SDC SOLENOID DESIGN #179

KEK *National Laboratory for High Energy Physics*
Oho 1-1, Tsukuba, Ibaraki-ken, 305, Japan

Tel: 81-298-64-1171
Fax: 81-298-64-7831

18th, June,1992

Dr. R. W. FAST
Fermi National Accelerator Laboratory
P. O. Box 500
Batavia, Illinois 60510
U.S.A.

Dear Ron

Here enclosed is a copy of transparency of my talk representing the magnet subgroup at the SDC collaboration meeting held at KEK on May 26 - 29,'92.

It would be appreciated, if you may file the copy into the SDC D/N at Fermilab.

Regards
Akira Yamamoto

P.S. I am now at Lynn Lake,Canada. You may reach me, when you need it, at the TEL/FAX number of 204-356-8318 (Dedicated line).

CONTENTS

- Progress of Design Study
  - Boundary Condition Revised
  - Support System and Impact on Transparency
- Progress of Prototype R&D
  - Conductor
  - Coil Winding
  - Vacuum Vessel (Honeycomb / Isogrid)
- Summary

REPORT ON SUPERCONDUCTING MAGNET

Akira Yamamoto

KEK

Presented SDC Collaboration Meeting held at KEK on
May 26, 1992

THIS IS A CO-OPERATIVE WORK

AMONG

FNAL

KEK

SSCL

P. S. ASSOCIATE.

TOSHIBA

FURUKAWA ELECTRIC.

IHI / SUMITOMO LIGHT METAL

Table 5-1
General requirements of SDC solenoid.

Magnet envelope		
Cryostat	Inner radius	1.70 m
	Outer radius	2.05 m
	Total half length	4.389 m
Nominal magnetic field		2 T
Transparency	(η=0)	1.2 X_0
		0.25 λ_I
Cool down time		< 14 days
Quench recovery time		< 4 hr

Superconducting Magnet

- Technical challenges : 1. material transparency ~ $1.2X_0$
  2. compressive force (1700 tonf)

  in addition to predictable and stable operation
  safety against quenches

- Solutions :

[A] $\frac{E(\text{stored energy})}{M(\text{cold mass})} = 7.4$ kJoule/kg ($\Delta = 0.4X_0$)

~ 5 in past

→ development of high strength aluminum stabilized superconductor

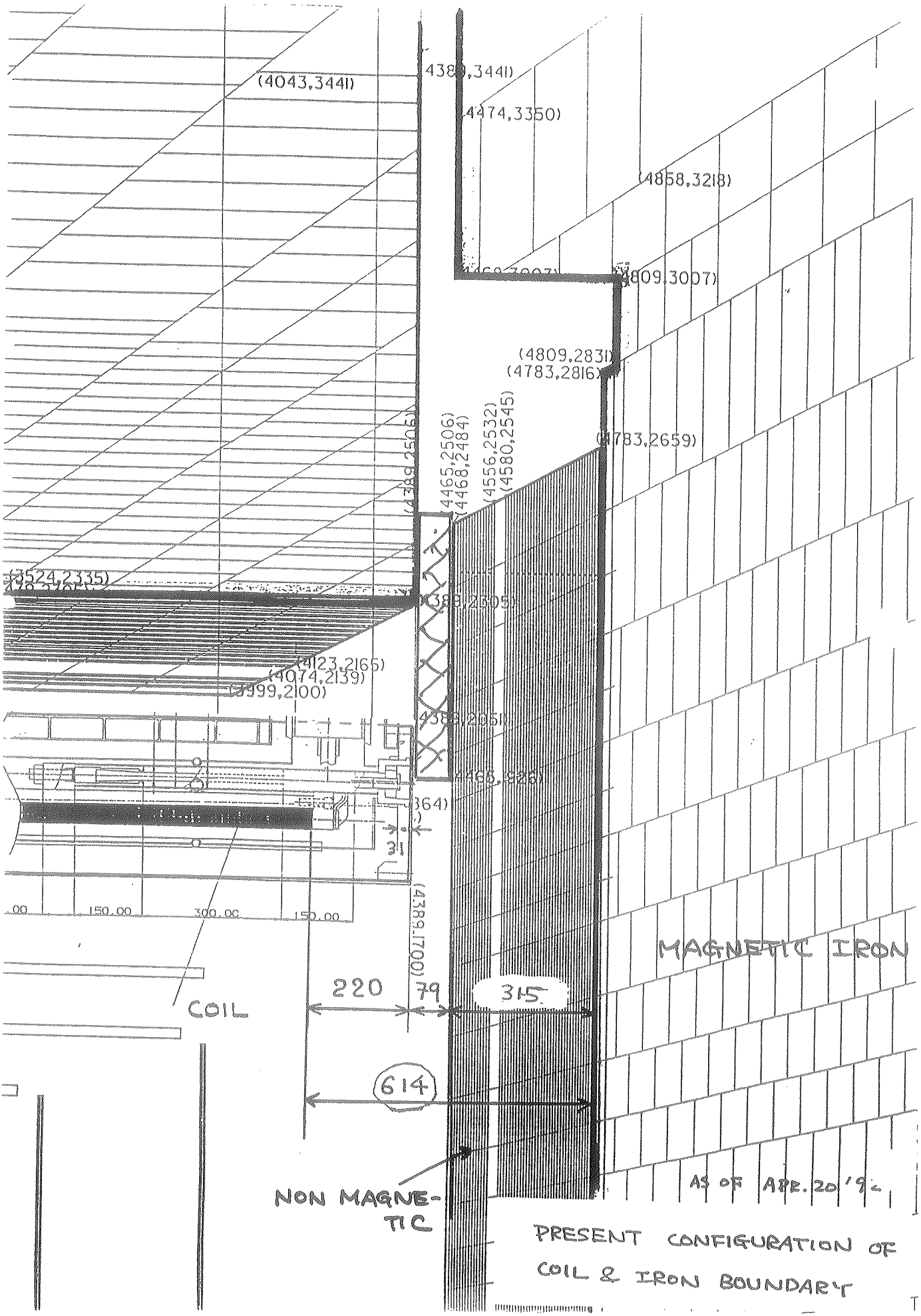
→ increase of quench propagation velocity by pure aluminum strips

[B] lighter material for outer vacuum vessel ($\Delta = 0.2X_0$)

→ isogrid (grid-stiffened) shell or brazed aluminum honeycomb panel

PARAMETERS IN PHYSICS AND ENGINEERING

Requirements from Physics	Engineering Parameters important
	<u>Coil</u>
- Magnetic Field	- <u>Mechanical Safety at 2 T</u>
$Bc = 2$ T	Max. Stress (2τ) < 60 MPa
$Fz = 1300$ tonnes	(@ $Y.S._{0.2\%} = 67$ MPa)
	associated with Outer Support Cylinder
- Tranparency	- <u>Stability in Superconductivity</u>
$X = 1.2\ X_o$ (@$\eta = 0$)	MQE $= 0.27$ J
$< 3.0\ X_o$ (@$\eta = 1.5$)	(same level as that in TOPAZ, CDF)
	- <u>Thermal Safety after QUENCH</u>
$\lambda_l = 0.25\ \lambda_l$ (@ $= 0$)	$T_{max} \lesssim 100$ K
	$\Delta\varepsilon < 0.05$ % (elastic condition)
	<u>Cryostat (Vacuum Wall)</u>
	- Stability against Buckling
	$P_{bkl} > 2$ atm


(4043,3441)
(4474,3350)
(4858,3218)
(4809,3007)
(4809,2831)
(4783,2816)
(4783,2659)
(4465,2506)
(4468,2484)
(4556,2532)
(4580,2545)
(4123,2165)
(4074,2139)
(3999,2100)
150.00
300.00
150.00
220
79
315
614
COIL
MAGNETIC IRON
NON MAGNE-TIC
AS OF APR. 20 '92
PRESENT CONFIGURATION OF COIL & IRON BOUNDARY

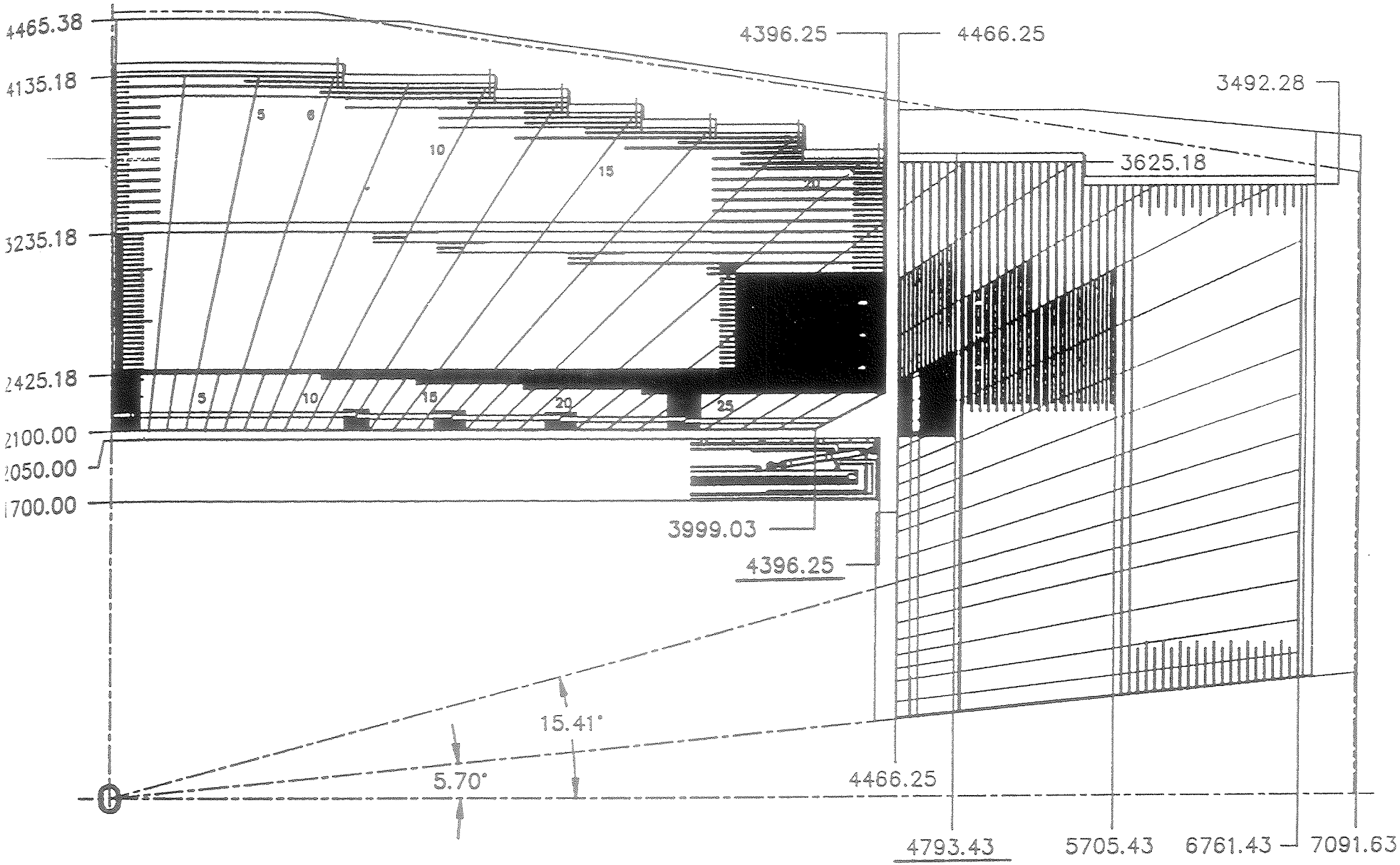


FIG. 6-39. Barrel Calorimeter—a quarter cross section of the tile/fiber central calorimeter. The EM sections are fabricated with cast lead alloy; the hadron sections are formed by stacked steel plates welded together. A shower maximum detector is included in the EM section.

According to recent technical decision for calorimeter to take feromagnetic iron abosorber option:

Axial Distance b/w Coil and Iron-end:	47 - 62 cm
Maximum Stress (2 τ) in the Coil :	52 - 54 MPa
Axial Compressive Force * :	1100- 1300 t
Axial Decentering Force :	20 - 15 t/cm

(* Axial Compressive Force in Air : 1,700 tonnes)

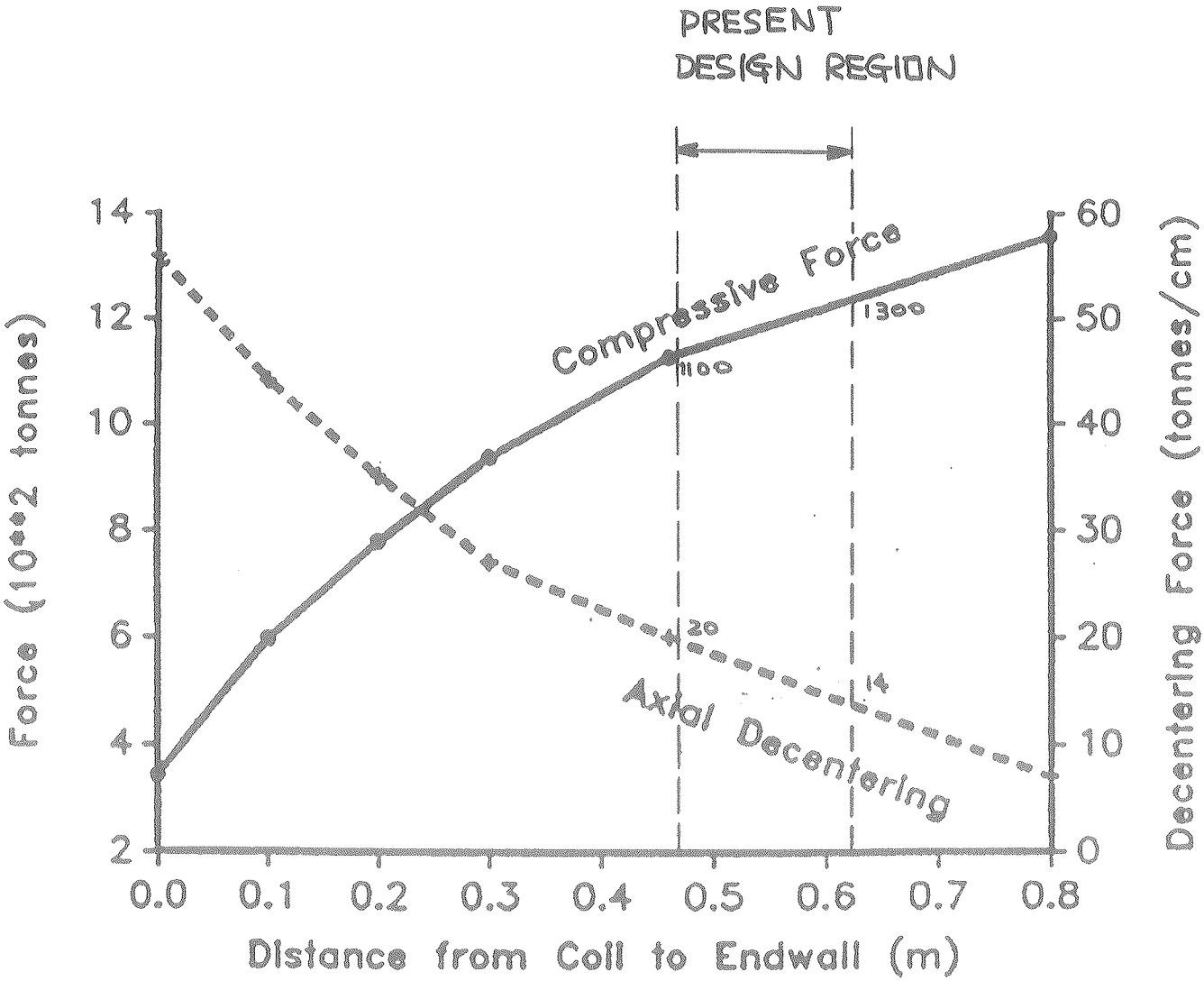


FIG. 5-1. Coil compressive force and axial decentering force as a function of the axial distance between the end of the coil and the iron endcap calorimeter.

Table 5-2
Baseline design parameters of SDC solenoid.

Dimensions:		
Cryostat	Inner radius	1.70 m
	Outer radius	2.05 m
	Half length	4.389 m
Coil	Effective radius	1.84 m
	Half length	4.12–4.18 m
Conductor	Thickness	44 mm
Outer support cylinder	Thickness	31 mm
Electrical parameters		
Central field		2.0 T
Nominal current		8,000 A
Inductance		4.6 H
Stored energy		146 MJ
Stored energy / cold mass		7.4 kJ/kg
Typical charging time		1 hour
Mechanical parameters		
Effective cold mass		20 tonnes
Total weight		25 tonnes
Radial magnetic pressure		1.6 MN/m^2
Axial compressive force		11 MN (15)

Table 5-3
Transparency of the solenoid.

Element		Thickness [mm]	X_0	λ_0	Saving X
Outer vac. wall	(Isogrid)	11	0.138	0.0321	$\Rightarrow \sim 0.2X_0$
	(Honeycomb)	(7.1)	(0.080)	(0.0180)	
Outer rad. shield		2.0	0.022	0.0051	
Outer sup. cylinder		31.0	0.348	0.0787	E/M $\Rightarrow \sim 0.4X_0$
Superconductor					=7.5 kJ/kg
(Al stab)		39.0	0.438	0.0990	
(Nb.Ti/Cu)		2.9	0.181	0.0167	
(GFRP)		3.1	0.016	0.0058	
(Al Strip)		2.0	0.022	0.0051	
Inner rad. shield		2.0	0.022	0.0051	
Inner vac. wall		6.0	0.067	0.0152	
Super-insulation		2.0	0.007	0.0023	
Total	(w/ isogrid)		1.261	0.2651	$\sim 0.6X_0$
	(w/ honeycomb)		(1.203)	(0.2510)	

Table 5-5
Design parameters of the SDC superconductor.

Aluminum stabilized superconductor	
Superconductor material	Nb Ti/Cu
Stabilizer	Al (99.999% +200 ppm Zn)
Area ratio (Nb/Ti/Cu/Al)	1/1/29.8
Conductor size	43.8×4.37 mm^2
Superconductor strand	
Strand diameter	1.277 mm
Nb Ti filament diameter	20 μm
Number of filaments.	4100
Superconductor cable	
Overall size	6.4×2.5 mm^2
Number of cables	10 (2×5)
Cabling pitch	50–60 mm
J_c in Nb Ti (at 5 T, 4.2 K)	2500 A/mm^2
Critical current (at 5 T, 4.2 K)	16,000 A
Characteristics of stabilizer	
RRR (Cu)	100
RRR (Al)	500
Yield Strength of Al (at 77 K)	67 MPa
Shear strength b/w Cu / Al	20 MPa
Conductor welding joint	
Joint resistance (at 4.2 K)	$< 10^{-9}\ \Omega$

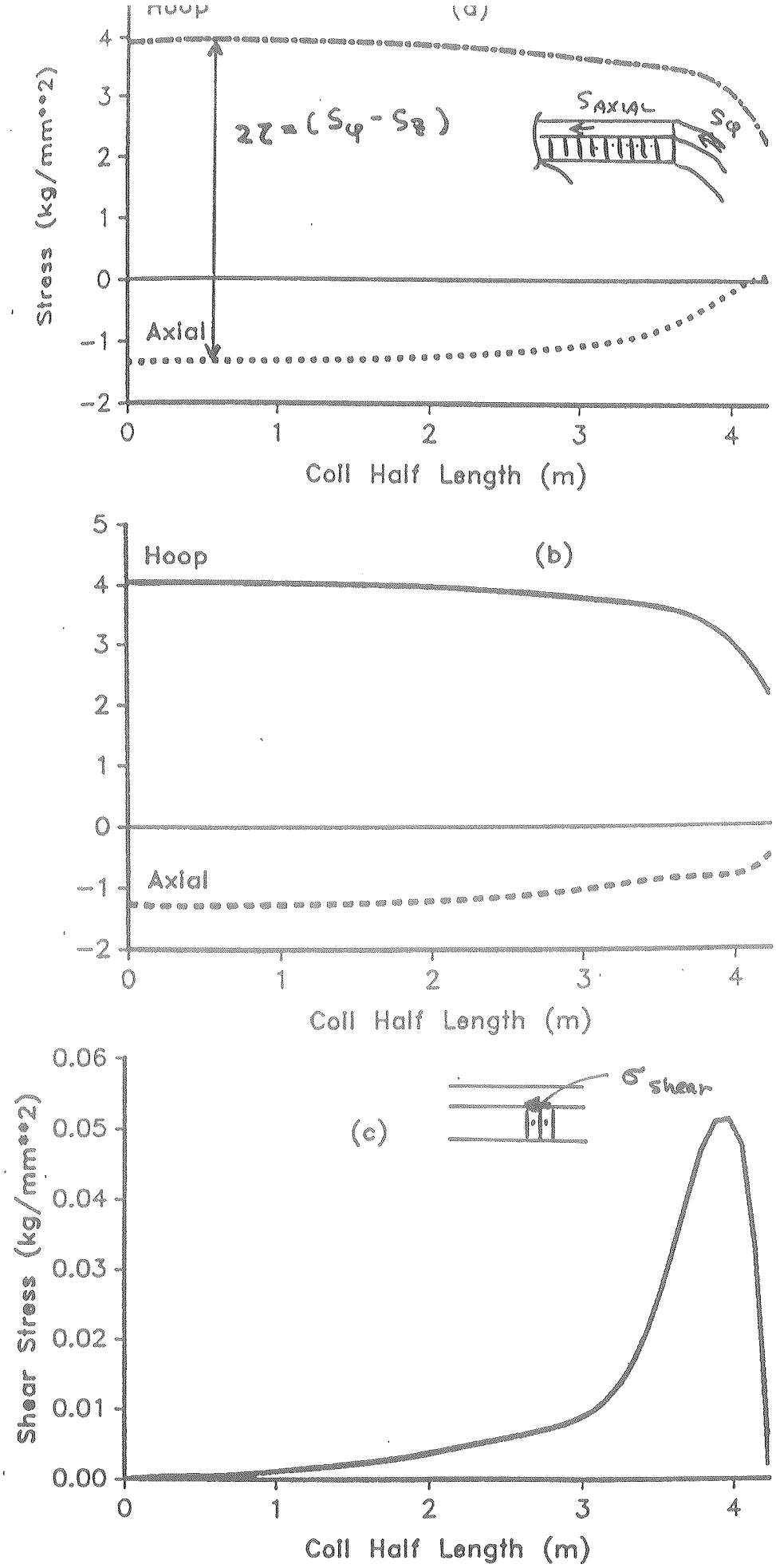


FIG. 5-9. Stresses as a function of axial position (a) on support cylinder, (b) on superconducting coil, and (c) on epoxy joint.

