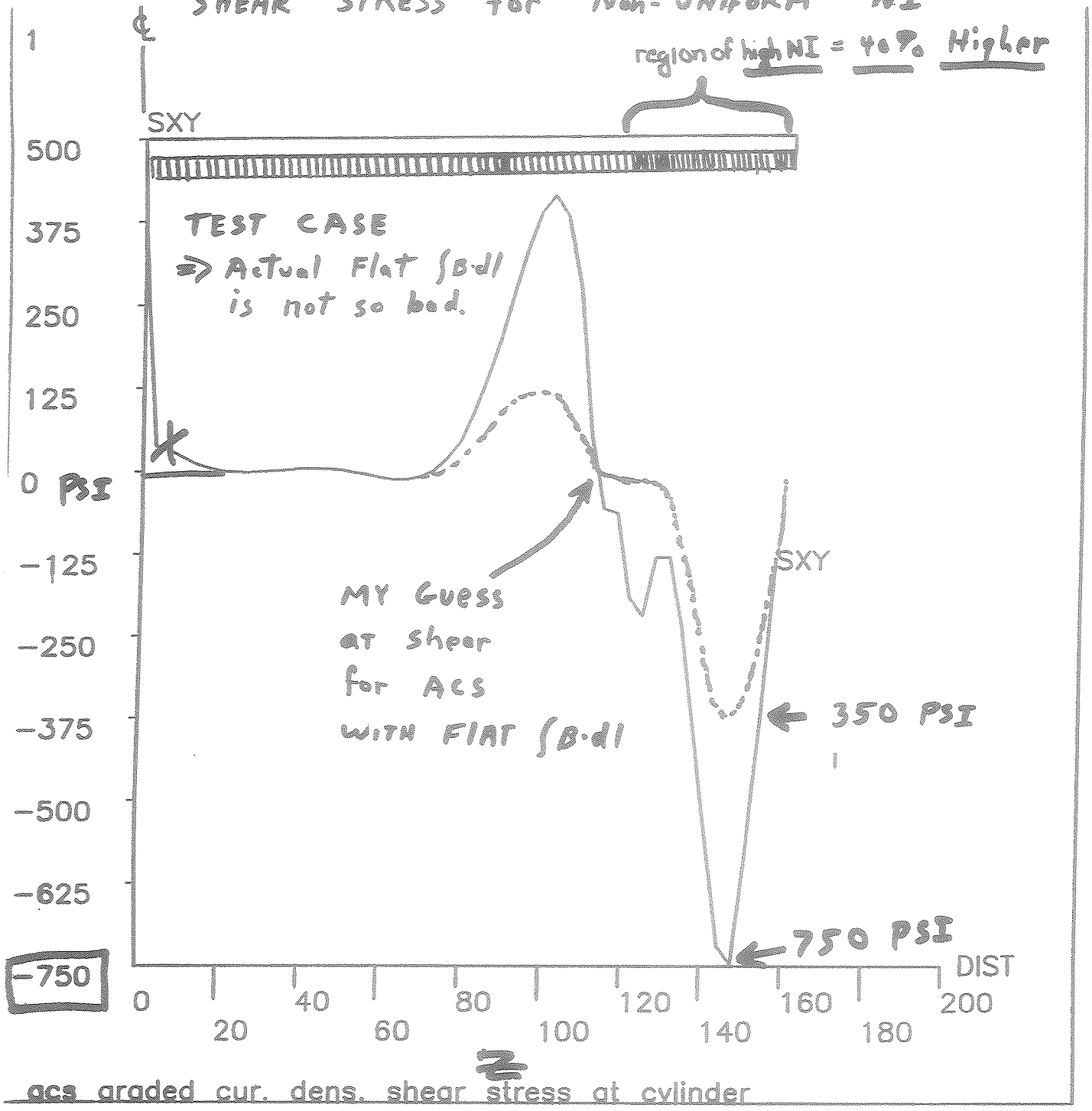
ZV =1
DIST=0.6666
XF =0.5
YF =0.5
ZF =0.5

Shear stress between coil and support cylinder for Air Core Solenoid with constant current density