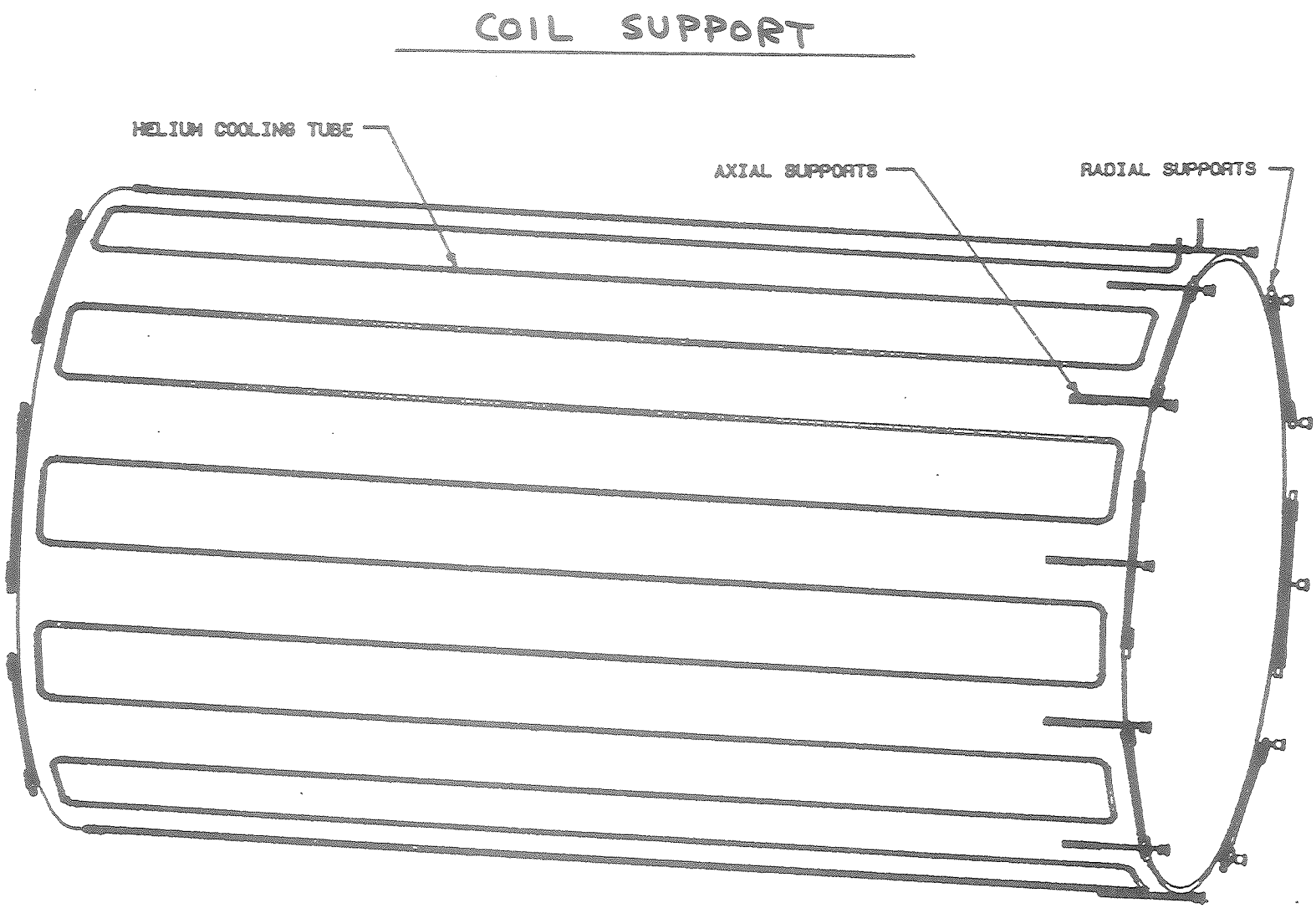
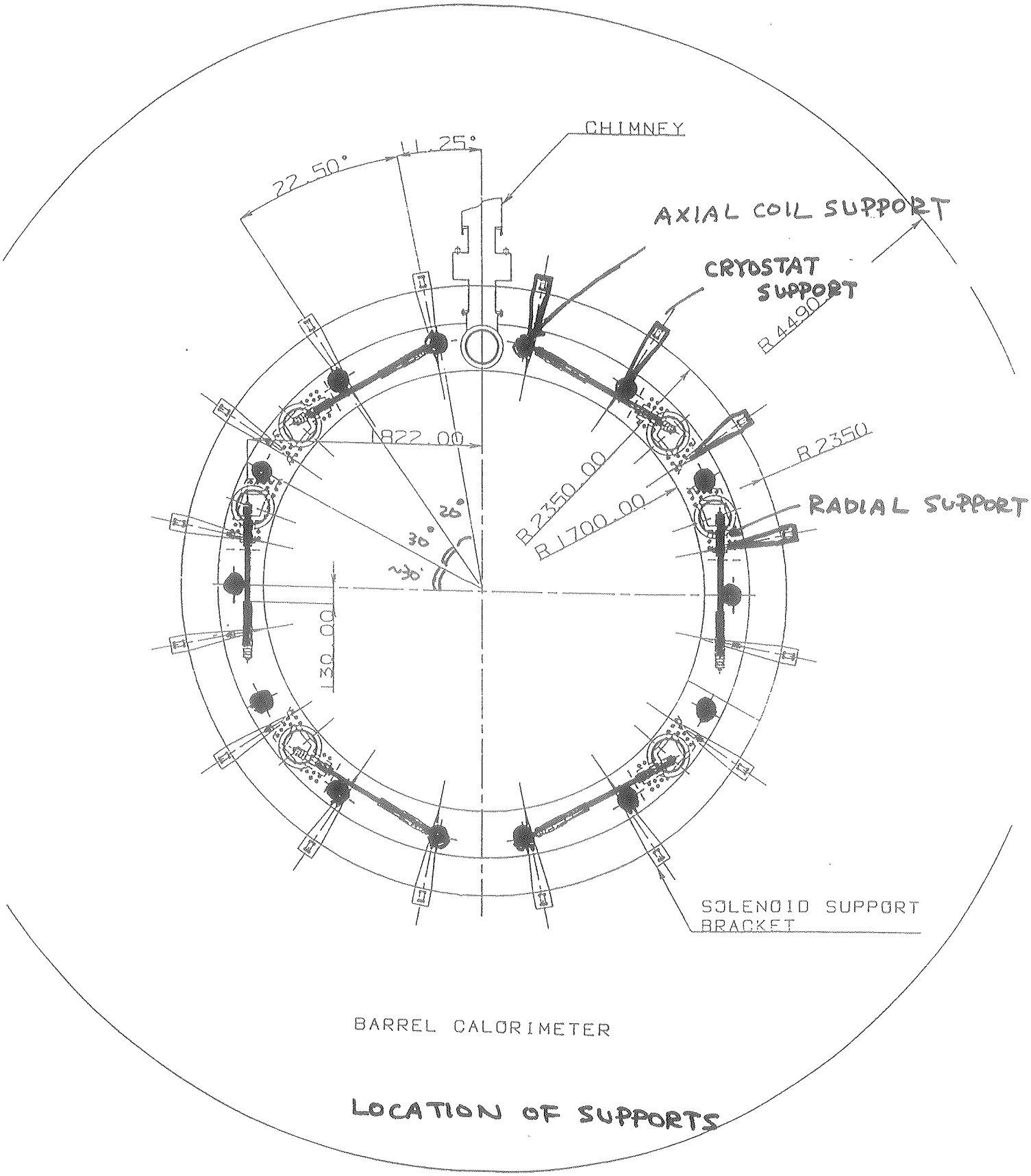
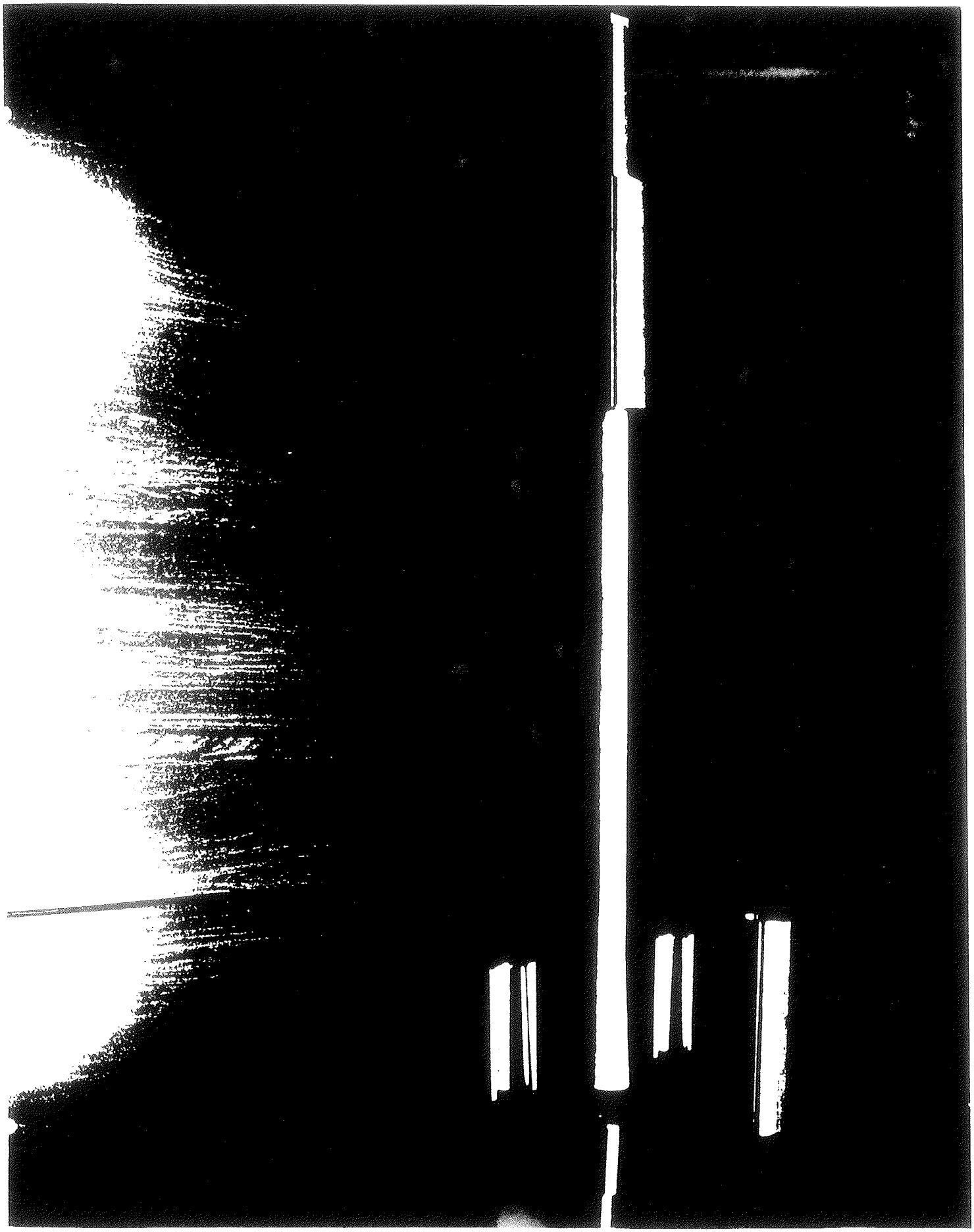


FIG. 5-7. Solenoid cold mass. Radial supports are on both ends, axial supports are on one end only.

COIL SUPPORT DESIGN



LOCATION OF SUPPORTS



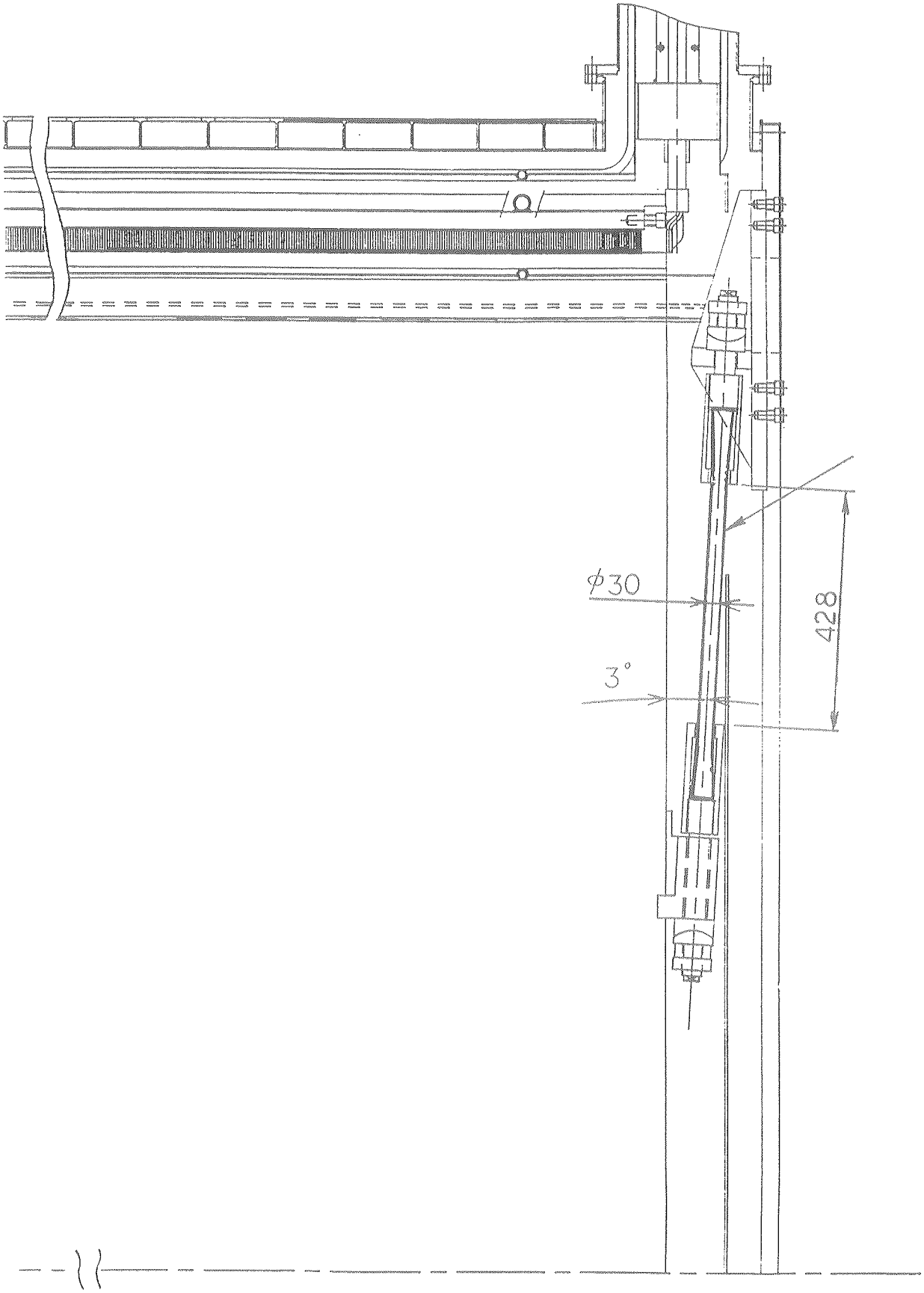
DESIGN OF AXIAL SUPPORTS OF THE COIL

	TDR	RE-REVISED (APRIL 28)
MATERIAL FOR SUP.	GFRP	GFRP
TYPE	SINGLE	SINGLE
DIA. OF SUPPORT	ϕ20mm	ϕ20mm (18)
EFFECTIVE LENGTH	300mm	300mm (240)
MATERIAL FOR BASE	Ti-Alloy	Al-Alloy(7075)
DIA. OF BASE	ϕ50mm	ϕ50mm
LENGTH OF BASE	~150mm	~150mm
# OF AXIAL SUPPORT	14	14
TENSILE FORCE/14RDS.	$\geq$300tonnes	$\geq$300tonnes
BUCKLING FORCE/14RDS.	100tonnes	100tonnes
THERMAL LOADS/14RDS.	~600mW	~600mW
BUMP IN TRANSPARENCY	3.7	1.4
(MAX) at η=1.4	at tR=60mm	(tR=60mm)

Table 5-8

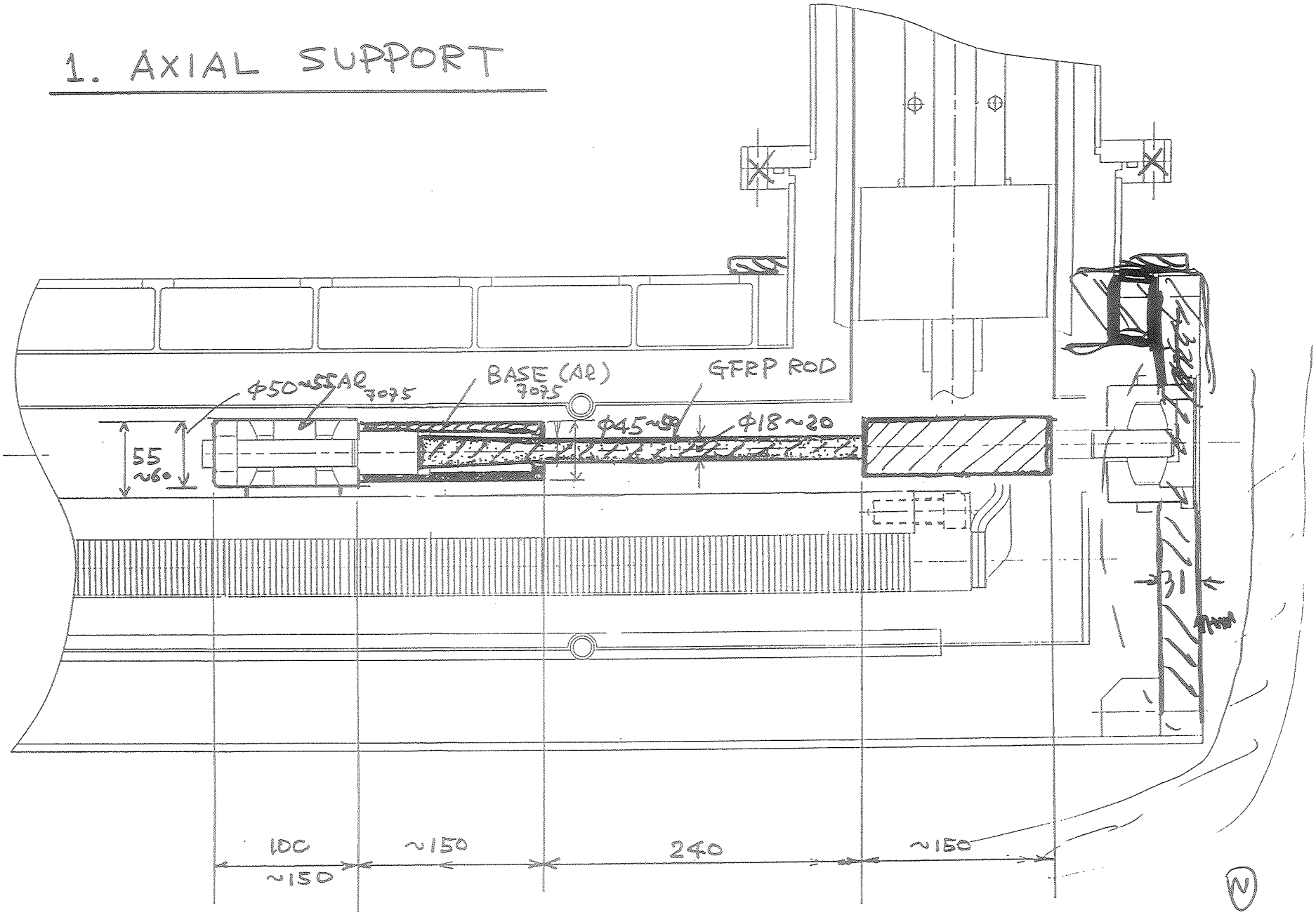
Design load of the coil support system. (RADIAL SUPPORT)

Function		Upward	Downward	Left/right	F/B-ward
Global force					
Coil weight	(ton)	−20	20		
Applied load	(ton)	40	40	40	40
Design load	(ton)	20	60	40	40
Force constant	(t/mm)	2	2	2	2
Support stiffness	(t/mm)	>10	>10	>10	>10


φ30
3°
428

155.00
300.00
155.00
20.00
SUS
A1
(A1-SUS)
R1700.00
R1840.00
R1930.00
R2050.00

1. AXIAL SUPPORT



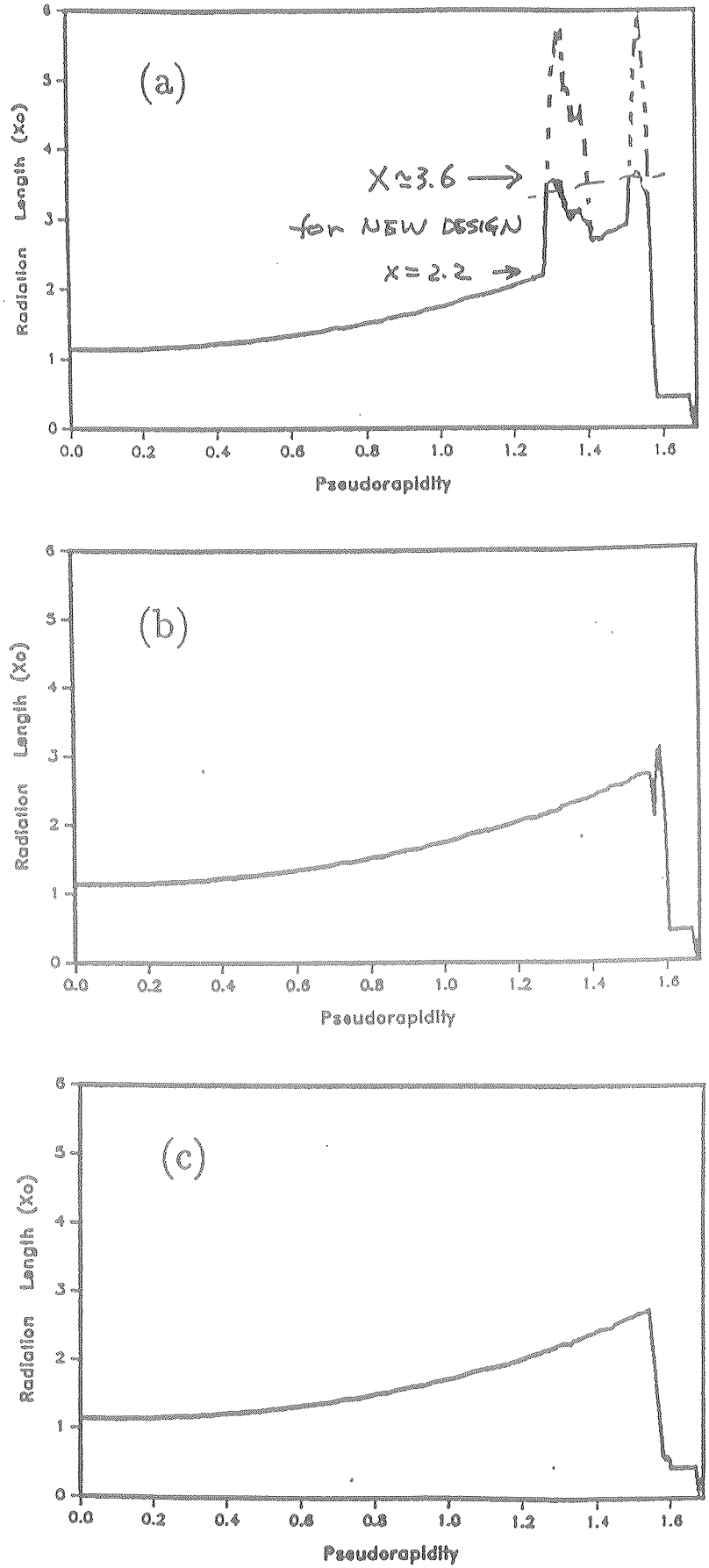


FIG. 5-5. Thickness of solenoid, in radiation lengths, as a function of pseudorapidity. (a) is a path through an axial support and is typical of 6% of the circumference, (b) is through the metallic end fitting of a radial support, 15% of the circumference, and (c) is through the GFRP section of a radial support, 21% of