R=1.8 m
B=2 T

SHEAR STRESS for Non-UNIFORM NI

region of high NI = 10% Higher



acs graded cur. dens. shear stress at cylinder

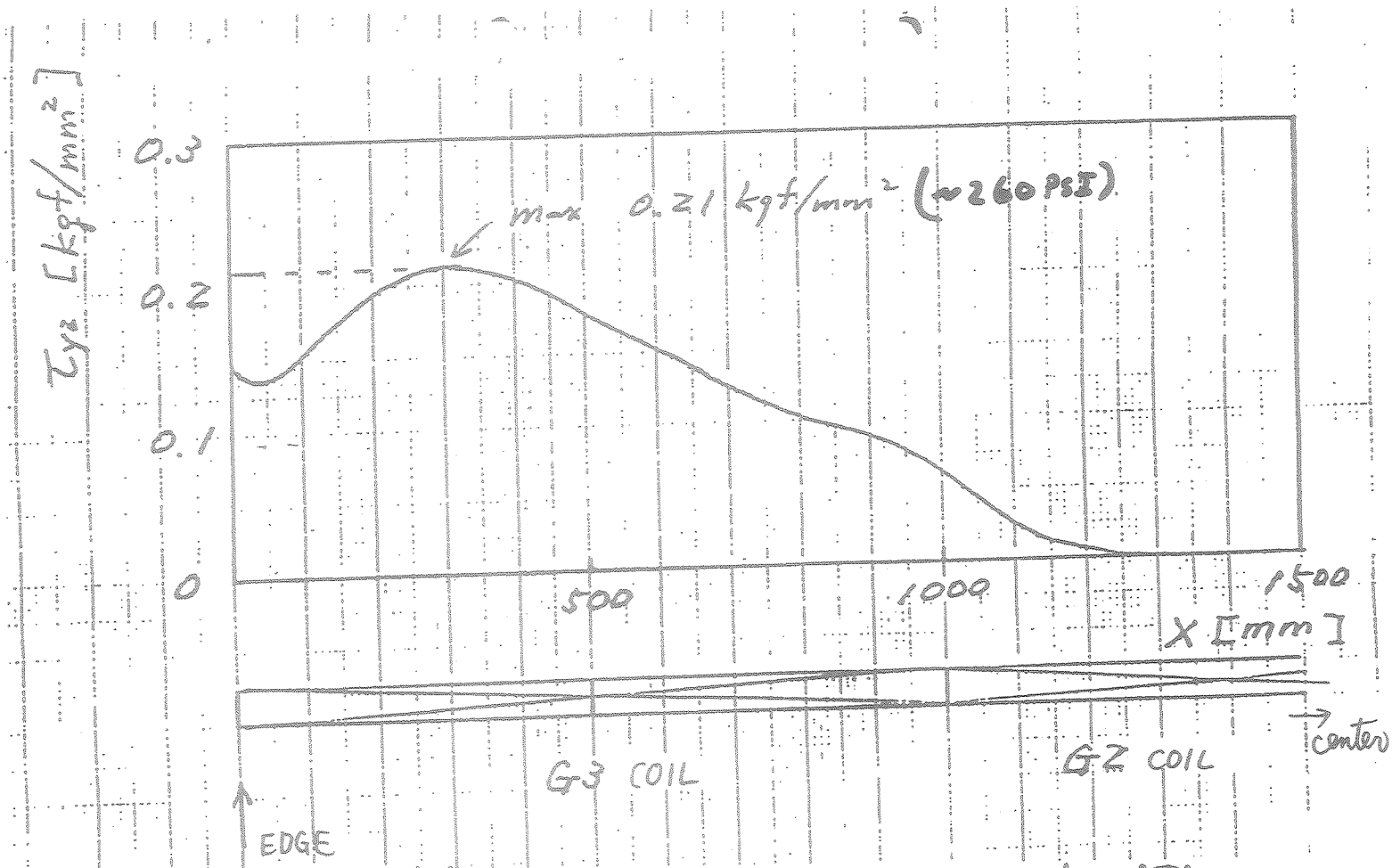
ANSYS 4.4
DEC 15 1989
11:23:08
PLOT NO. 2
POST1
STEP=2
ITER=1
PATH PLOT
NOD1=2
NOD2=4
SXY
STRESS GLOBAL

ZV =1
DIST=0.6666
XF =0.5
YF =0.5
ZF =0.5

Shear stress between coil and support cylinder for Air Core Solenoid with graded current density

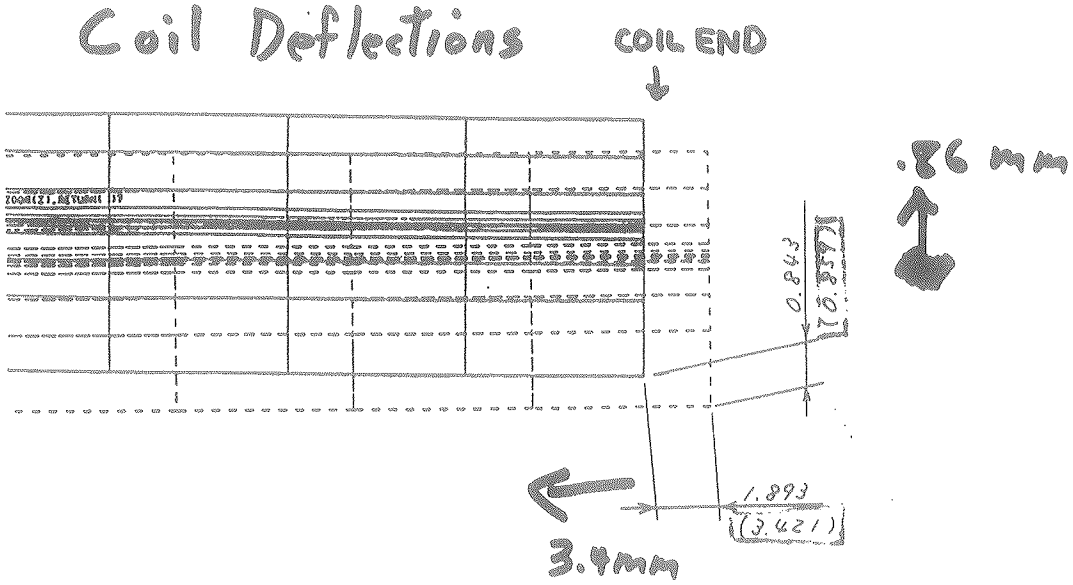
R=1.8M
B=2.T

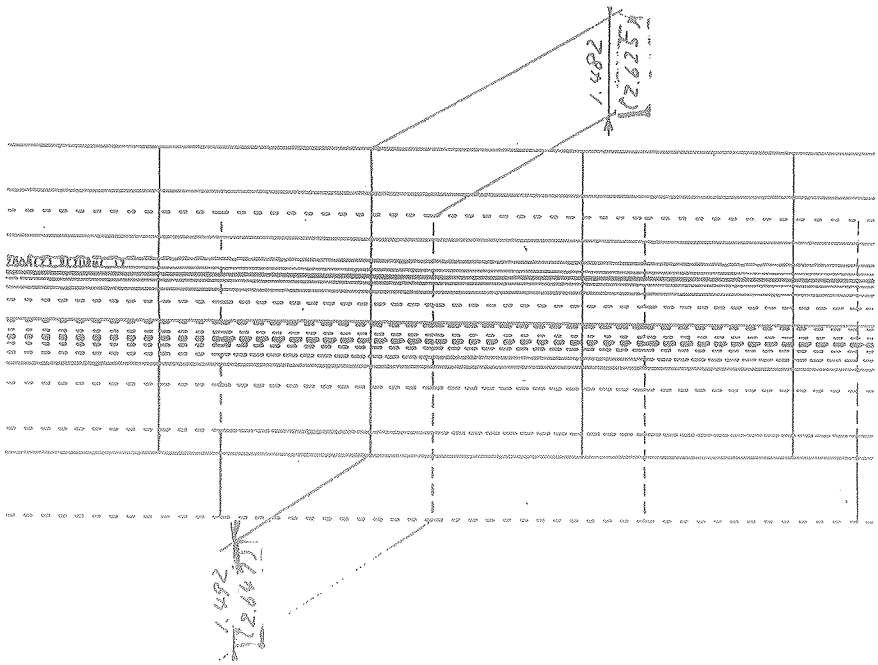
NEEDS MORE WORK!