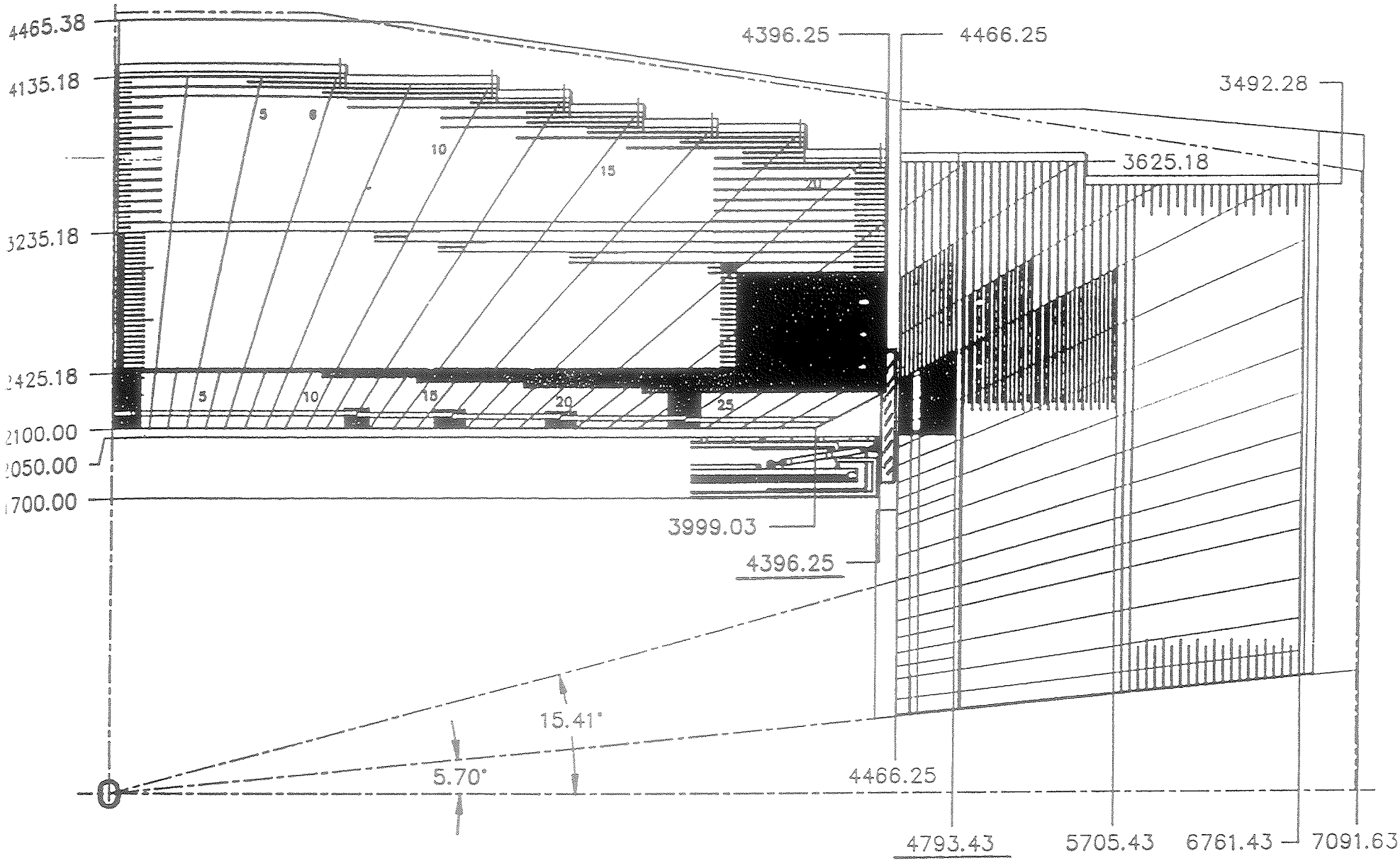


FIG. 6-39. Barrel Calorimeter—a quarter cross section of the tile/fiber central calorimeter. The EM sections are fabricated with cast lead alloy; the hadron sections are formed by stacked steel plates welded together. A shower maximum detector is included in the EM section.

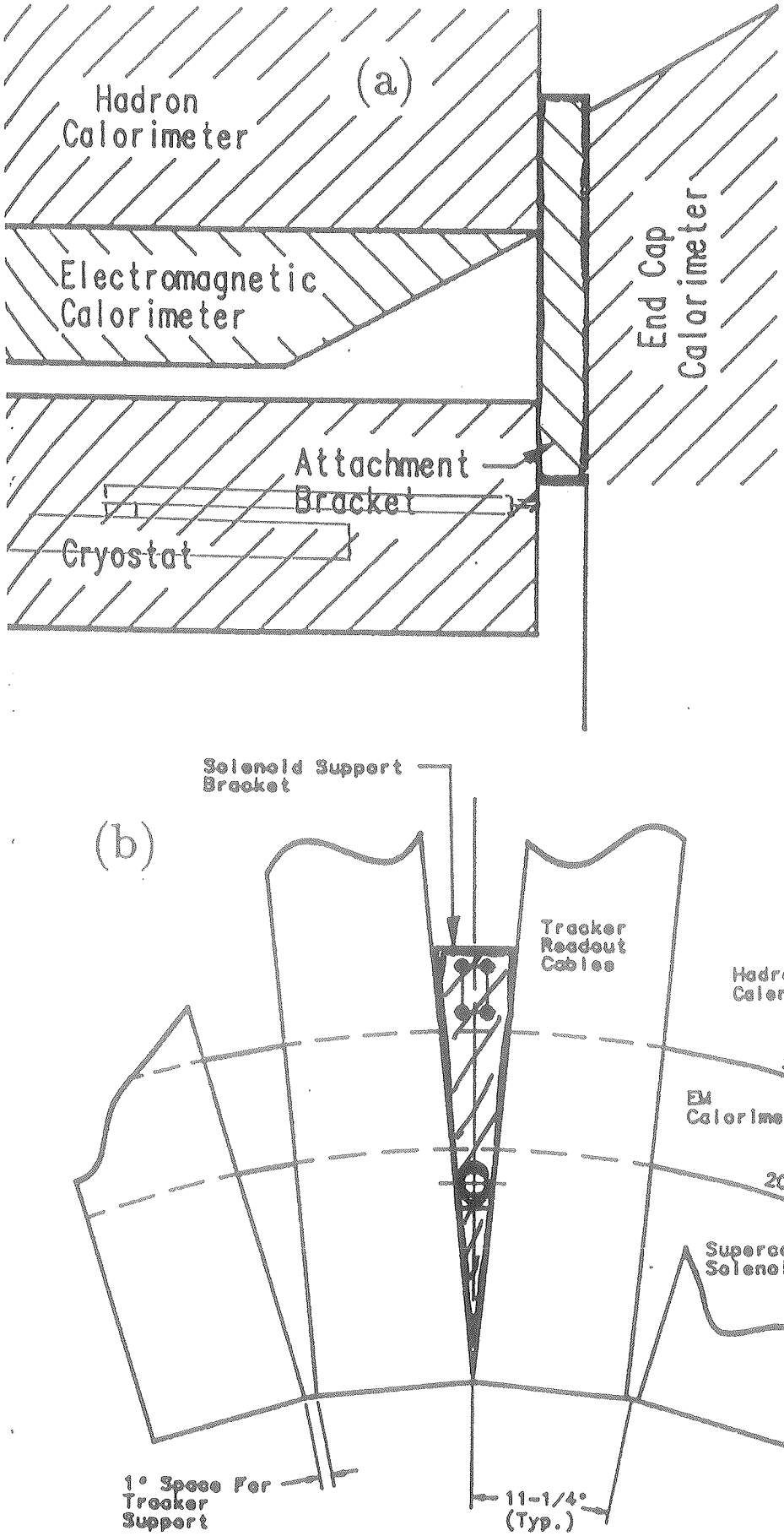
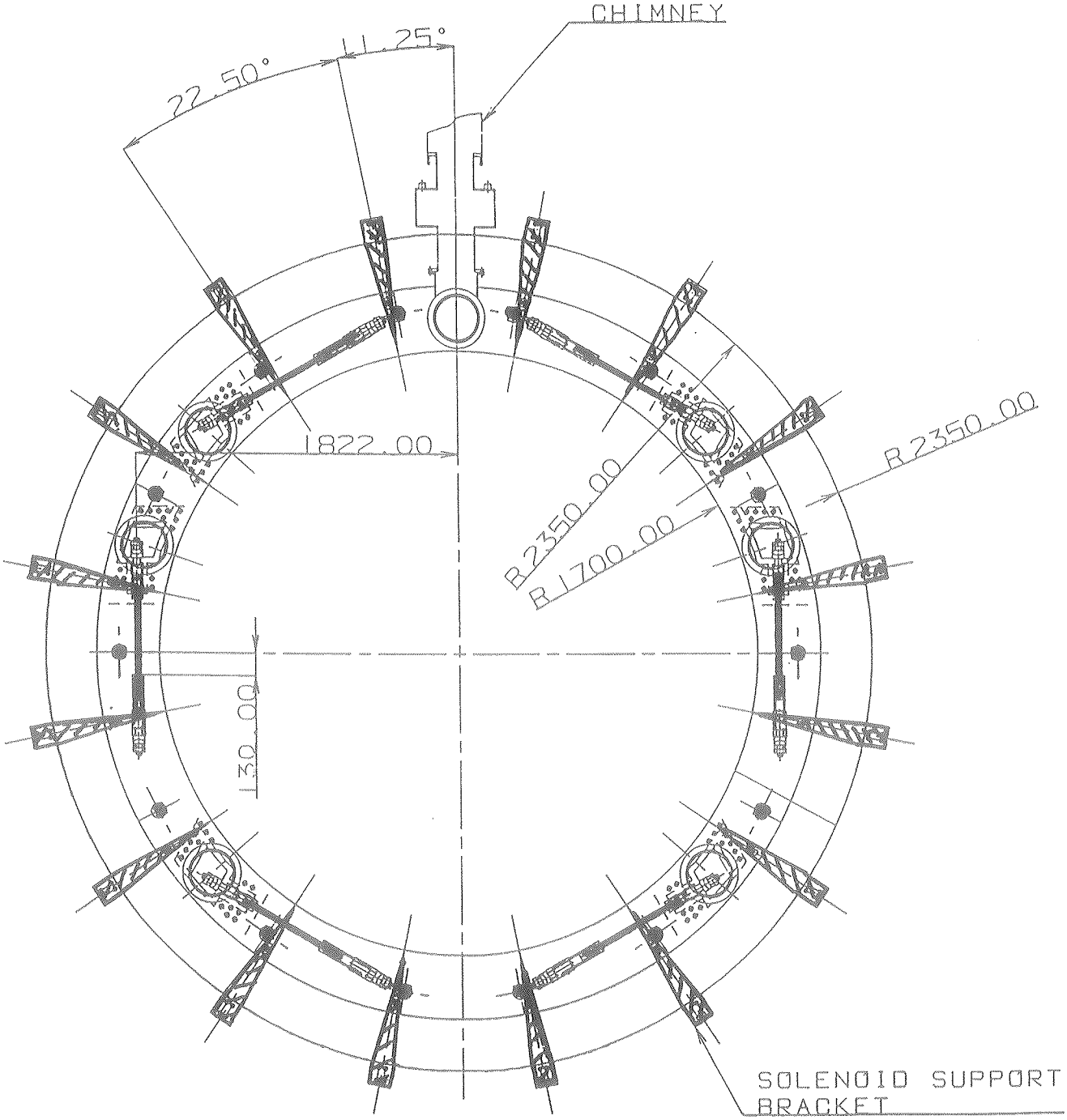
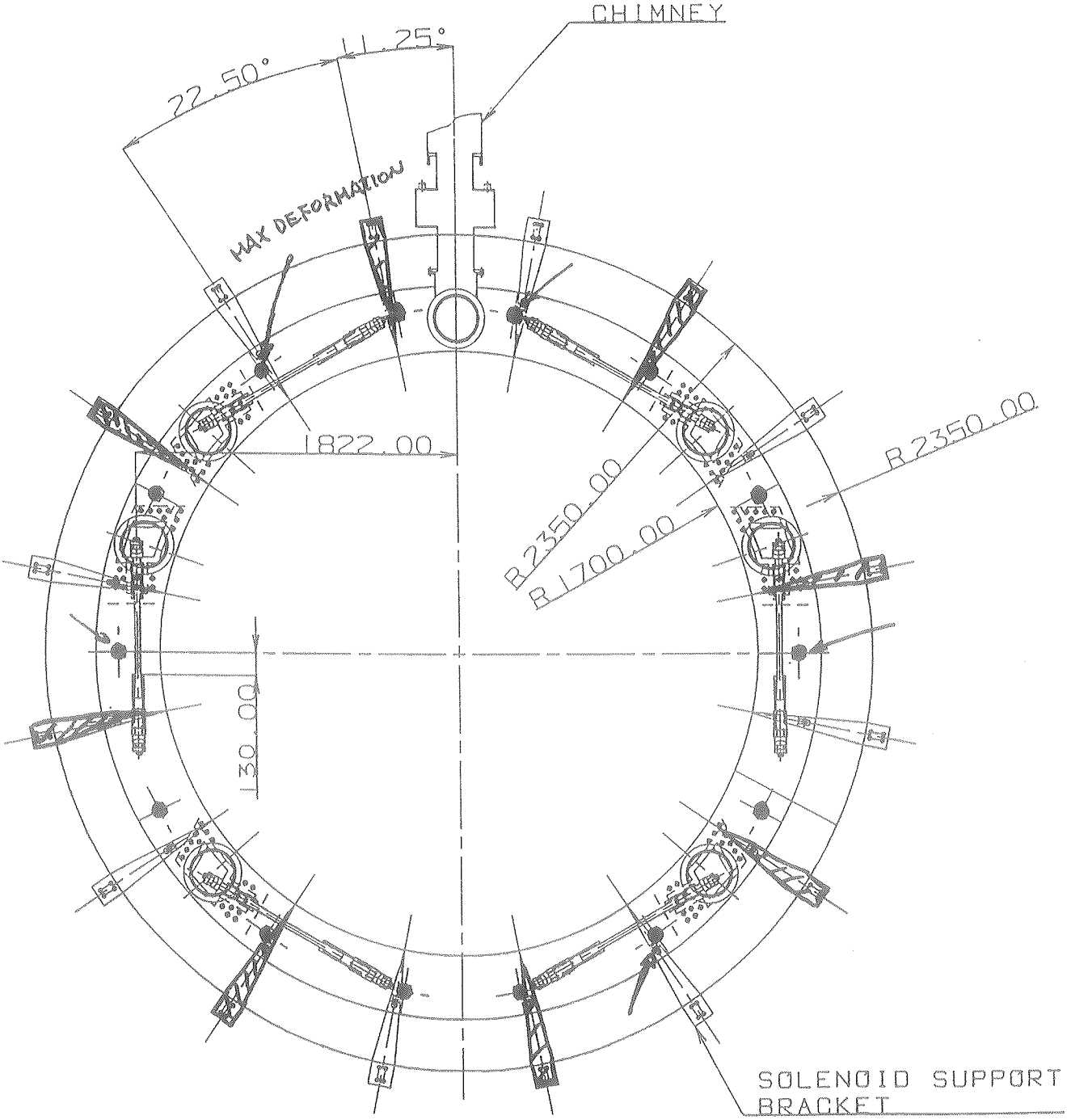


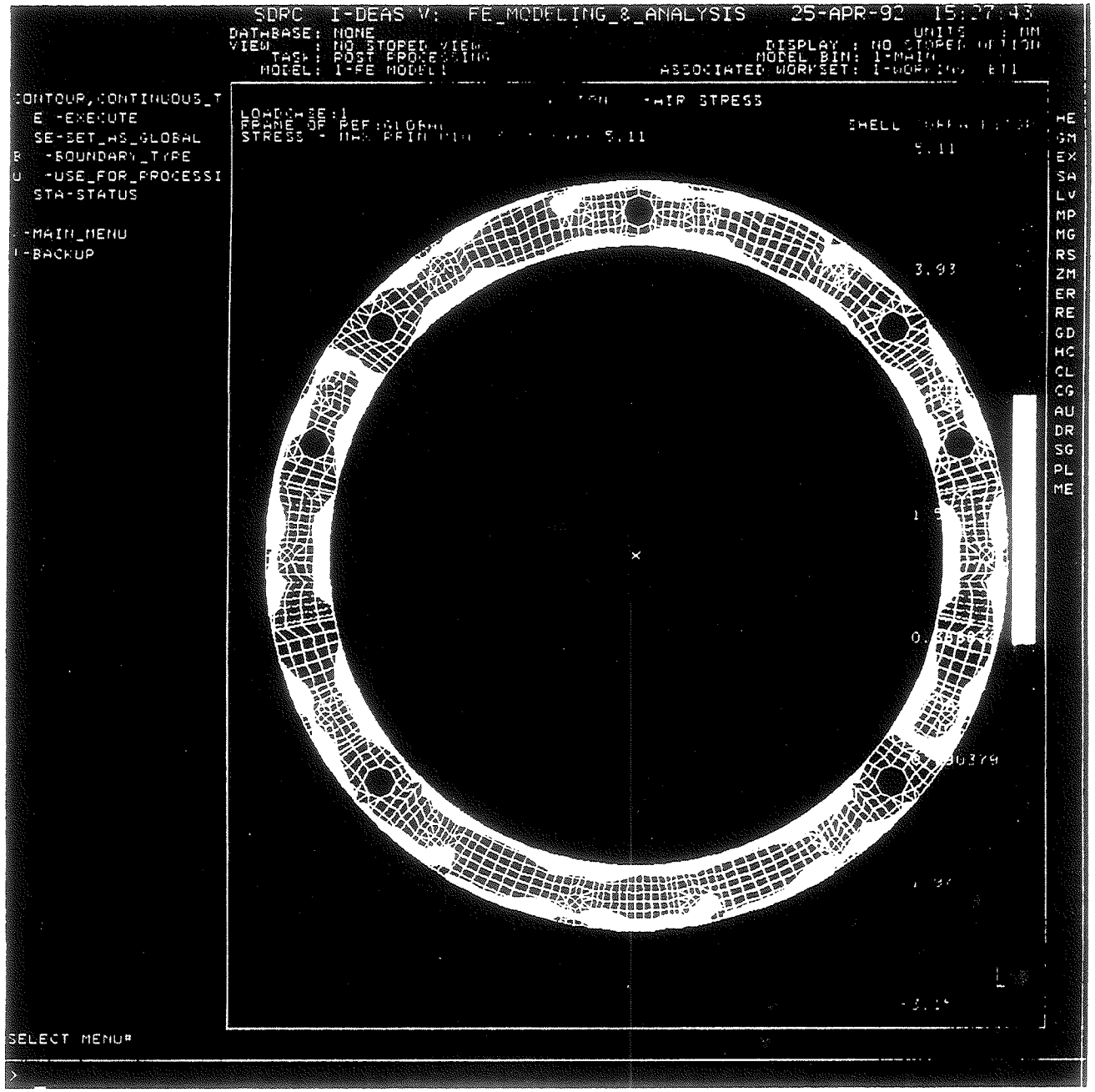
FIG. 5-13. Cryostat attachment to the barrel hadron calorimeter, (a) section view, (b) enlarged end view.