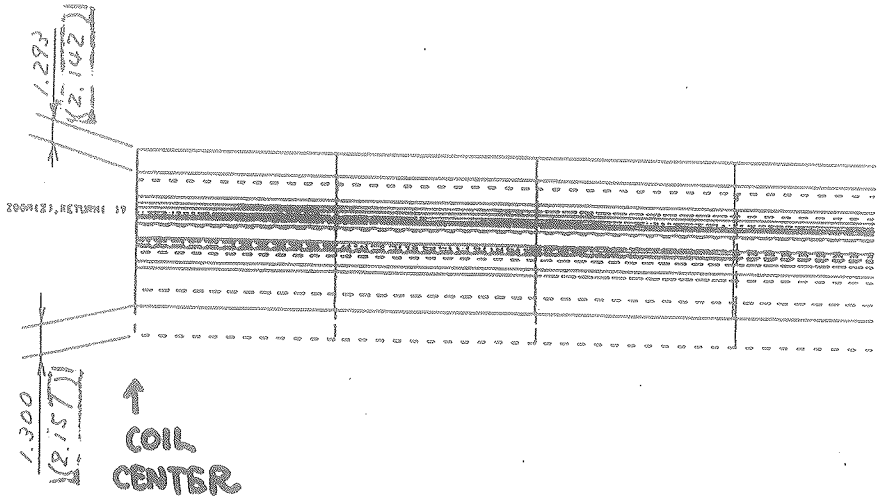


3 different current densities
(NOT OPTIMIZED)

Coil Deflections

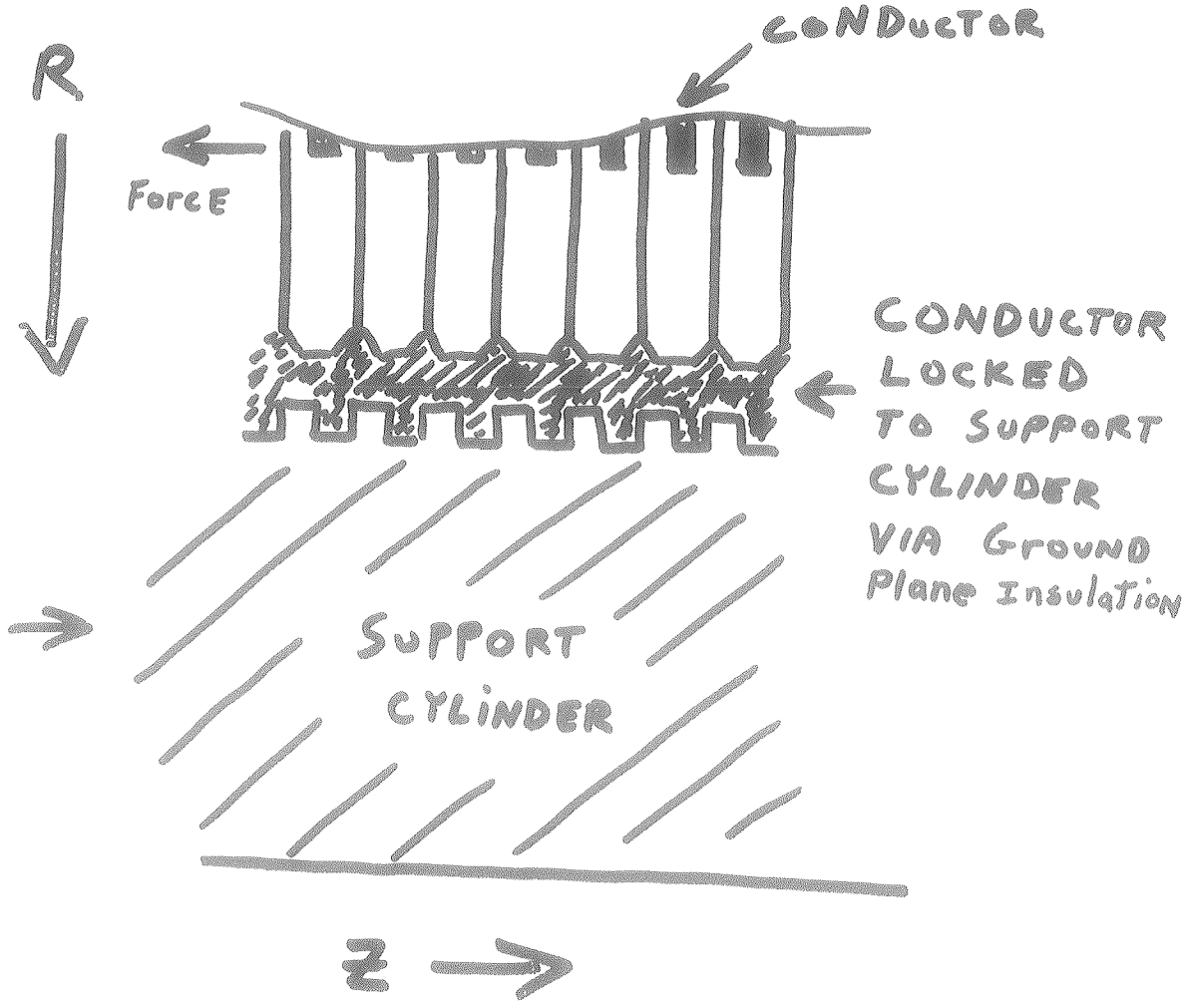






- UNIT IN mm
- NUMBERS IN ( ) FOR NON-LINEAR STRESS-STRAIN RELATION.

Possible Solution To Transmit Axial Force from Conductor To Support Cylinder in TYPE 5 DESIGNS.



IE: RELY ON a MECHANICAL INTERLOCK RATHER Than GLUE JOINT IN SHEAR.

NEEDS TO BE STUDIED + R+D?

12/15/89 B. Wands

Results for Adiabatic Temp Rise $\int_4^{T_{max}} \frac{C(T)}{\rho(T)}\,dT = \int_0^{\infty} J^2(t)\,dt$

Note: t_s = stabilizer radial Thickness, cm, from adiab. consid.

t_b = support cylinder radial thickness from t_s + hoop stress

$J(t) = J_0 e^{-\frac{Rt}{L}}$

$T_{MAX} = 100°K$

5000 A dump r = 0.1 Ω

500 V ON TERMINALS DURING DISCHARGE

	t_s cm	t_b cm	
LS1	7.4	0.12	(r = 1.8, B = 2)
LS2	6.1	0.17	(r = 2.1, B = 1.7)
ACS1	5.9	0.56	(r = 1.8, B = 2)
ACS2	5.2	0.39	(r = 2.1, B = 1.7)

Thin ⇒ Not Good for support attachments + roundness

10000 A, 0.05 Ω

LS1	5.0	1.05
LS2	4.1	0.92
ACS1	4.0	1.32
ACS2	3.6	1.04

EVEN AT 10,000 A Bobbin Thickness is Probably determin by factors other Than hoop stress.

CONCLUDE That Higher Current is Better Match.

Hoop stress criteria is 0.1% conductor strain + STRAIN Limit.

Axial forces on Coil

This is the sum of $\vec{J} \times \vec{B}$ forces. Units are Newtons

		METRIC TONS	
LS1	$5.07 (10^6)$ N,	507	
LS2	$4.18 (10^6)$	418	
ACS1	$16.4 (10^6)$	1640	~x4 larger
ACS2	$16.1 (10^6)$	1610	

Are There other Places ONE CAN SAVE MATERIAL WITHIN REASONABLE "TECHNICAL RISK" LIMITS ?

CDF SOLENOID--THICKNESS OF COMPONENTS

Item-Material	Thickness (mm)	Rad. Length (X0)
Inner vac shell-Al	6.4	0.071
Inner shield-Al	2.0	0.022
Conductor-Al,Cu,NbTi	20.0	0.312
Insulation-GFRP	2.0	0.011
Outer Support Cyl-Al	16.0	0.179
Outer shield-Al	2.0	0.022
Outer vac shell-Al	19.0	0.214 ← 25% OF TOTAL.
	Total	0.831

YES: OUTER VACUUM SHELL IN CDF is SOLID Aluminum. Stress is low, Thickness determined by Elastic InsTability criterion. (EXTERNAL Pressure)