BARREL CALORIMETER



BARREL CALORIMETER



(−) (−)

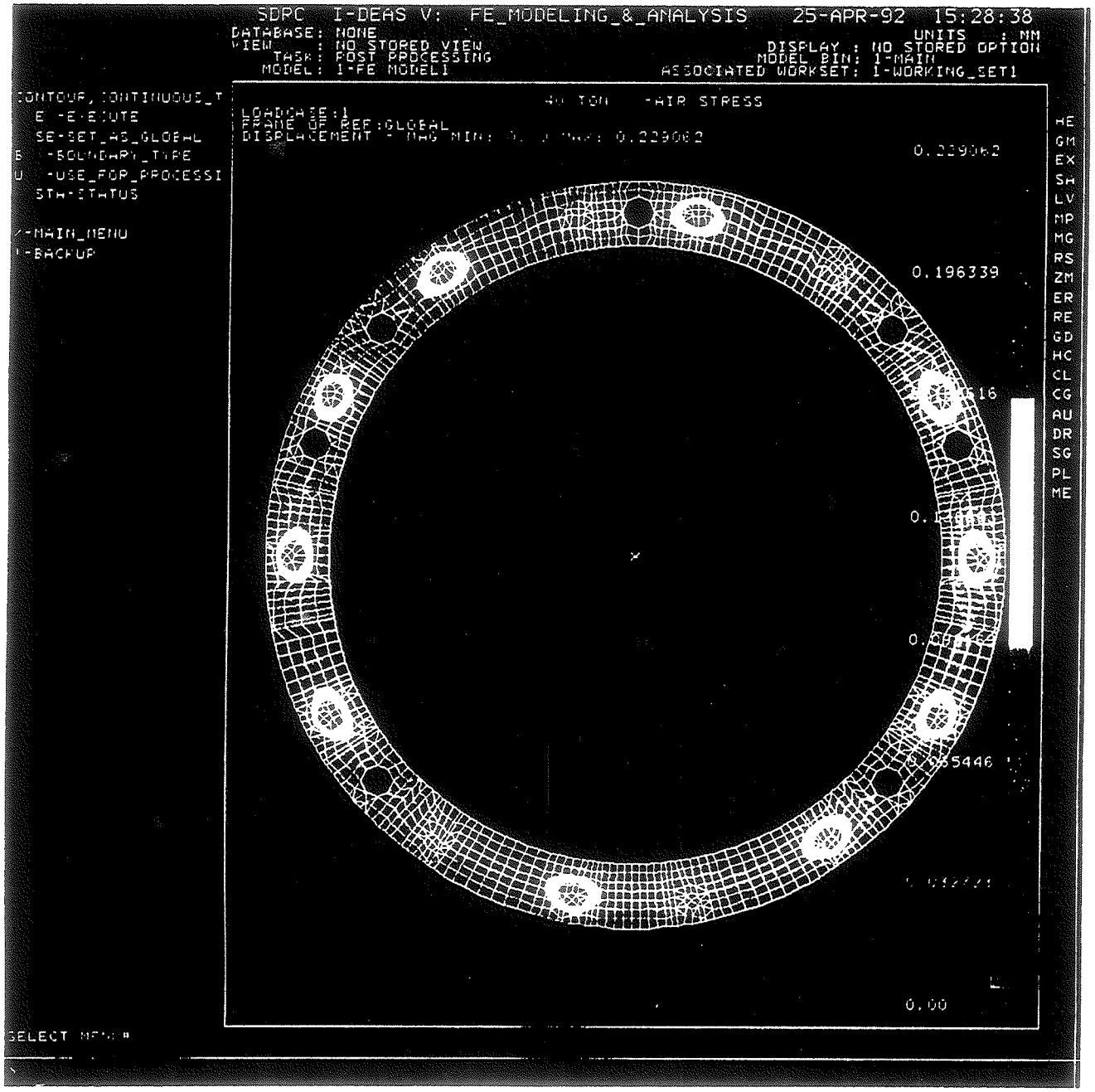
40 TON/14

25mm

5.11kg f/mm²

STRESS

8 FOLD SYM.

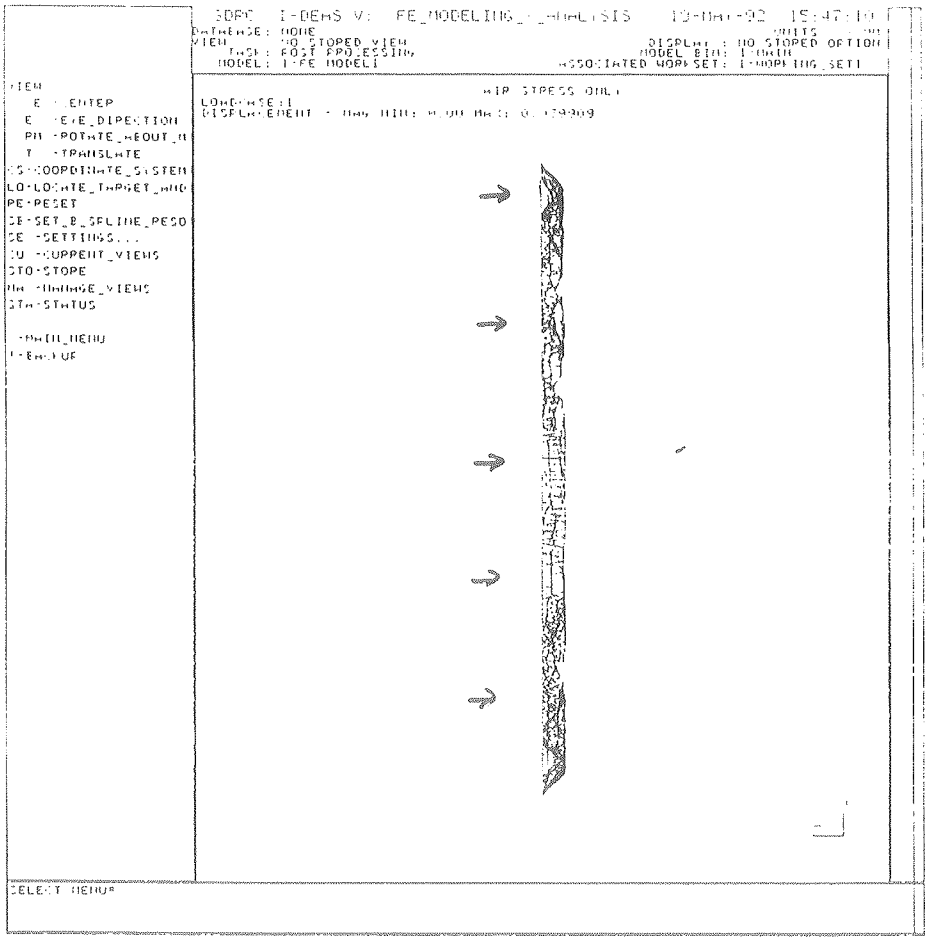


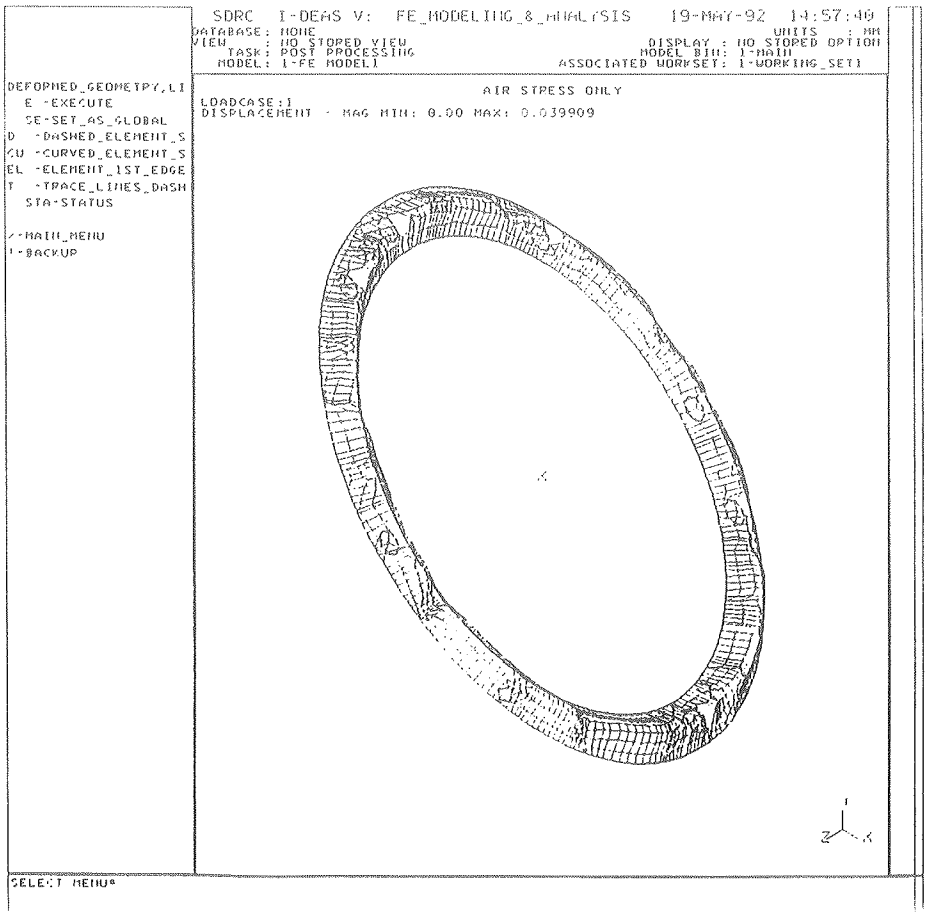
(-) (-)

40 TON/IN

DISPLACEMENT

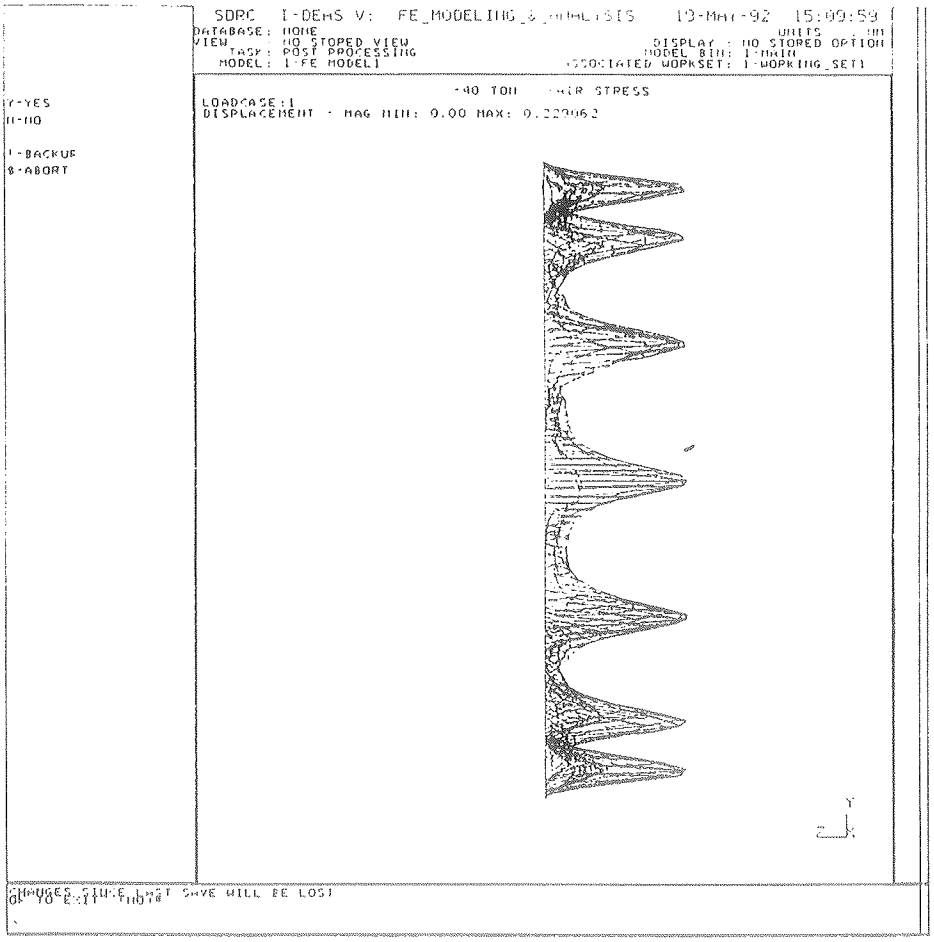
8 FOLD SYM

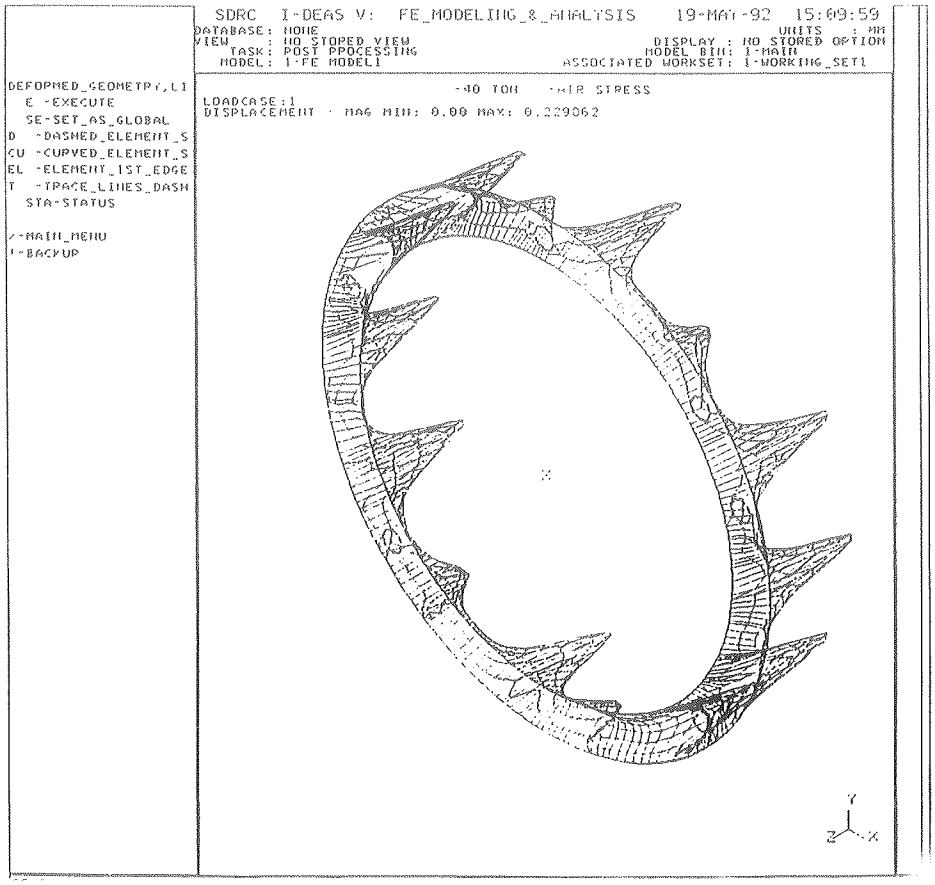




大気圧のみ

AIR ONLY


SDRC I-DEAS V: FE_MODELING_&_ANALYSIS 19-MAY-92 15:09:59
DATABASE: NONE
VIEW: NO STORED VIEW
TASK: POST PROCESSING
MODEL: 1-FE MODEL1
UNITS : MM
DISPLAY : NO STORED OPTION
MODEL BIN: 1-MAIN
ASSOCIATED WORKSET: 1-WORKING_SET1
Y-YES
N-NO
1-BACKUP
8-ABORT
40 TON AIR STRESS
LOADCASE:1
DISPLACEMENT - MAG MIN: 0.00 MAX: 0.229062
CHANGES SINCE LAST SAVE WILL BE LOST
OK TO EXIT


SDRC I-DEAS V: FE_MODELING_&_ANALYSIS 19-MAY-92 15:09:59
DATABASE: NONE
VIEW: NO STORED VIEW
TASK: POST PROCESSING
MODEL: 1-FE MODEL1
UNITS : MM
DISPLAY : NO STORED OPTION
MODEL BIN: 1-MAIN
ASSOCIATED WORKSET: 1-WORKING_SET1
DEFORMED_GEOMETRY,LI
E -EXECUTE
SE-SET_AS_GLOBAL
D -DASHED_ELEMENT_S
CU -CURVED_ELEMENT_S
EL -ELEMENT_1ST_EDGE
T -TRACE_LINES_DASH
STA-STATUS
/-MAIN_MENU
1-BACKUP
40 TON AIR STRESS
LOADCASE:1
DISPLACEMENT - MAG MIN: 0.00 MAX: 0.229062

AIR & ΔF_8
(-)

SUPPORT FOR CRYOSTAT &BULKHEAD STRESS ANALYSIS

	16 FOLD SYMMETRY		8 FOLD SYMMETRY	
	MAX STRESS	DISPLACE-MENT	MAX STRESS	DISPLACE-MENT
1 ATM. (-40T)	0.65 kgf/mm2 [6.5 MPa]	0.04 mm	0.78	0.04
1 ATM+Fz(40ton) ← →	3.1	0.16	3.1	0.16
1 ATM-Fz(-40T) ← ←	4.4	0.23	5.1	0.23

CRYOSTAT VACUUM WALL DESIGN

Table 5-6
Outer vacuum shell requirements.

Vacuum load	1 atm radial and axial
Design standard	
Radial collapse pressure	> 2 atm
Axial buckling load	> 2 atm
Allowable stress	Based on ASME press. vessel code
Material	Aluminum alloy
Construction	Welded joints

- HOW WE MAY SAVE MATERIAL?

  ⇒ HONEYCOMB / ISOGRID IN OUTER VESSEL

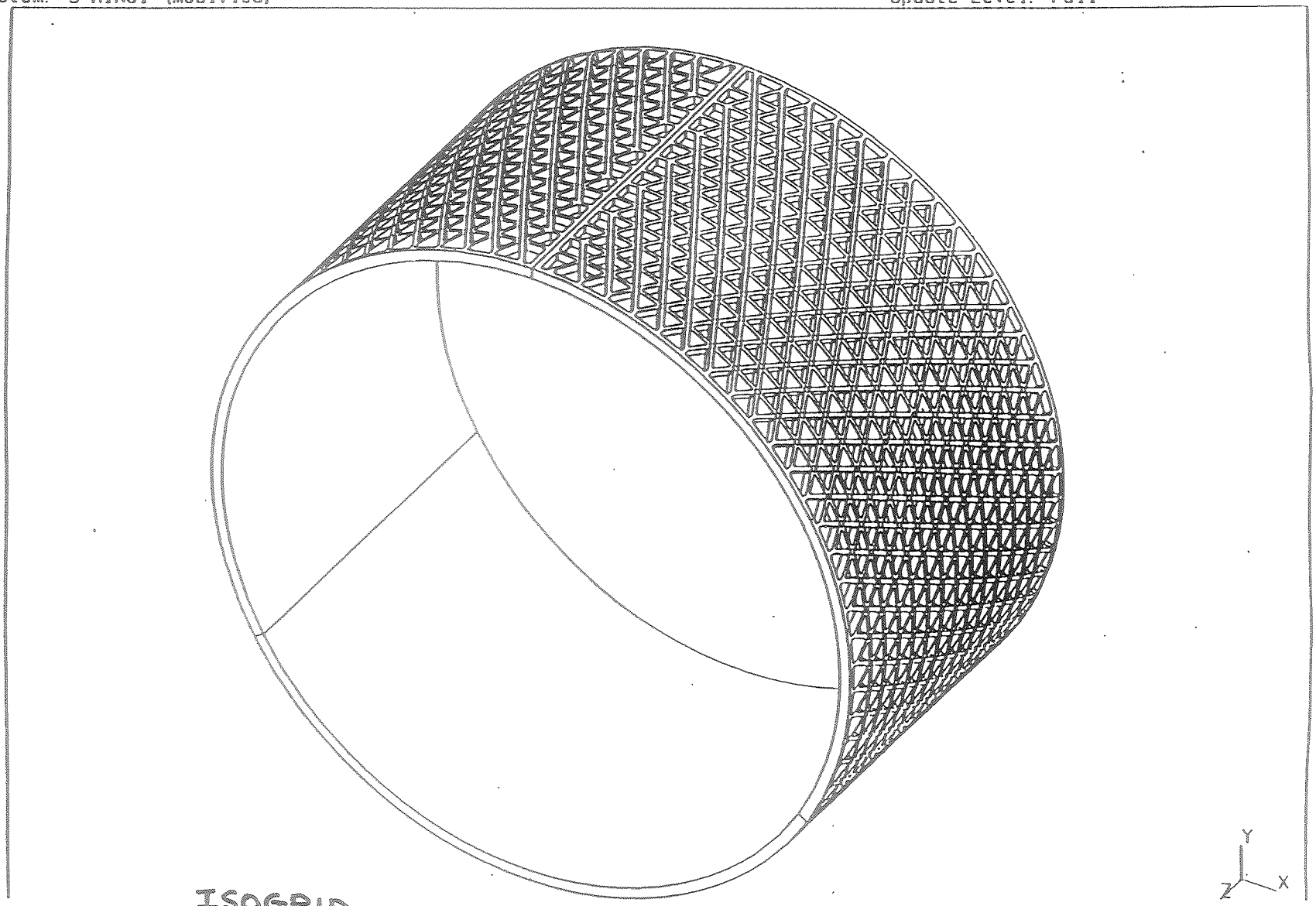
Table 5-7
Comparison of solid, isogrid, and honeycomb outer vacuum shells.

	Solid	Isogrid	Brz. honeycomb
Aluminum alloy	5083	5083-H32	6951/4045-T6
Total thickness (mm)	27	46	46
Skin thickness (mm)	—	4.0	3.0 + 3.0
Skin layers	—	single	double
Node configuration	—	triangle	hexagon
Effective thickness (mm)	27	11	7
Weight reduction ratio	1	1/2.5	1/3.9
Radiation thickness (X_0)	0.303	0.123	0.079
Maximum size of plate (m × m)	2 × 6.4	2.2 × 4.3	1.2 × 4
Units to be welded	8 (= 2 × 4)	12 (= 3 × 4)	21 (= 3 × 7)

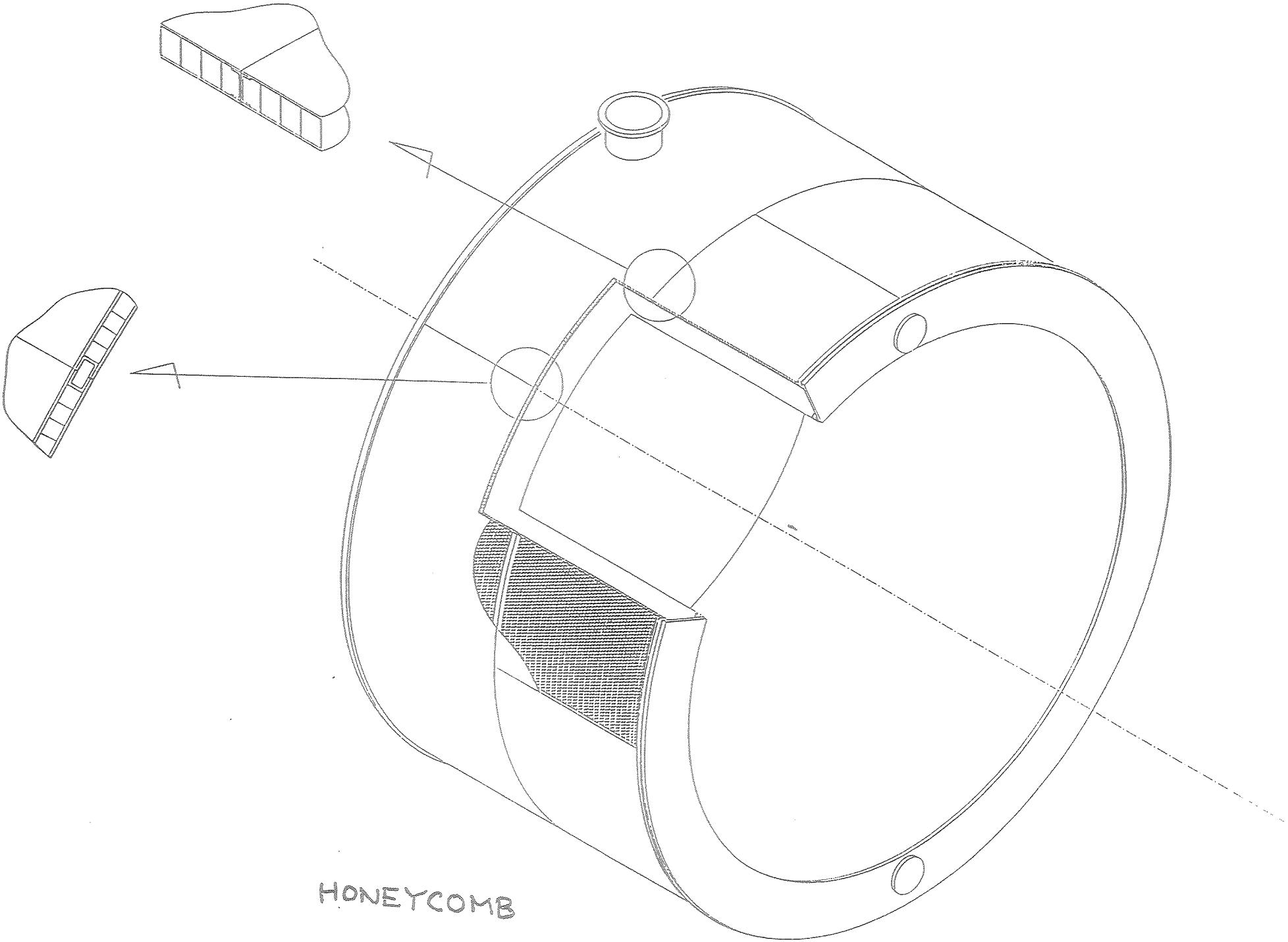
SDRC I-DEAS VI: Solid_Modeling 14-NOV-91 11:59:

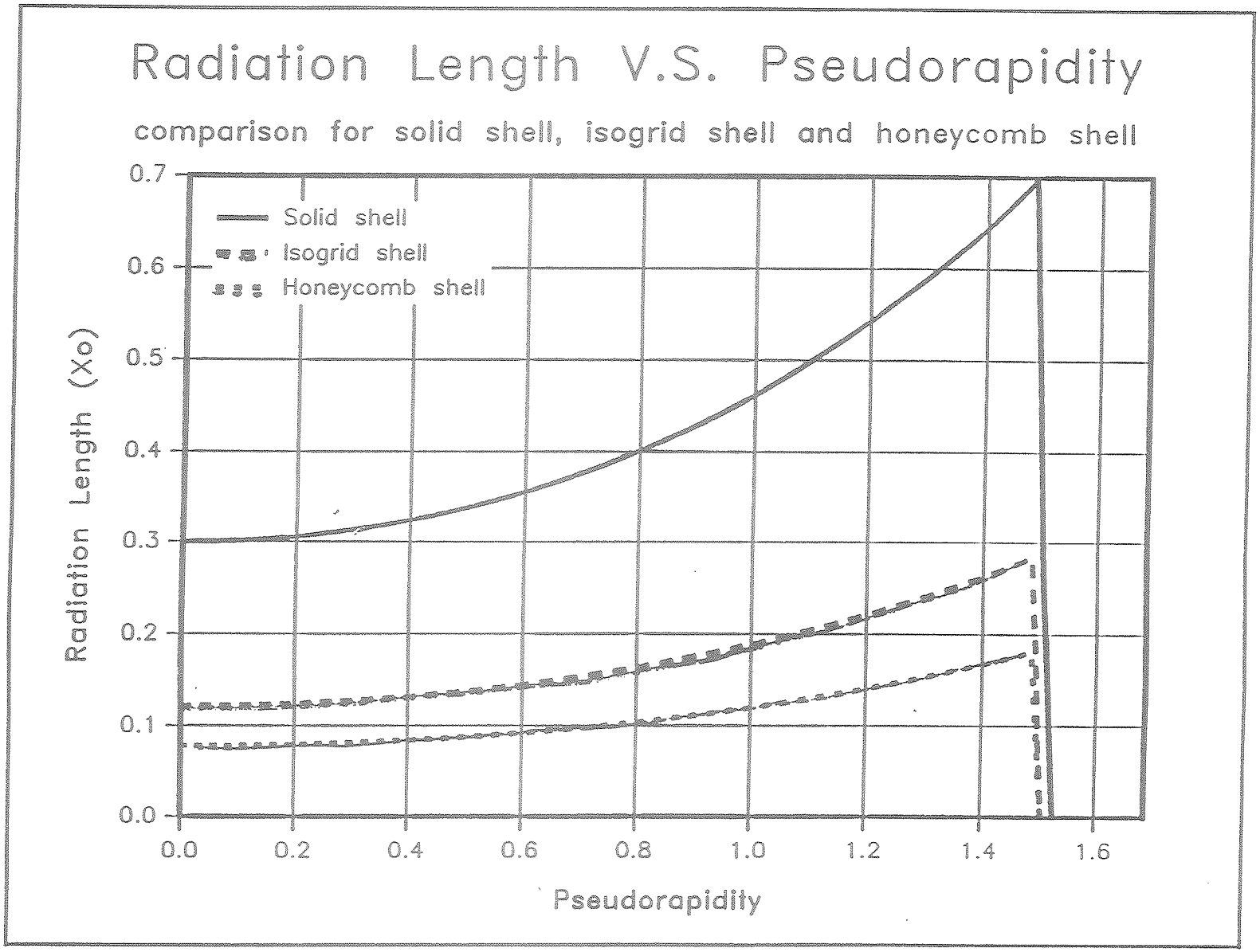
Database: isogrid tank
View : No stored View
Task: Assembly
System: 3-RING1 (modified)

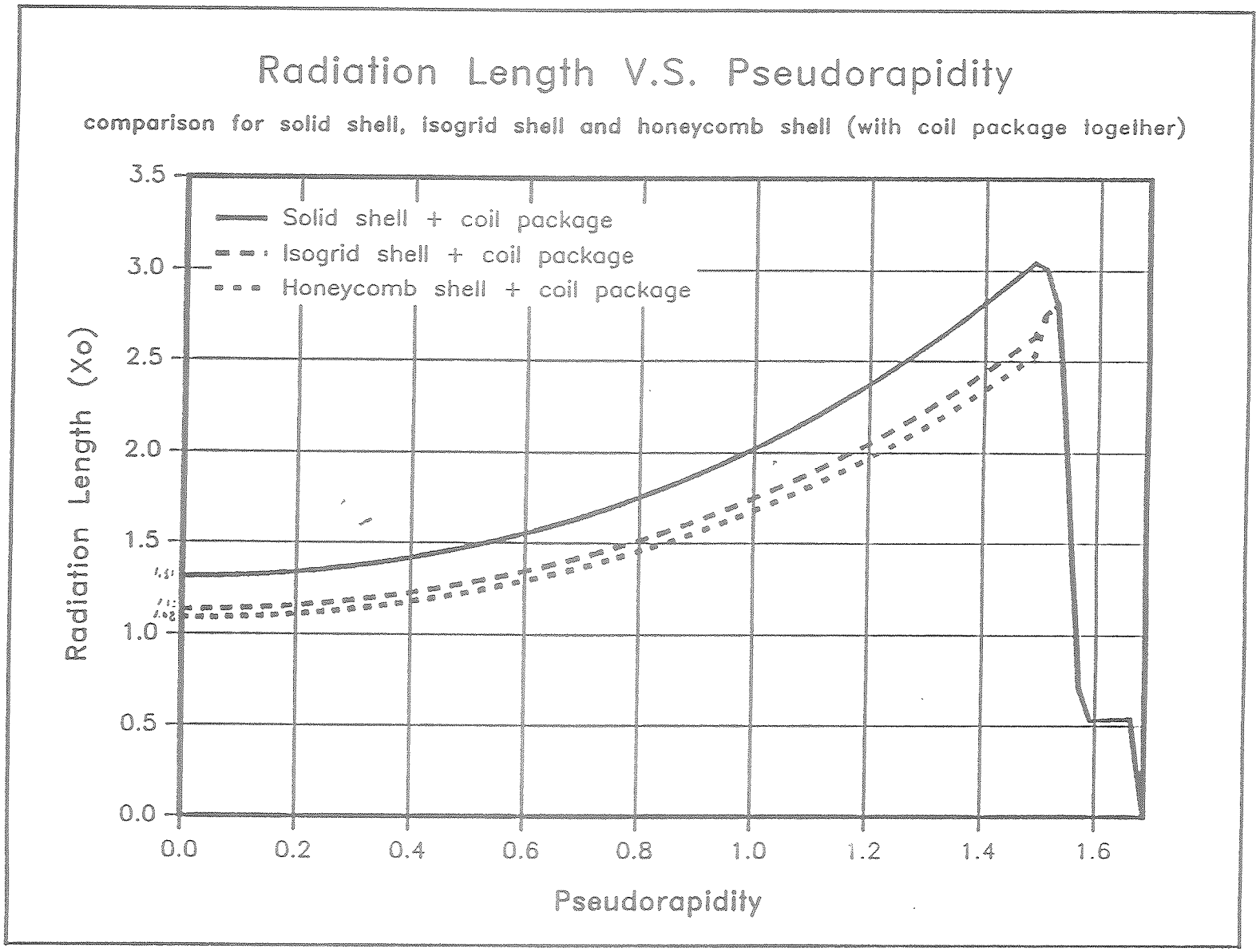
Units
Display : No stored Op
Bin: 1-MAIN
Update Level: Full



ISOGRID


HONEYCOMB


Radiation Length V.S. Pseudorapidity
comparison for solid shell, isogrid shell and honeycomb shell
Solid shell
Isogrid shell
Honeycomb shell
Radiation Length (Xo)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Pseudorapidity


Radiation Length V.S. Pseudorapidity
comparison for solid shell, isogrid shell and honeycomb shell (with coil package together)
Solid shell + coil package
Isogrid shell + coil package
Honeycomb shell + coil package
Radiation Length (Xo)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Pseudorapidity

THERMAL LOAD AND COOLING CHARACTERISTICS

Table 5-9
An estimate of steady state thermal loads for the SDC solenoid.

Component	300 to 77 K	77 to 4.2 K	300 to 4.2 K
Thermal radiation	300	30	—
Conduction			
Coil support rods ($n = 24$–36)	24	2.5	—
Shield support rods ($n = 12$)	3	—	—
Chimney and service port	36	4.5	—
Current leads (8 kA pair)	—	—	30
Total thermal load	363 W	37 W	30 L/hr

WITH CONTINGENCY OF 20%

Table 5-12
Cooling parameters in excitation and after quench.

Excitation of the coil		
Static heat-in-leakage		37 W
Eddy current loss in support cylinder	(@ 1 mT/s)	88 W
Quality of two phase helium	Inlet	0.8
	Outlet	0.5
He mass flow into cooling pass required		23 g/s
He mass flow into current leads	$(2 \times 8,000$ A)	1 g/s
Quench recovery in coil		
Energy dumped into coil		88 MJ
Recovery time assumed		4 hr
Cooling power required		6.2 kW
Cooling efficiency assumed		0.8
Liquid (two phase) helium flow required		28 g/s (830 L/hr)
Total liquid helium for recovering		3,300 L

Table 5-14
General requirements on the cryogenics for the SDC solenoid.

Typical refrigeration capacity	1,500 W at 4.4 K
Liquid helium transfer rate	750 L/hr (after quench)
Liquid helium storage capacity	5,000–10,000 L
Cold gas helium mass flow at 60 K	12 g/s

SDC CRYOGENIC SYSTEM

STEADY STATE 4.35 K LIQUID HELIUM REFRIGERATION LOADS

	ESTIMATED
1. SOLENOID SYSTEM	37 WATTS
2. CONTROL DEWAR	13
3. TRANSFER LINE	50
4. 10,000 LITER LHe DEWAR	4
5. VLPC SYSTEM - DISTRIBUTION	200 (BUDGET-?)
TOTAL	304 WATTS

SDC CRYOGENIC SYSTEM

MINIMUM 4.35 K COOLING POWER REQUIREMENT FOR THE REFRIGERATOR/LIQUEFIER

1. STEADY STATE: 304 WATTS PLUS 1.2 G/S RETURNING AT 300 K -> 425 WATTS

2. CHARGING: (35 MINUTES) 88 + 425 = 513 WATTS

3. COOLDOWN: (14 DAYS) 700 WATTS

4. QUENCH RECOVERY: (4 HOURS) 2500 WATTS AT 4.5 K

SDC CRYOGENIC SYSTEM

SOLENOID QUENCH RECOVERY

1. 3300 LITERS OF LIQUID HELIUM REQUIRED.

2. 10,000 LITER STORAGE DEWAR - ENOUGH LIQUID IS AVAILABLE TO RECOVER FROM 2 BACK-TO-BACK QUENCHES.

3. COMPRESS AND STORE THE GAS. RELIQUEFY DURING STEADY STATE OPERATION -> 12 HOURS/QUENCH WITH 1500 WATT REFRIGERATOR/LIQUEFIER.

4. A PRESSURE OF 0.31 MPa (45 PSIG) IS NEEDED IN THE LIQUID HELIUM SUPPLY DEWAR AT THE START OF QUENCH RECOVERY TO DELIVER THE REQUIRED FLOW RATE OF 28.5 GRAMS/SEC (3300 LITERS IN 4 HOURS). DEWAR NORMAL OPERATING PRESSURE IS 0.07 MPa (10 PSIG).

Prototype Superconducting Magnet

- started in 1991 and will be completed in 1993
- one quarter length with a full diameter
- joint work by KEK and FNAL

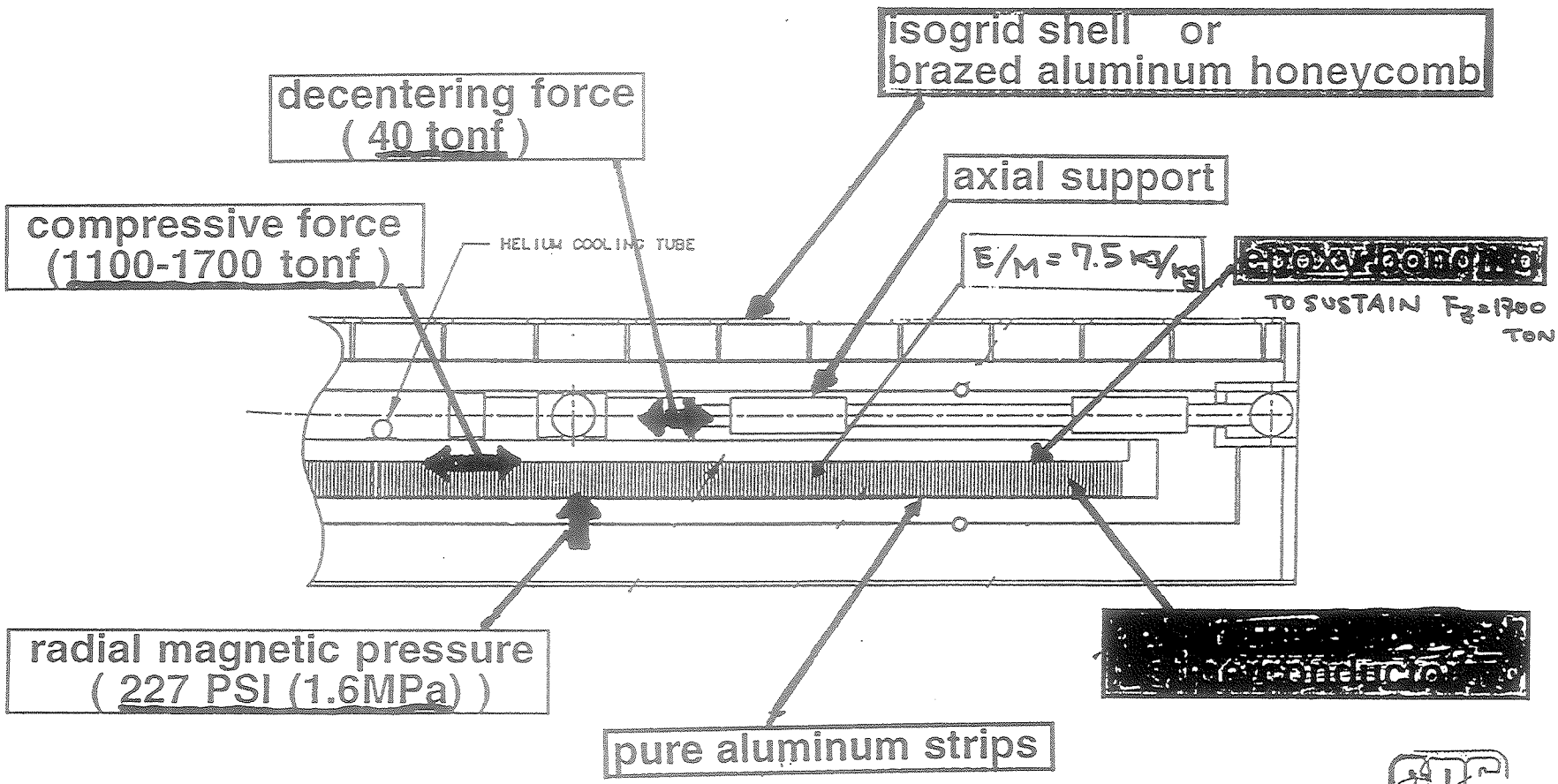


Table 5-16
Design parameters of the prototype R&D solenoid.

Dimensions		
Cryostat	Inner radius	1.70 m
	Outer radius	2.06 m
	Half length	1.17 m
Coil	Effective radius	1.85 m
	Half length	0.95 m
Conductor	Thickness	44 mm
Outer cylinder	Thickness	33 mm
Transparency	Radiation thickness	1.23 X_0
	Interaction length	0.26 λ_0
Electrical parameters		
Central field		1.54
Nominal current		11,250 A
Inductance		0.68 H
Stored energy		48 MJ
E/M		10 kJ/kg
Mechanical parameters		
Effective cold mass		4.5 tons
Total weight		8 tons
Radial mag. pressure (@z =0)		1.73 MPa
Axial compressive force		16.7 MN
Maximum hoop stress		43 MPa
Maximum axial stress		−19 MPa
Maximum shear stress		62 MPa
Peak field in coil		3.8 T
Load line ratio		70%

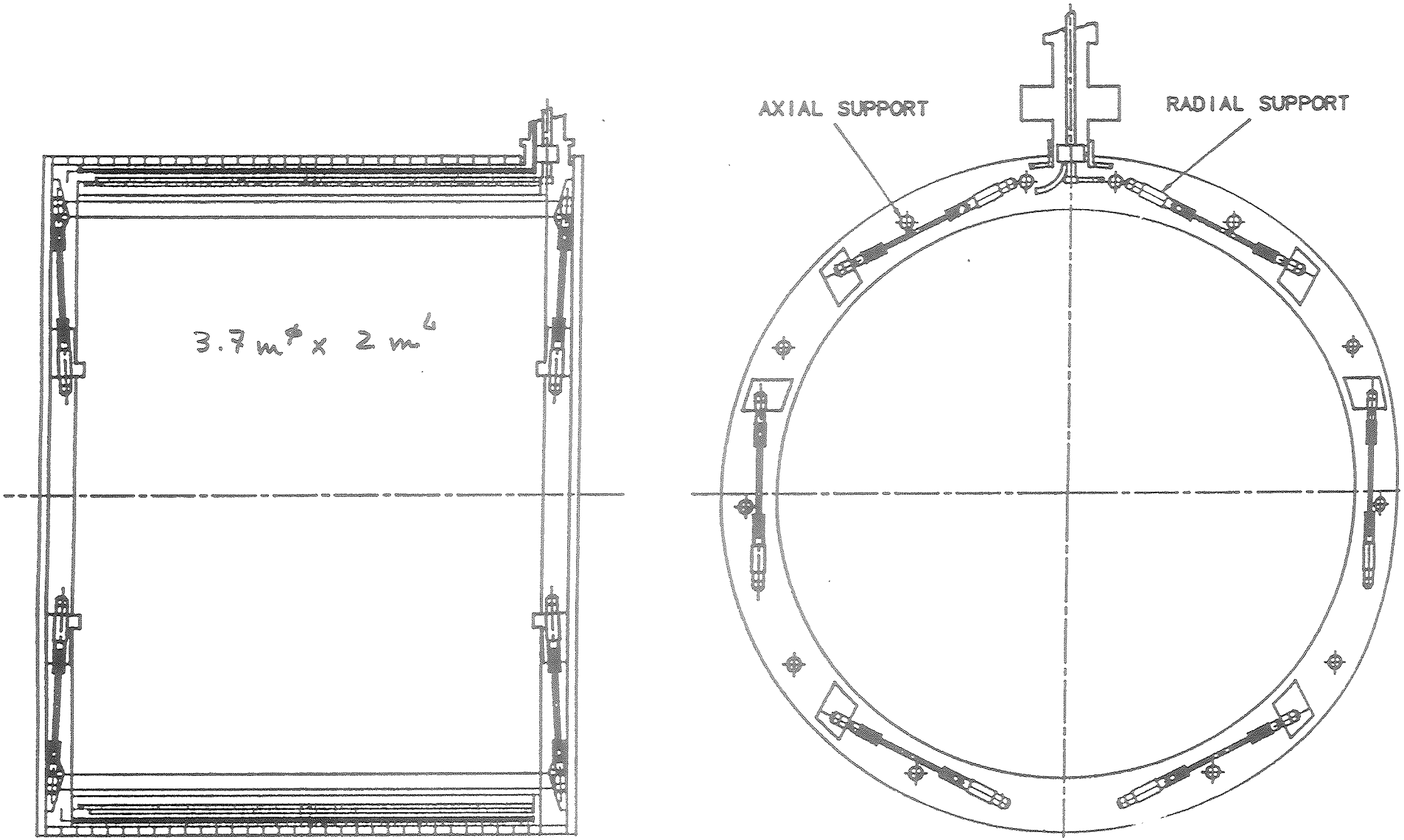


FIG. 5-16. SDC prototype solenoid. Dimensions are given in Table 5-16.

DEVELOPMENT OF

HIGH STRENGTH AL STABILIZED SUPERCONDUCTOR

WHY IS IT NECESSARY?

- Present superconductors used in CDF, TOPAZ etc. are mechanically too weak to sustain electromagnetic force at B = 2 T.

- Mechanical design under elastice boundary condition is desired in the SDC thin solenoid to be loaded with combined stress in terms of hoop and axial components ($2\ \tau. = S_\phi - S_z$)

GOAL OF DEVELOPMENT

- Yield Strength (0.2%) at 4.2 K	> 60 MPa (min) > 70 MPa (desired)

HOW TO IMPROVE MECHANICAL STRENGTH?

- Specially Additional Impurity	Zn (200 ppm)
- Mechanical Cold Work	Drawing and/or Rolling (10 - 20 %)

COMPARISON OF RADIAL (HOOP) STRESS AND STARAIN IN CASES OF 5N-AL A .D <4N-AL COND.