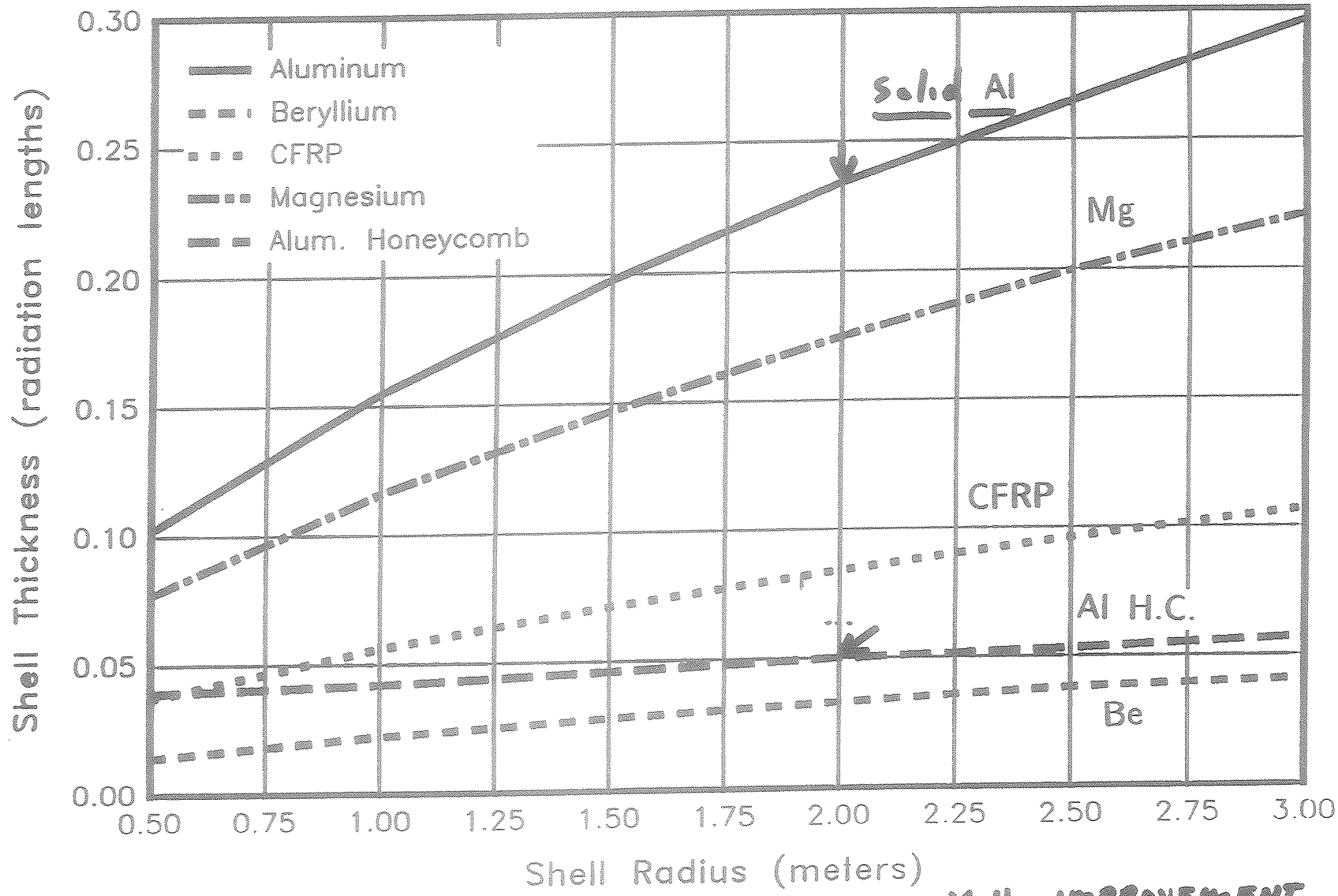
$$P_c \simeq 2.6\, E \left(t/D\right)^{2.5} / \left[(L/D) - 0.45\,(t/D)^{0.5} \right]$$

P_c: CRITICAL Collapse Pressure; E: Modulus (Psi); t: Thickness; D: dia.; L: length