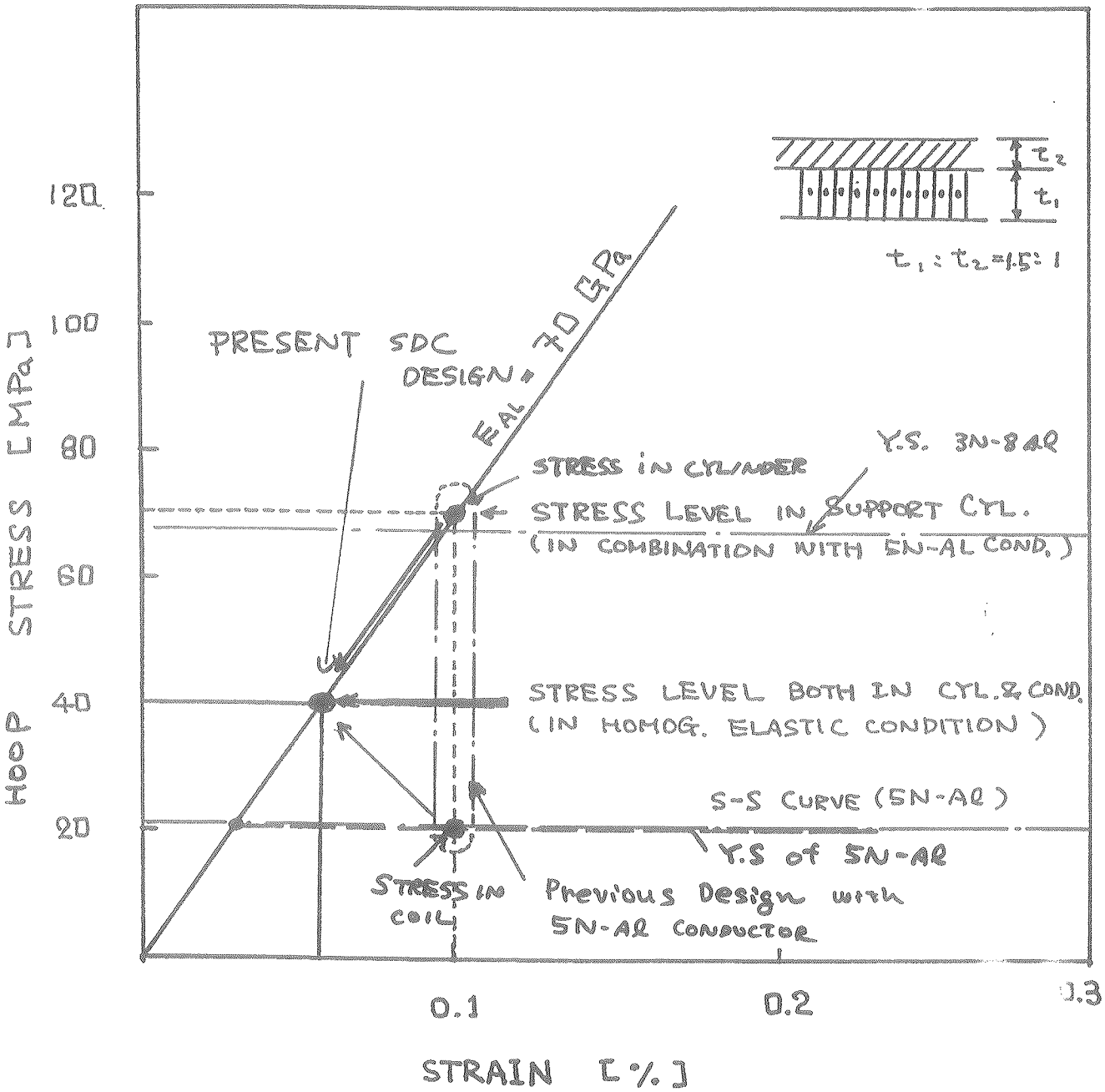
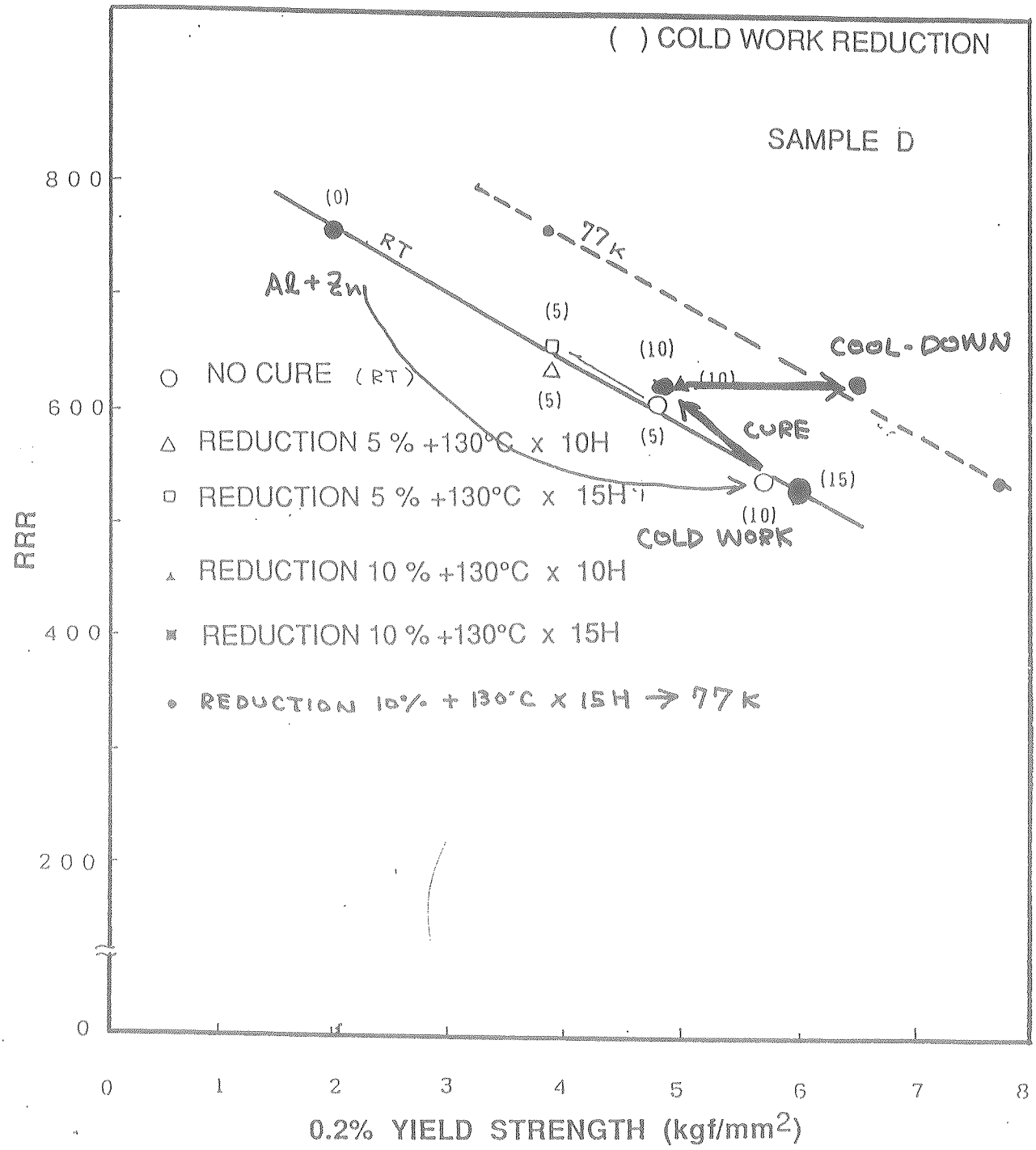


Table 3. Mechanical strength and RRR of aluminum matrix on production stages

Step	at RT(kgf/mm2)		at 77K(kgf/mm2)		RRR
	σB	σ0.2	σB	σ0.2	
1.5N (based material)		2.3		~3	2,500
2.Alloyed (200ppmZn)			13.6~15.5	2.6~3.6	680
3.Extruded	5.2	2.3	15.7	2.9	630
4.Cold-worked(12%)	6.6	6.5	15.9~17	7.5~8.9	490
5.Curred	6.3~6.6	5.3~5.6	15.6~16.1	6.5~7.3	530
6.Aged at RT(after 6months)			same as above		



RRR v.s. Y/S in SAMPLE D

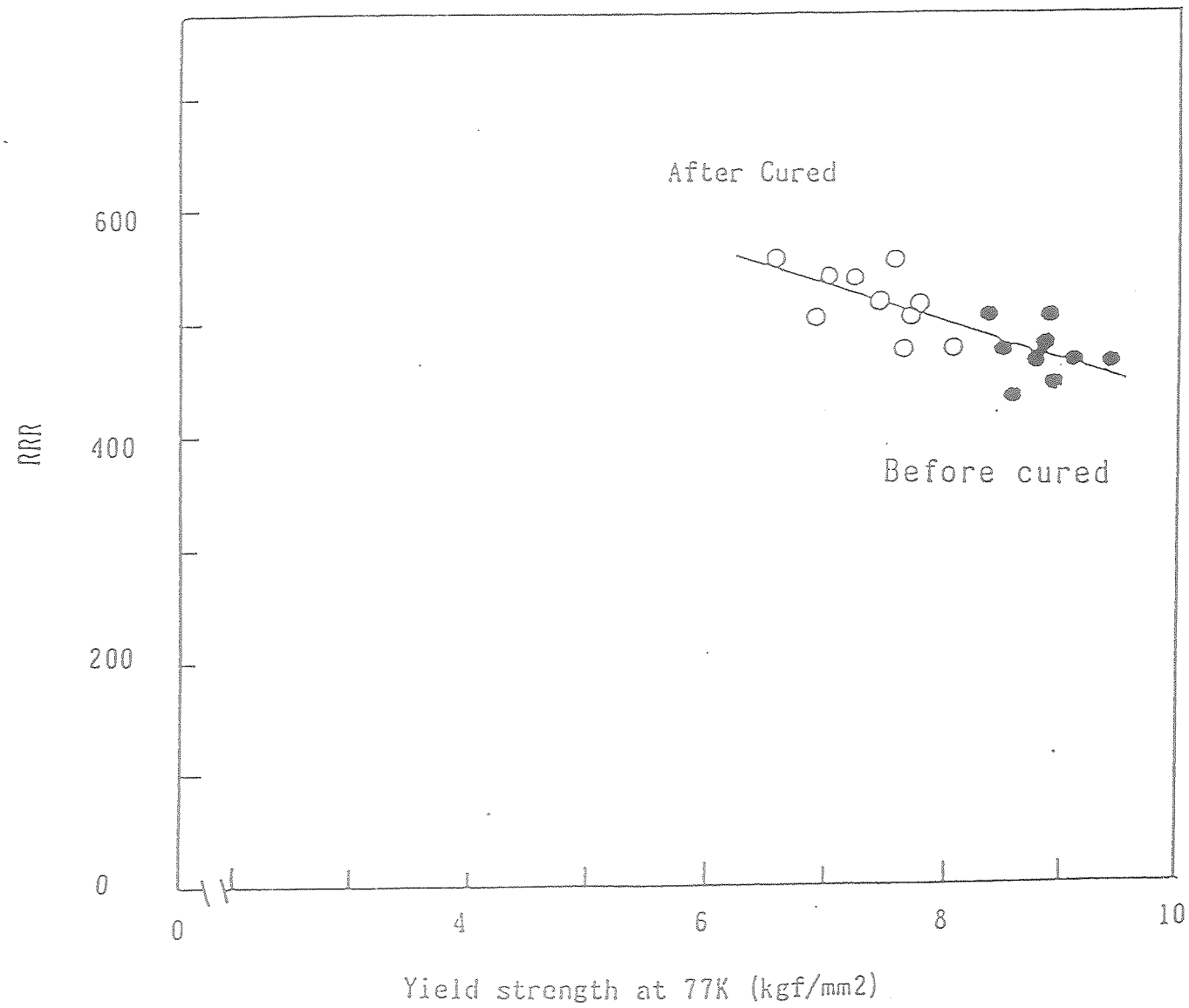
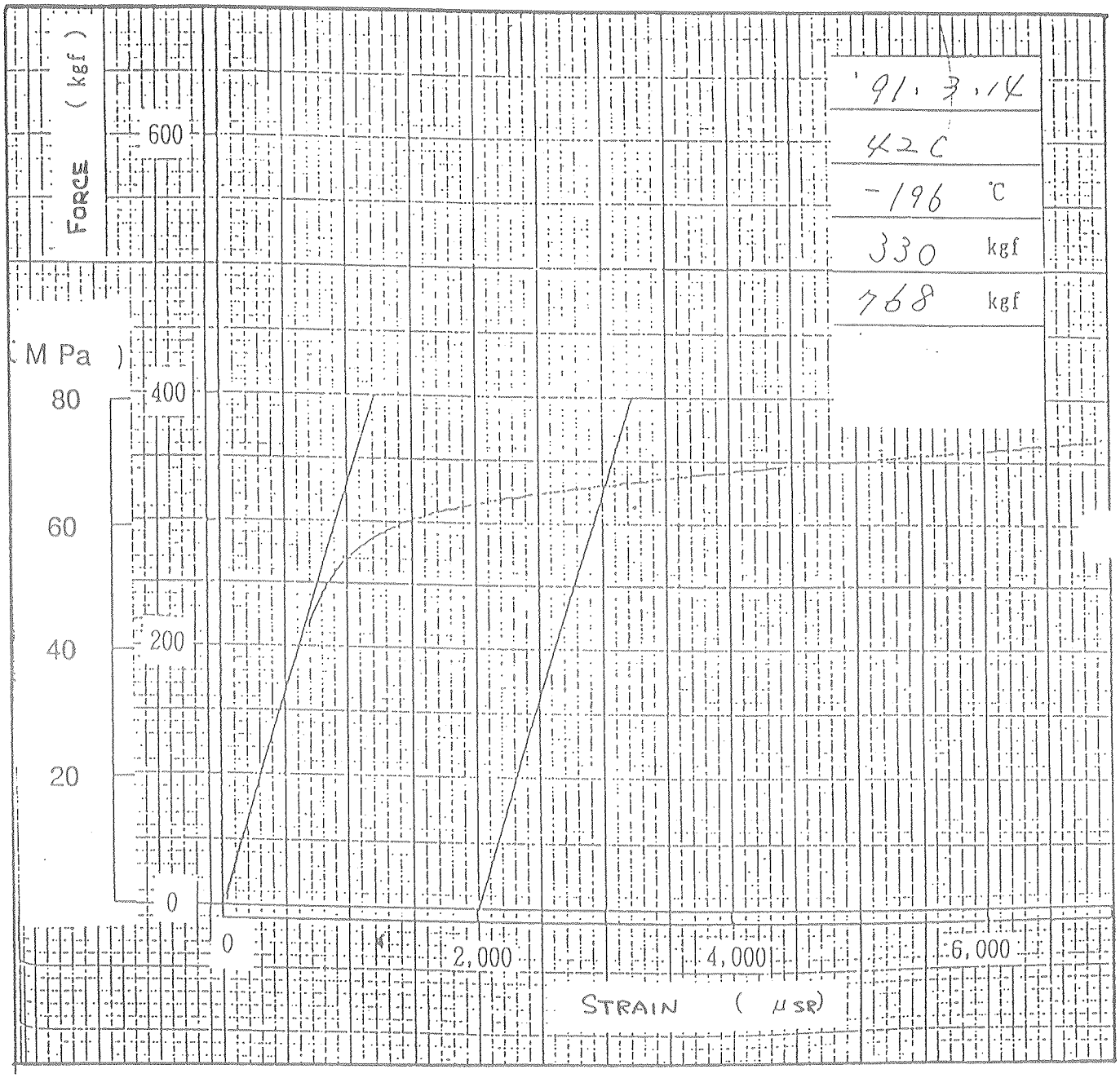
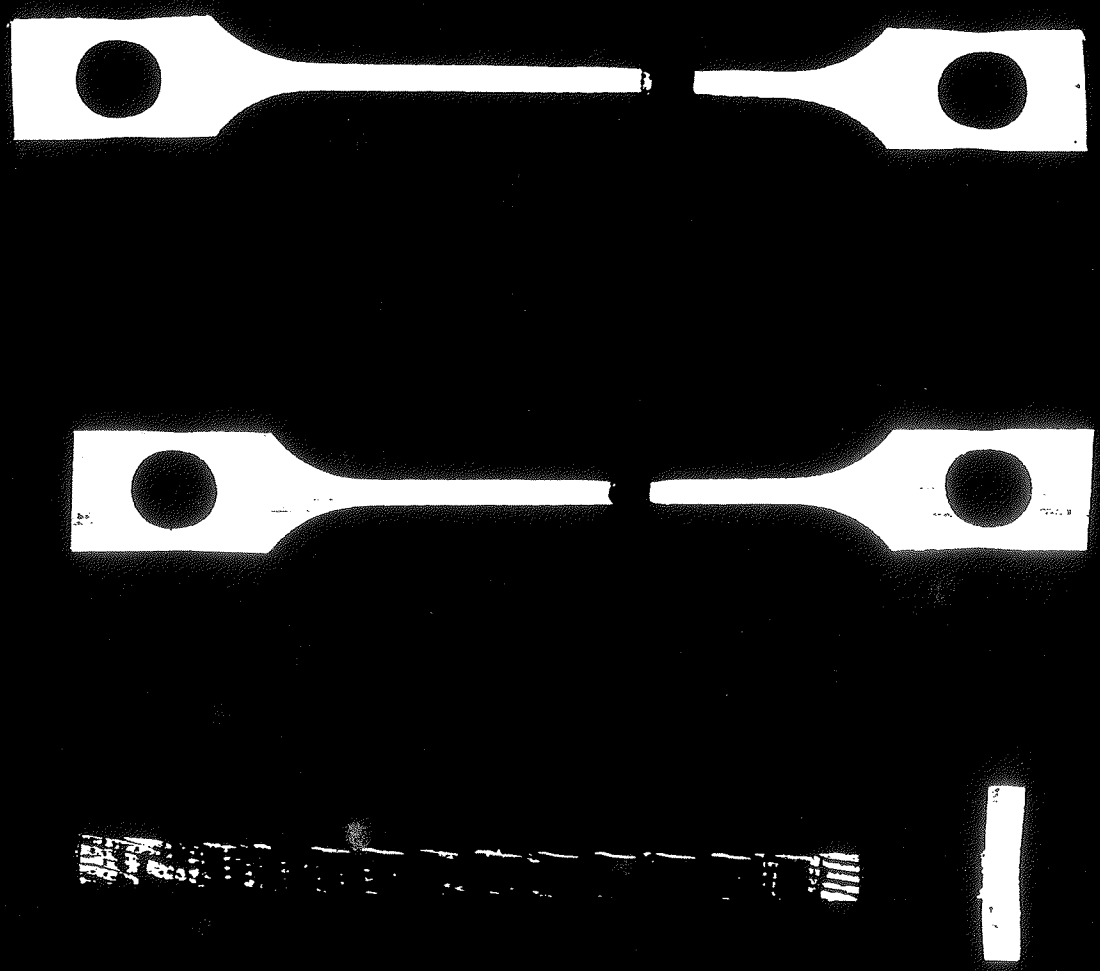


Figure 10. The relationship between the yield strength (77K) and RRR of aluminum matrix on the cold reduction ratio for the full-sized SDC conductor.



A STRESS- STRAIN CURVE OF HIGH STRENGTH PURE Al (4N)



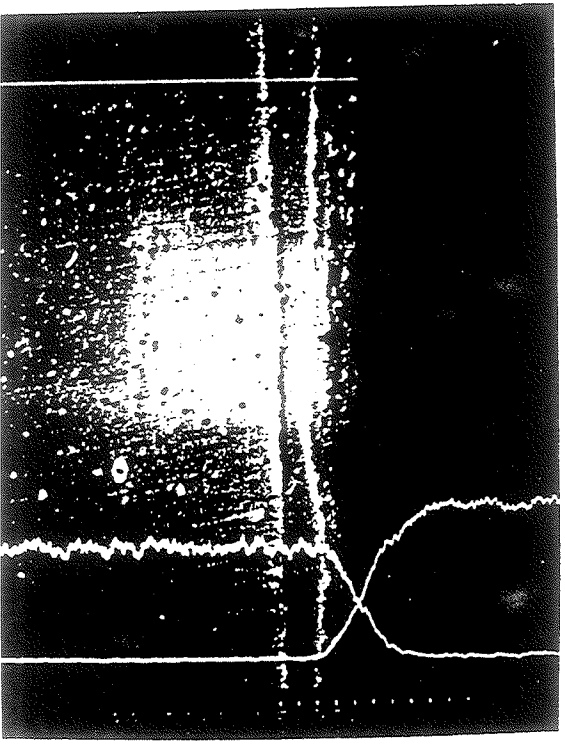
LN2
前-1
LN2
後-1

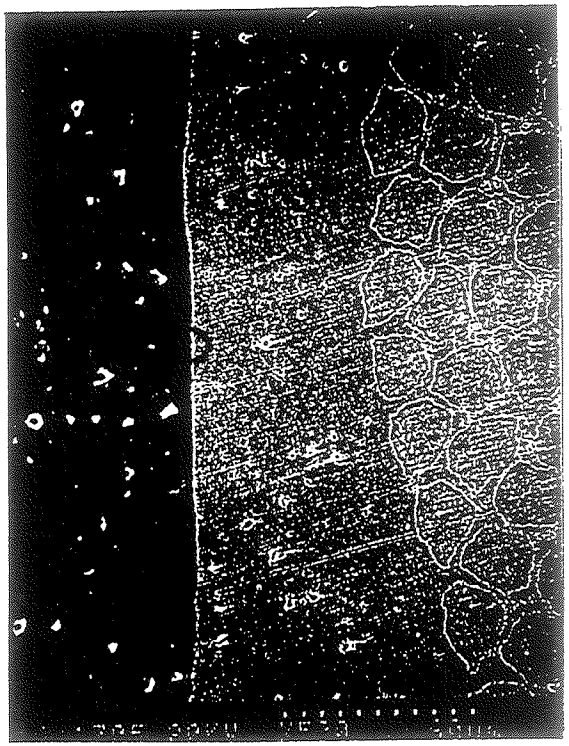
MECHANICAL CHARACTERISTICS OF SDC SUPERCONDUCTOR

ITEM	SPEC	TEST RESULT before Curing			after Curing		
S C Strand		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		88.9	121.1	150.3			
		(88.7)	(121.0)	(155.7)			
		(89.4)	(121.1)	(144.9)			
		(88.6)	(121.1)				
Y.S.(0.2%) [kgf/mm²]		40.2	47.4	76.9			
		(42.9)	(46.7)	(76.9)			
		(38.6)	(45.0)	(76.8)			
		(39.0)	(50.4)				
Elogation [%]		3.0	1.5	1.6			
		(3.0)	(1.5)	(1.6)			
		(3.0)	(1.5)	(1.6)			
		(3.0)	(1.5)				
Stabilizer (AL)		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		6.3	14.7	30.4	6.0	14.5	30.2
		(6.2)	(14.6)	(30.6)	(6.0)	(14.4)	(30.2)
		(6.4)	(14.7)	(30.1)	(6.0)	(14.5)	(30.2)
Y.S.(0.2%) [kgf/mm²]	6.0	6.0	8.0	9.7	5.2	6.7	7.4
		(5.8)	(8.0)	(10.0)	(5.4)	(6.6)	(7.0)
		(6.2)	(7.9)	(9.3)	(4.9)	(6.7)	(7.7)
Elogation [%]		22.4	53.9	55.0	33.4	61.4	54.7
		(23.0)	(55.4)	(55.0)	(32.8)	(64.2)	(58.6)
		(21.8)	(52.4)		(34.0)	(58.6)	(52.7)
Overall		RT	77K	4.2K	RT	77K	4.2K
T.S. [kgf/mm²]		11.2	17.9		10.7	16.8	30.2
		(11.2)	(17.8)	( )	(10.7)	(16.7)	( )
		(11.2)	(17.9)	( )	(10.7)	(16.8)	( )
Y.S.(0.2%) [kgf/mm²]		10.3	11.2		7.9	8.1	
		(10.2)	(11.0)	( )	(8.0)	(7.7)	( )
		(10.3)	(11.4)	( )	(7.8)	(8.4)	( )
Elogation [%]		10.8	15.6		11.9	16.8	
		(11.0)	(15.3)	( )	(11.9)	(16.8)	( )
		(10.5)	(15.8)	( )	(11.9)	(16.7)	( )
Shearing(Al/Cu)		RT	77K	4.2K	RT	77K	4.2K
[kgf/mm²]	2	3.9	5.8	4.5	3.7	5.7	8.7
		(3.9)	(5.4)	(4.5)	(3.9)	(6.6)	(8.7)

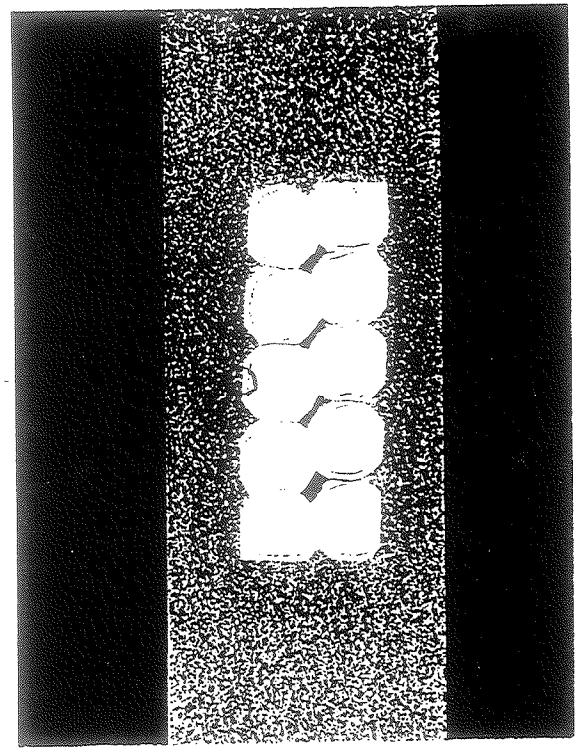
CHARACTERISTICS OF SDC SUPERCONDUCTOR

ITEM	SPEC	before Curing	after Curing
Diamension(mm)			
Strand Dia.	1.277	1.273	
Cable			
thicness	~2.5	2.34	
width	~6.4	6.14	
Conductor			
thickness(L)	(4.42)	4.42	
(S)	(4.32	4.35	
width	43.8	43.8	
corner	≤0.5	0.4	
Al/Cu/NbTi Ratio	27.9/1/1	27.9/0.9/1	
Twist pitch(mm)		27	
IC(A)*1			
at 3.0T		23950	24580 *2
at 4.0 T		19750	20250
at 5.0 T	≥16000	16025	16475
at 6.0 T		12600	13075
at 7.0 T		9225	9500
at 8.0 T		5890	6120
4.2k, $10^{-11}\Omega$cm			
RRR	Al Cu	Al Cu	Al Cu
at 0 T	~600,100	497 95	506 97
at 1.0 T		215 79	243 81
at 2.0 T		162 66	198 67
at 3.0 T		140 55	184 56
at 4.0 T		127 47	178 48
at 5.0 T		118 41	176 42





×500



SG-92016 ×10

CROSS SECTIONS OF SDC SUPERCONDUCTOR

COIL WINDING

WHAT TO BE LEARNT?

- HOW DO WE WIND SUCH HIGH STRENGTH CONDUCTOR ($\sigma_{0.2} = 60 \sim 70$ MPa)?

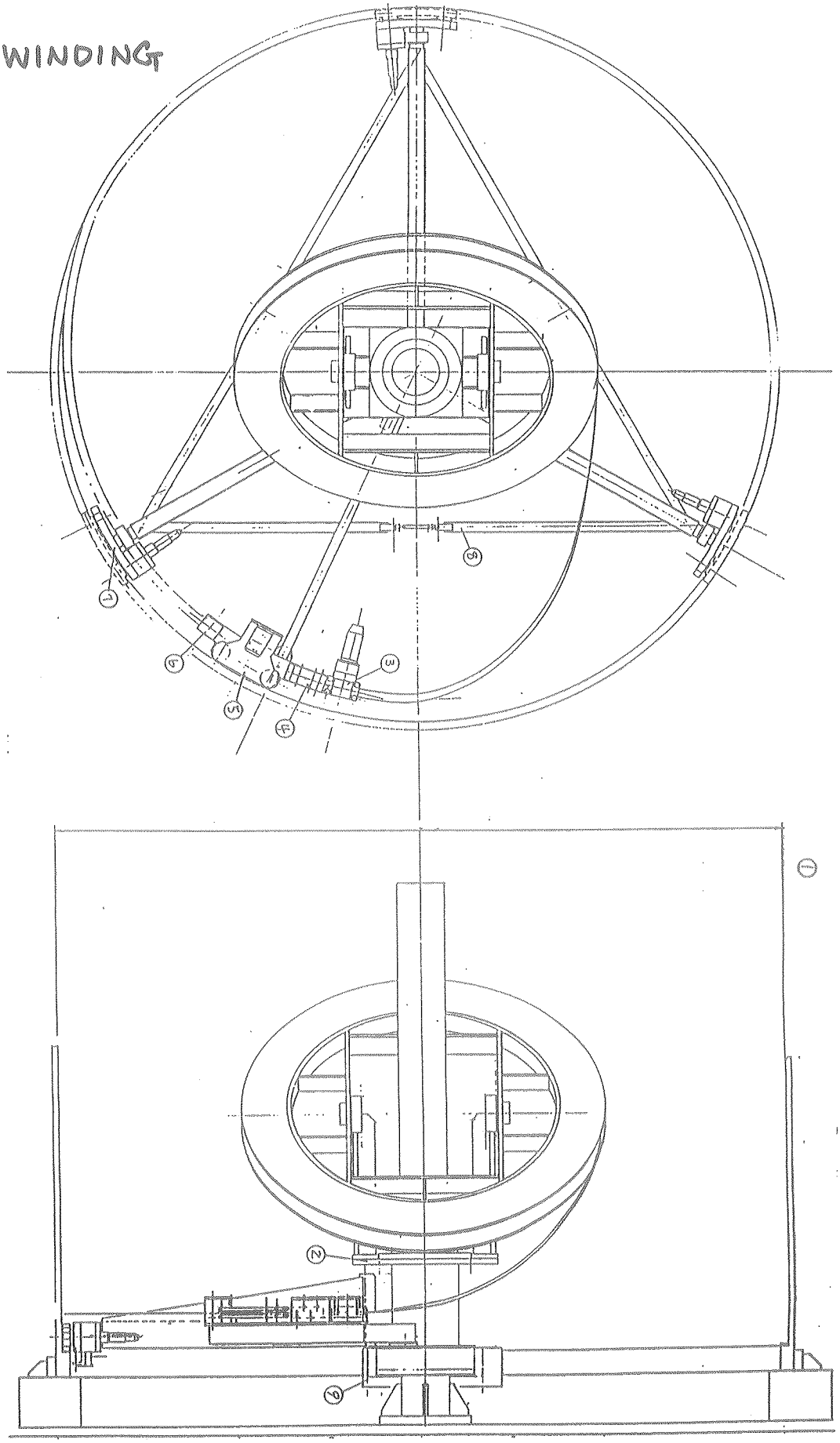
  ⇓

  - HIGH SPRING-BACK EFFECT CORRESPONDING $\sigma_{0.2}$
- HOW MAY WE APPLY INTERNAL PRESSURE DURING WINDING AND MAY KEEP IT AFTER COIL WINDING.

PLAN

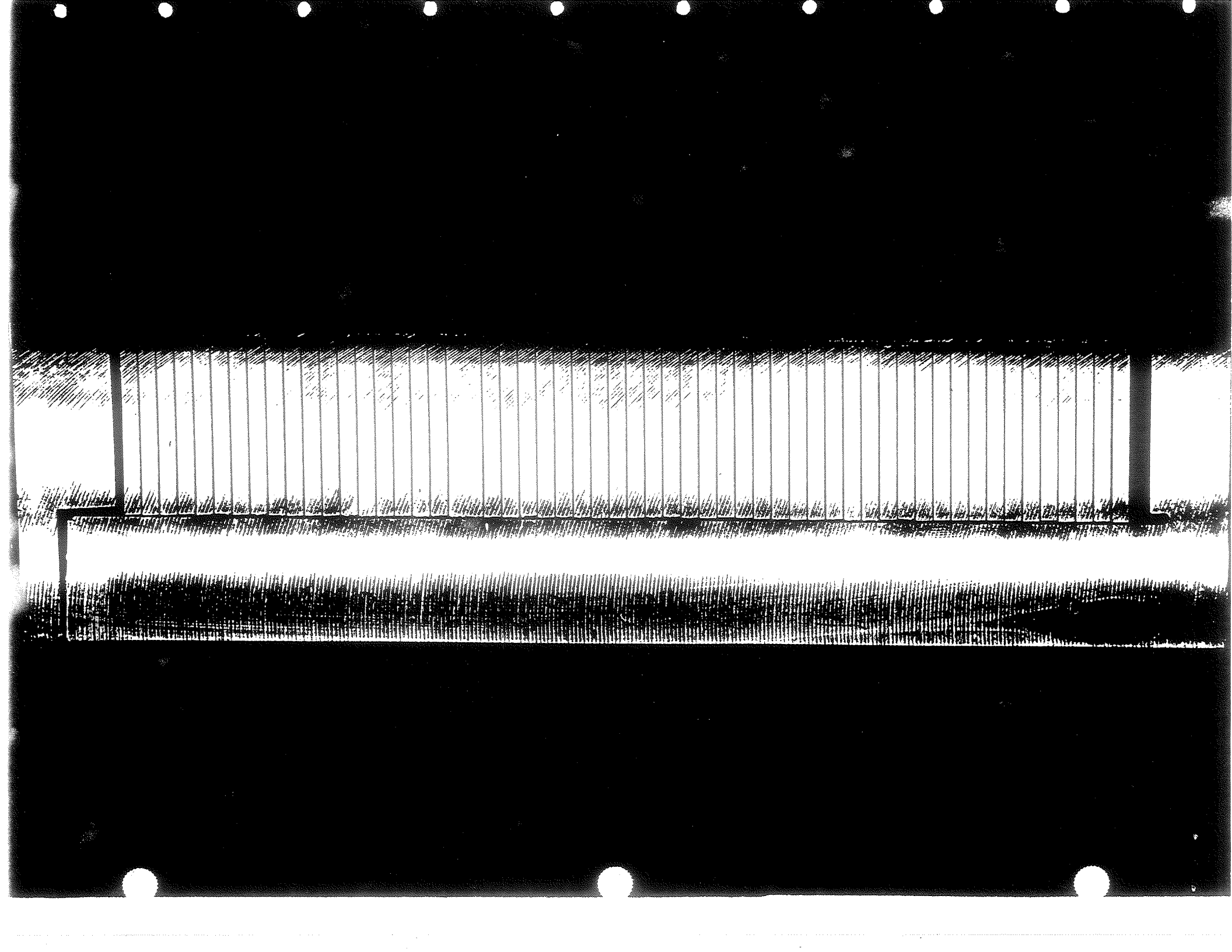
1. STIFF GND INSULATION COMPLETED BEFORE WINDING
2. PRE-FORMING (WINDING) OF CONDUCTOR ON TEMPORAL MANDREL
3. INNER WINDING WITH HOOP COMPRESSION ON INNER SURFACE OF OSC / GND INS.
4. CURING WITH APROPRIATE FORCE

COIL WINDING



FIST WINDING TEST

FIG.10-1 SCHEMATIC VIEW OF THE PROTOTYPE COIL WINDING MACHINE



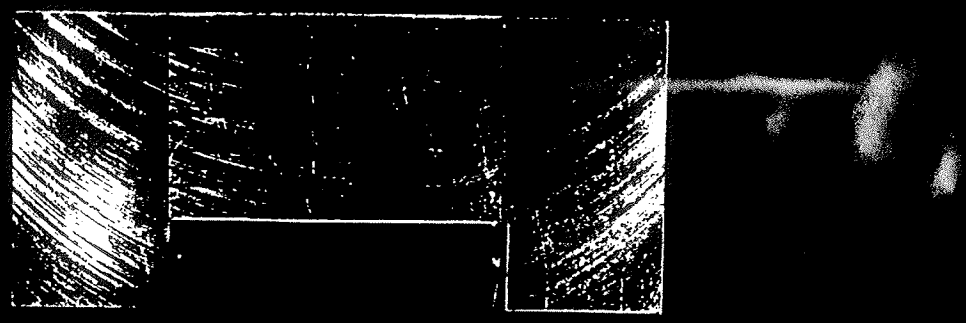
RESULTS OF EPOXY BONDING STRENGTH TEST

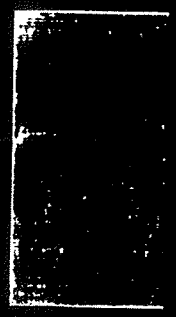
$\sigma_s > 5$ MPa (measured)

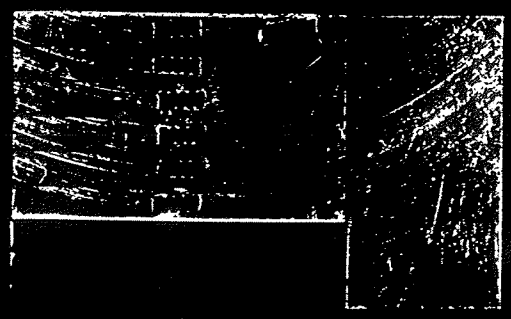
at sample from 1st Winding

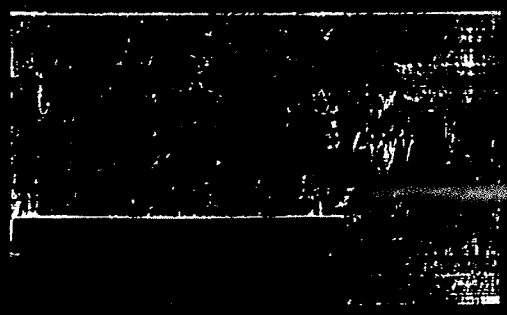
(Calculated Shear Force

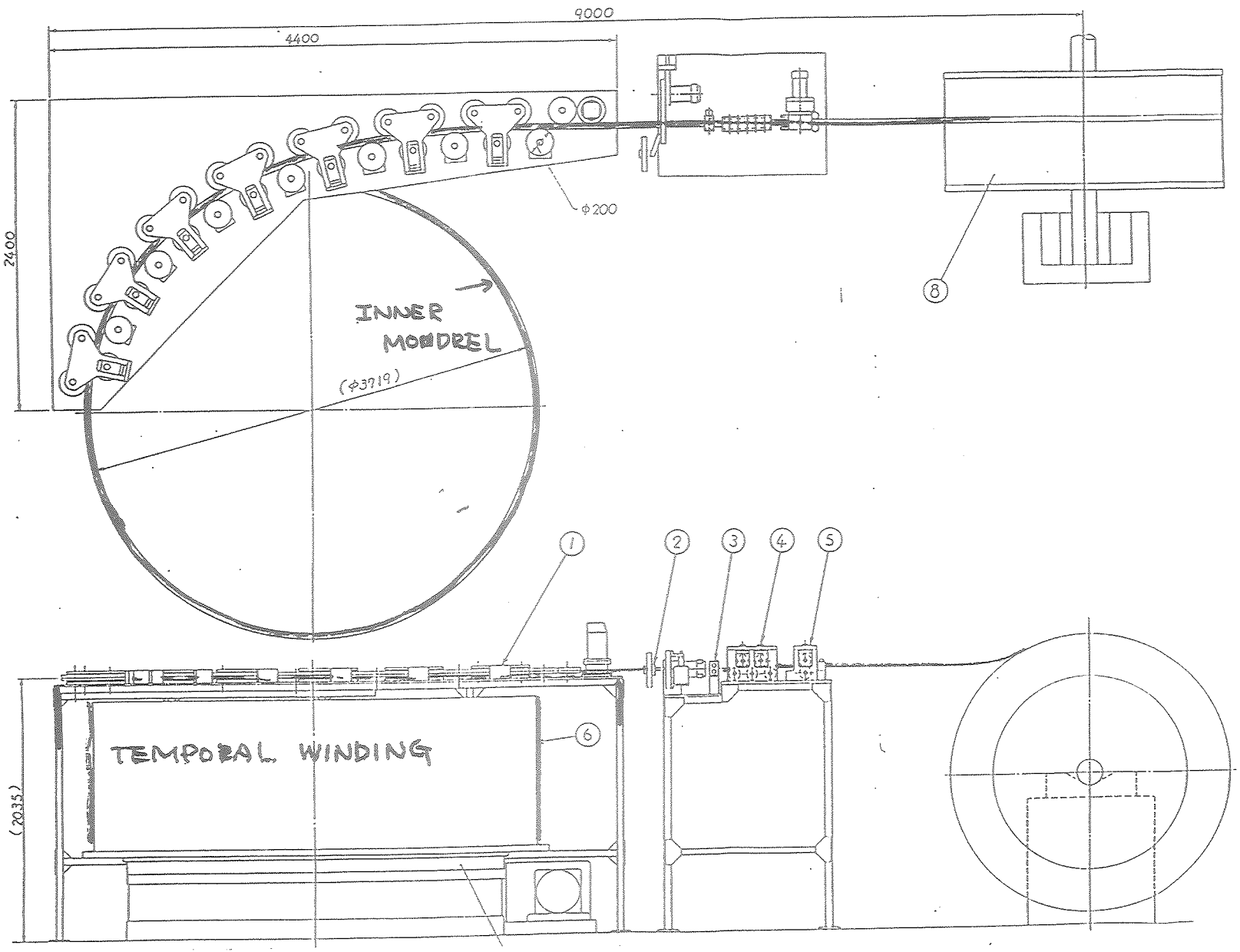
< 0.5 MPa)