$\Rightarrow$ INCREASE t_{eff} $\Rightarrow$ Honeycomb OUTER VAC. SHELL

Cylindrical Vacuum Shell Thickness

based on 30psi collapse and L=7.2m

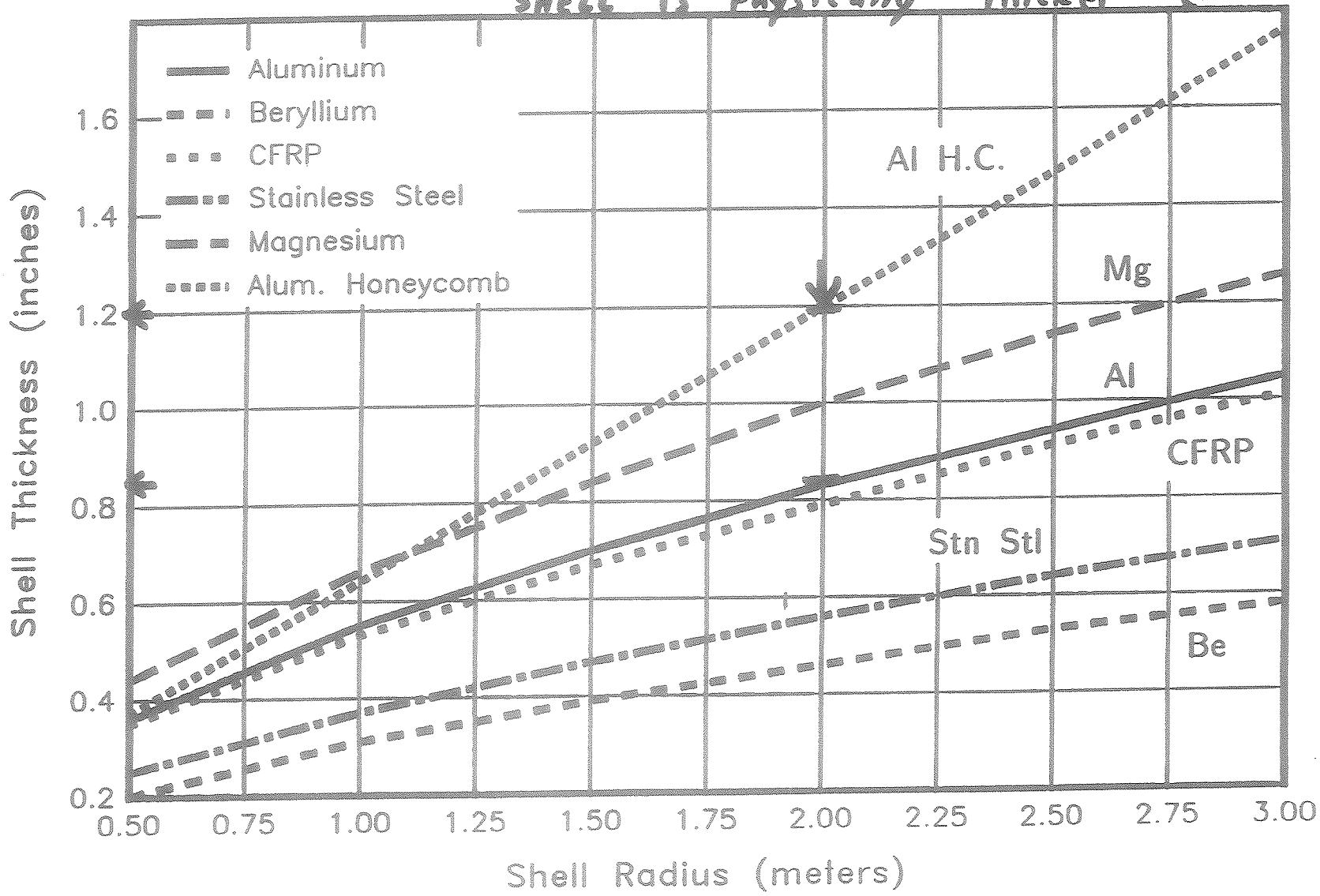


x 4 IMPROVEMENT
Possible but at what cost?

Cylindrical Vacuum Shell Thickness

based on 30psi collapse and L=7.2m

SHELL is Physically Thicker (small effect)



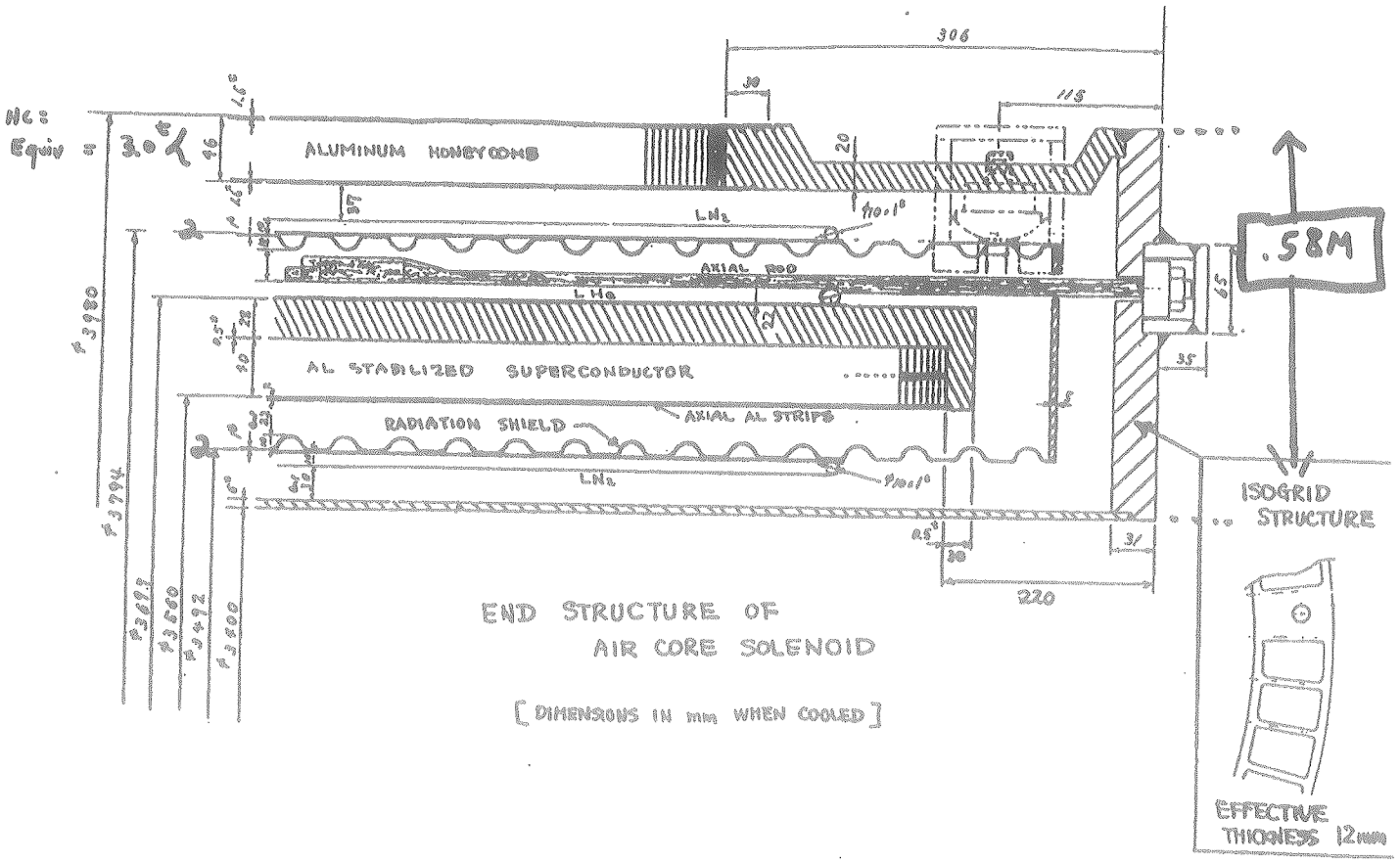
Aluminum Honeycomb Vacuum Shell

1) Thinner in Terms of λ_R (Looks VERY ATTRACTIVE)
2) Physically Thicker than solid Al. (x1.5)
3) END TERMINATIONS ?
4) WELDING Thin - Thick member
5) OUTGASING, VACUUM VESSEL Properties
6) skin attachment To CORE (Glue?)
7) Not much Experience (NONE with VESSELS this SIZE)

$\Rightarrow$ R+D NEEDED

1) WE HAVE TIME IF WE START SOON
2) solid VESSEL = FALL BACK Position

Possible Coil cross SECTION (T Kondo)



Estimated Thickness @ θ = 90°

ITEM	Thickness of Al (cm)	# λ_R
INNER VAC SHELL	.64	.07
RAD. SHIELDS	.2 + .2	.04
CONDUCTOR Al	4.0	.45
Cu/NbTi	—	.16
Insulation	0.1	.01
OUTER SUPPORT CYL.	2.8	.31
OUTER VAC. SHELL	.32 + .3	.07
TOTAL		1.10 λ_R

+ Supports
+ PRELOAD?

III Conclusions / Plans

1) We are making Progress { Toward CONCEPTUAL DESIGN REPORT }

2) Effort could benefit from more help.

a) WANDS + KREBS SALARY = SSC GENERIC R+D ~ GONE

b) John Purcell ?

c) Designer + 1 FTE Eng. at FNAL

d) US-JAPAN Collaboration ⇒ TRAVEL MONEY

e) Industrial Partners? US / JAPAN

f) R+D
- CONDUCTOR fabrication (EFT CABLE SC)
- HONEYCOMB VAC. VESSELS
- LOCKING insulation SCHEMES
- Glue / Preload Techniques
- MATERIALS Properties of RRR = 750 ALUMINUM

g) FWD SC TOROIDS ?

At some point soon we should ask SSCL for $ To make additional Progress.