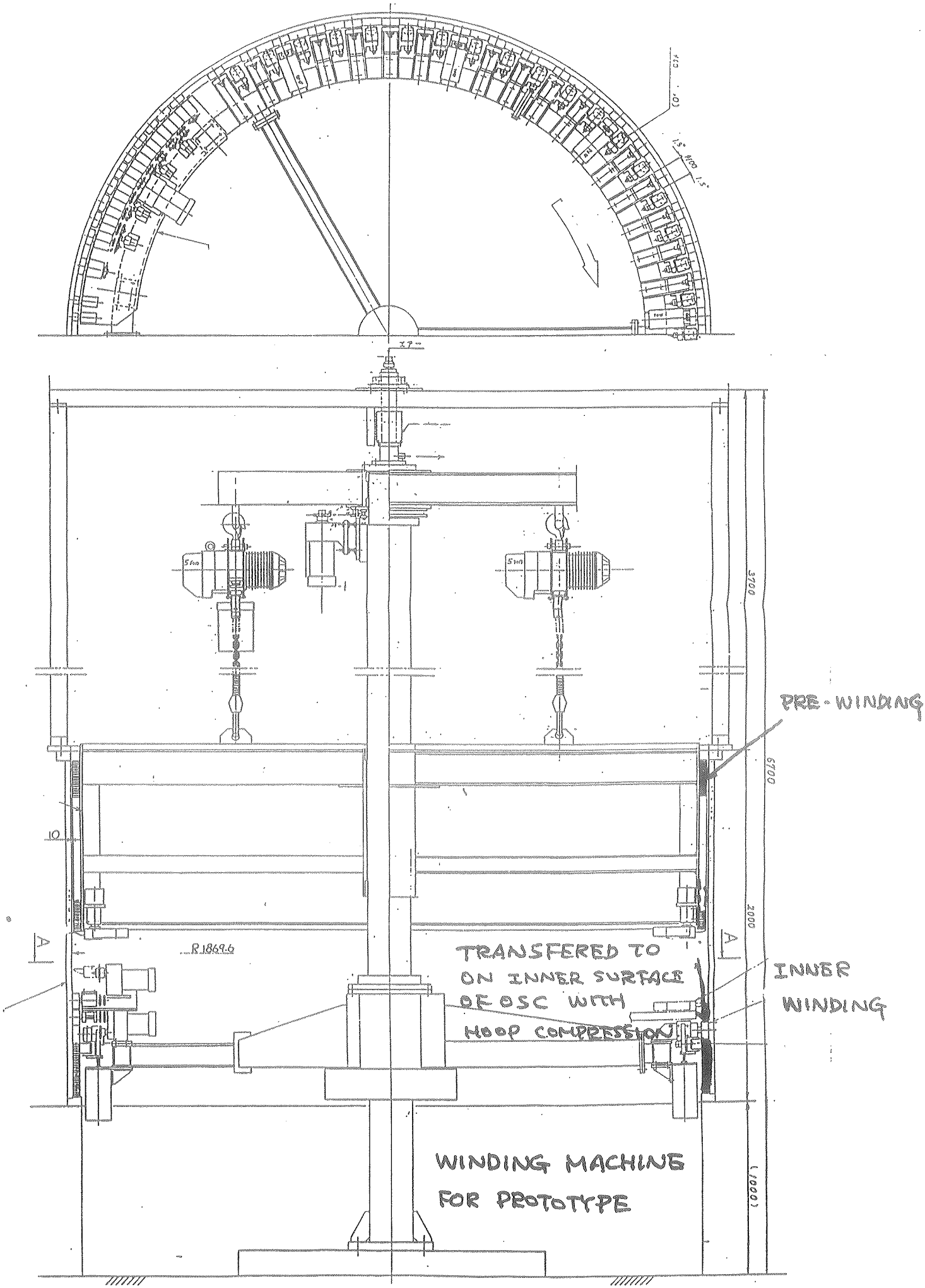


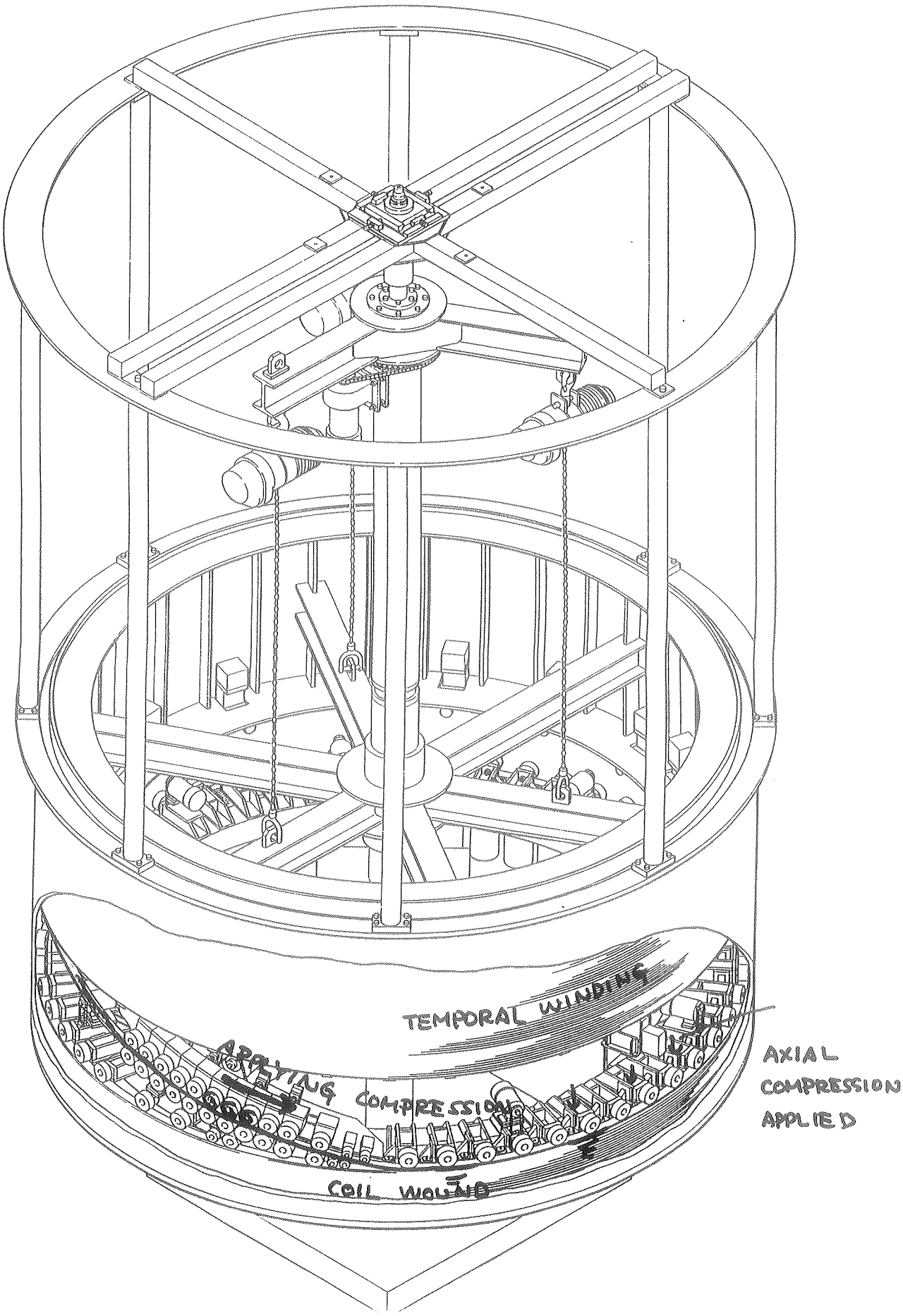


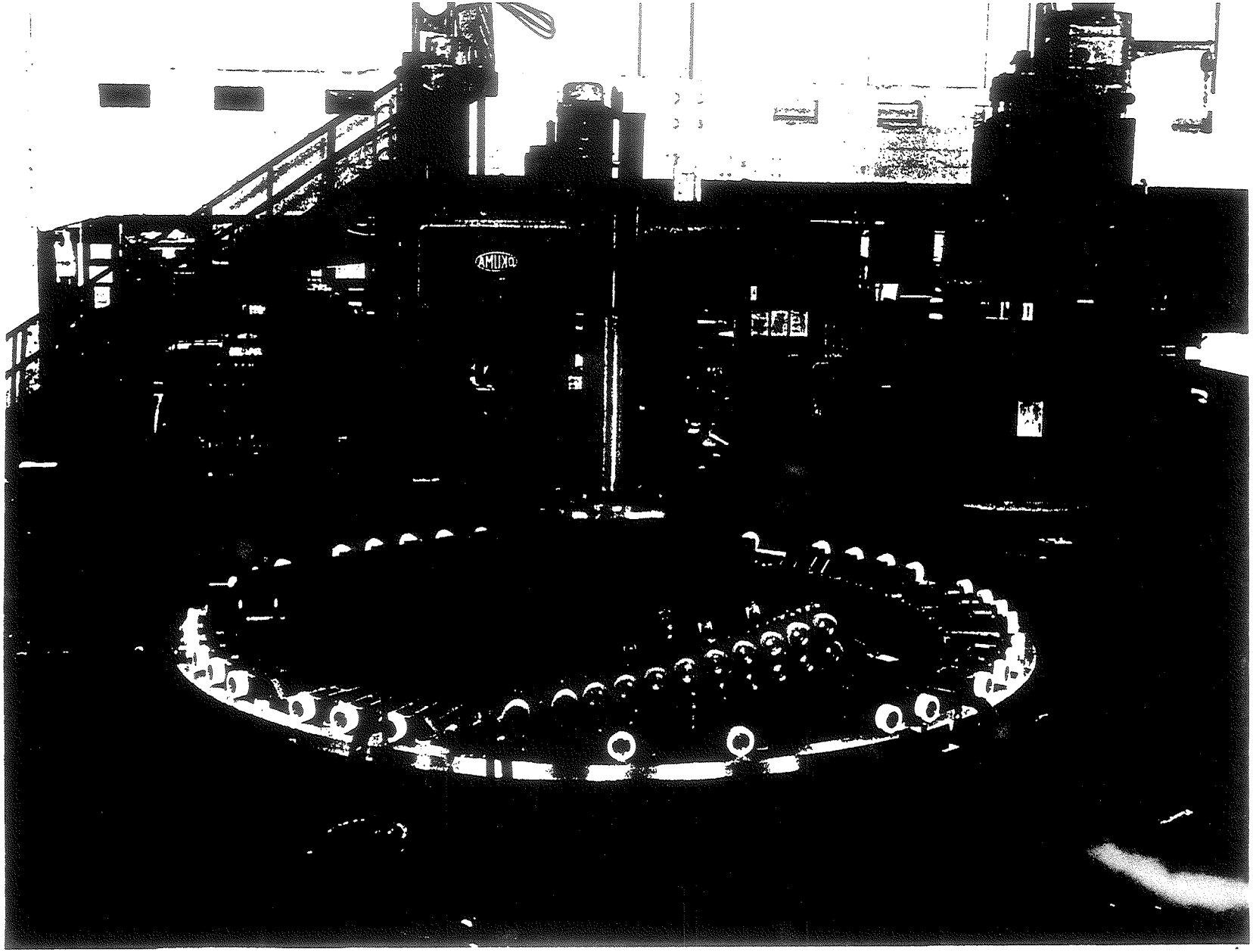


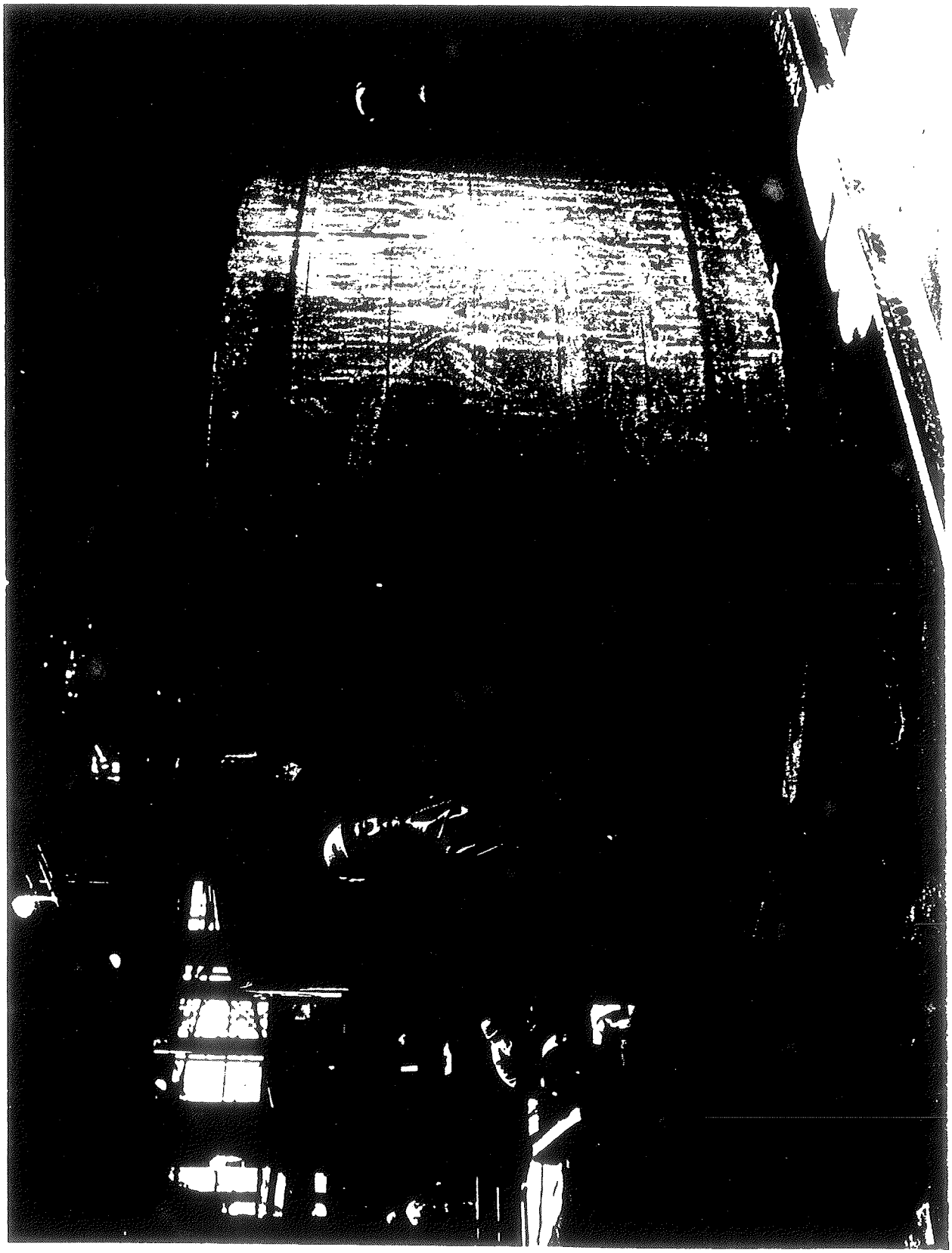


PREWINDING TO HAVE APPROPRIATE CURVATURE


PRE-WINDING
TRANSFERED TO ON INNER SURFACE OF OSC WITH HOOP COMPRESSION
INNER WINDING
R1869.6
3700
6700
2000
(1000)
10
A
A
WINDING MACHINE FOR PROTOTYPE


TEMPORAL WINDING
ARRESTING COMPRESSION
COIL WOUND
AXIAL
COMPRESSION
APPLIED


AMIXA



SDC Solenoid
Outer Vacuum Shell R&D

Purpose:

The SDC solenoid is required to be thin in terms of radiation lengths. If this shell were made with conventional techniques (e.g. Welded shell of solid aluminum) then it would be a major contributor to the overall thickness of the coil in terms of radiation lengths. (.3 λ_r) For this reason the SDC magnet group began a program to develop an improved technique to fabricate this shell.

Outer Vacuum Shell Specifications:

outer radius	2.05 m
total length	8.72 m
High Reliability	metallic - welded
Radiation tolerant	> 6 megarads (10 yrs @ 10^{34} cm^{-2} s^{-1})
Safe - predictable	built to ASME/CGA codes

Plan:

The outer vacuum shell thickness for a solid shell is determined by elastic stability criterion for a cylindrical shell under external pressure.

The SDC magnet group evaluated various fabrication techniques intended to achieve the equivalent stiffness of a solid plate but with much less material.

We chose to pursue R&D on two techniques that we judged most likely to lead to a practical shell that would meet the requirements of SDC:

1) Brazed Aluminum Honeycomb

2) Aluminum ISO grid

R&D is in progress at this time on both techniques. I will discuss our progress and plans:

Option 1) Honeycomb

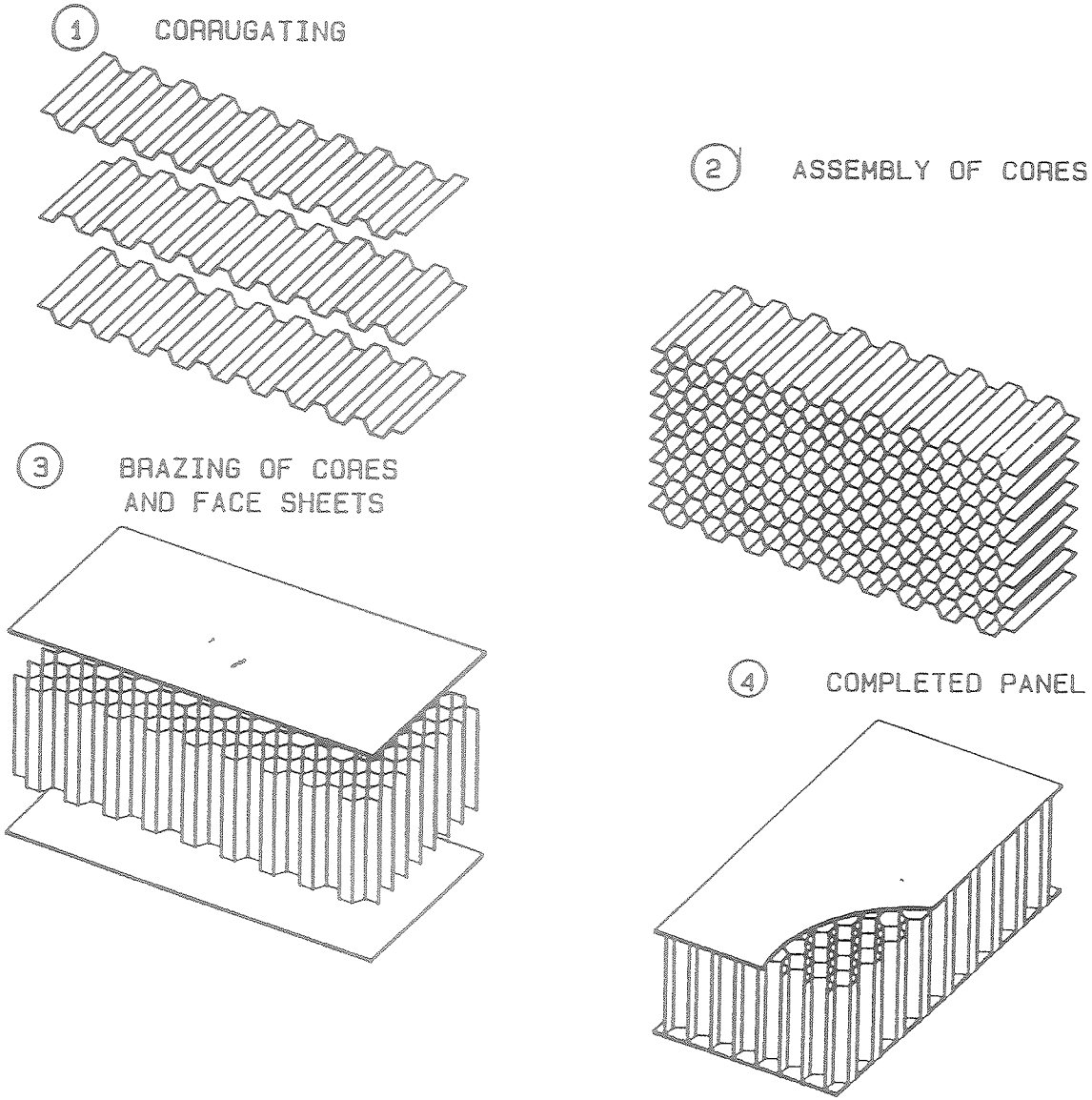
Characteristics of Brazed Aluminum Honeycomb Panels

- Near optimal use of material for high stiffness
- High Thermal Resistance = => Weld able
- High Reliability (no epoxy adhesives)

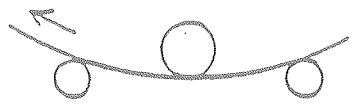
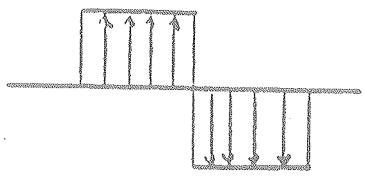
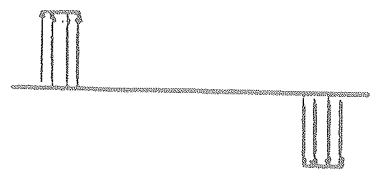
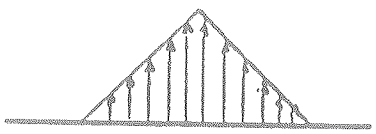
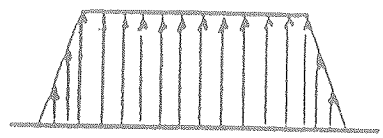
Honeycomb Vacuum Shell Design Specifications

Honeycomb Outer Vacuum Shell

Aluminum alloy	A6951/A4045
Total thickness	45 mm
Skin thickness	3.0 mm + 3.0 mm
Skin layers	double
Node configuration	hexagon
Effective thickness	7.1 mm (Al)
Weight reduction ratio	1/3.83
Radiation thickness	0.08 Xo



BRAZING PROCESSES OF HONEYCOMB PANELS

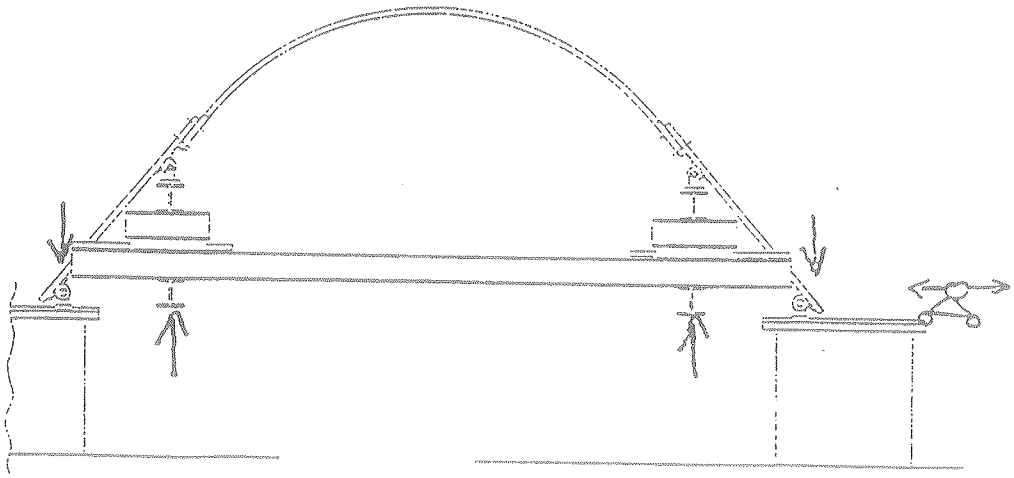
	3 POINT BENDING with Bending Roller	4 POINT BENDING
Concept		
Shearing Force Distribution		
Bending Moment Distribution		
Possibility of Cores Collapsed	Expected	None
Possibility of Shearing Deformation	Expected	None
Bending Size	Long	Limited

HONEYCOMB VACUUM STRUCTURE

RESEARCH AND DEVELOPMENT

(3RD EFFORT)

4 POINT PNAEL BENDING WITH CONSTRAINT FIXTURES

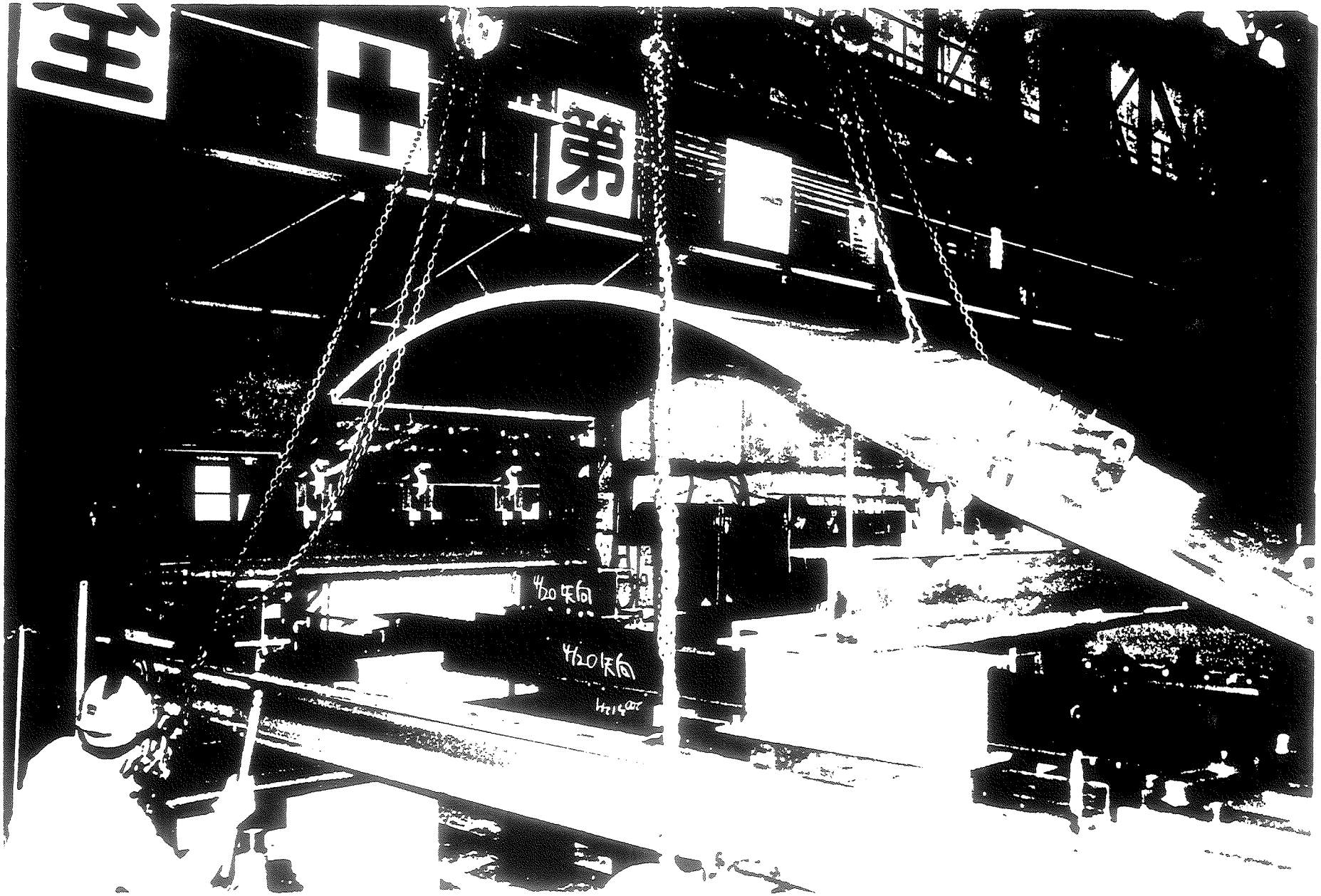


RESULTS

1. BENDING SUCESSFUL DOWN TO R/T RATIO OF 46 WITHOUT BUCKLING,

2. RADIAL SPRING BACK OF 10 % OBSERVED AFTER RELEASING,

3. ~~HORSE BACK~~ (SADDLE) SAGITA OF 15 MM ,
(IT COULD BE ELIMINATED WITH ANOTHER CONSTRAINT FIXTURE).


第
420東向
420東向

Option 2) ISO grid Shell

Characteristics of Aluminum ISO grid construction

- A lattice of intersecting ribs forming an array of equilateral triangles.
- Isotropic (no directions of instability or weakness)
- Efficient use of material for either compression and/or bending
  - Lightweight
  - Proven analysis techniques
  - Can be optimized for wide range of loading intensities
  - Readily reinforced for concentrated loads and cutouts
  - Regular pattern of nodes provides attach points for other structures
- Easily fabricated from solid Al plate with NC machine tools yielding a very reliable material of known costs.

- Large experience base :

  In use on major space programs, extensively investigated by NASA, military, and industry.

  Fermilab has received structural analysis and engineering design assistance from P.S. Associates

  Companies with ISO grid construction experience are available for R&D and for production of final shell. (e.g. machining, welding, bending)

R&D on Machining and Bending ISO grid Panels

Machining

Panel size -	0.63 m x 1.1 m (two panels)
Panel thickness -	46 mm
Sin thickness -	4 mm

Bending RESULTS

Radius Formed To:		Thickness:
Plate 1	2.05 m	46 mm
Plate 2	2.05 m	46 mm

CONCLUSIONS

1. No significant problems in brake forming plates if skin is on outside radius. No buckling or web crippling observed.

2. Small deformations observed near edge nodes...understood and easily fixed ===> no problems

ISO grid Vacuum Shell Design Specifications

ISO grid Outer Vacuum Shell

Aluminum alloy	5083
Total thickness	46 mm
Skin thickness	4.0 mm
Skin layers	single
Node configuration	triangle
Effective thickness	11 mm (Al)
Weight reduction ratio	1/2.5
Radiation thickness	0.12 Xo

Conclusions of ISO grid R&D and Plans

- Technique is likely to be successful but somewhat less efficient than Aluminum honeycomb.
- SDC magnet group decided to fabricate prototype shell using this technique. (3 Al plates 2.5 m x 5 m are on order from Alcoa)
- We will fabricate a large test panel from 5083-H321. This will have exact circumferential and longitudinal weld configurations as Prototype shell. Test panel will be formed to 2.05 m radius.
- More weld joint tests will be done with 5083-H321
- Decision for final shell will depend on outcome of Honeycomb R&D effort.

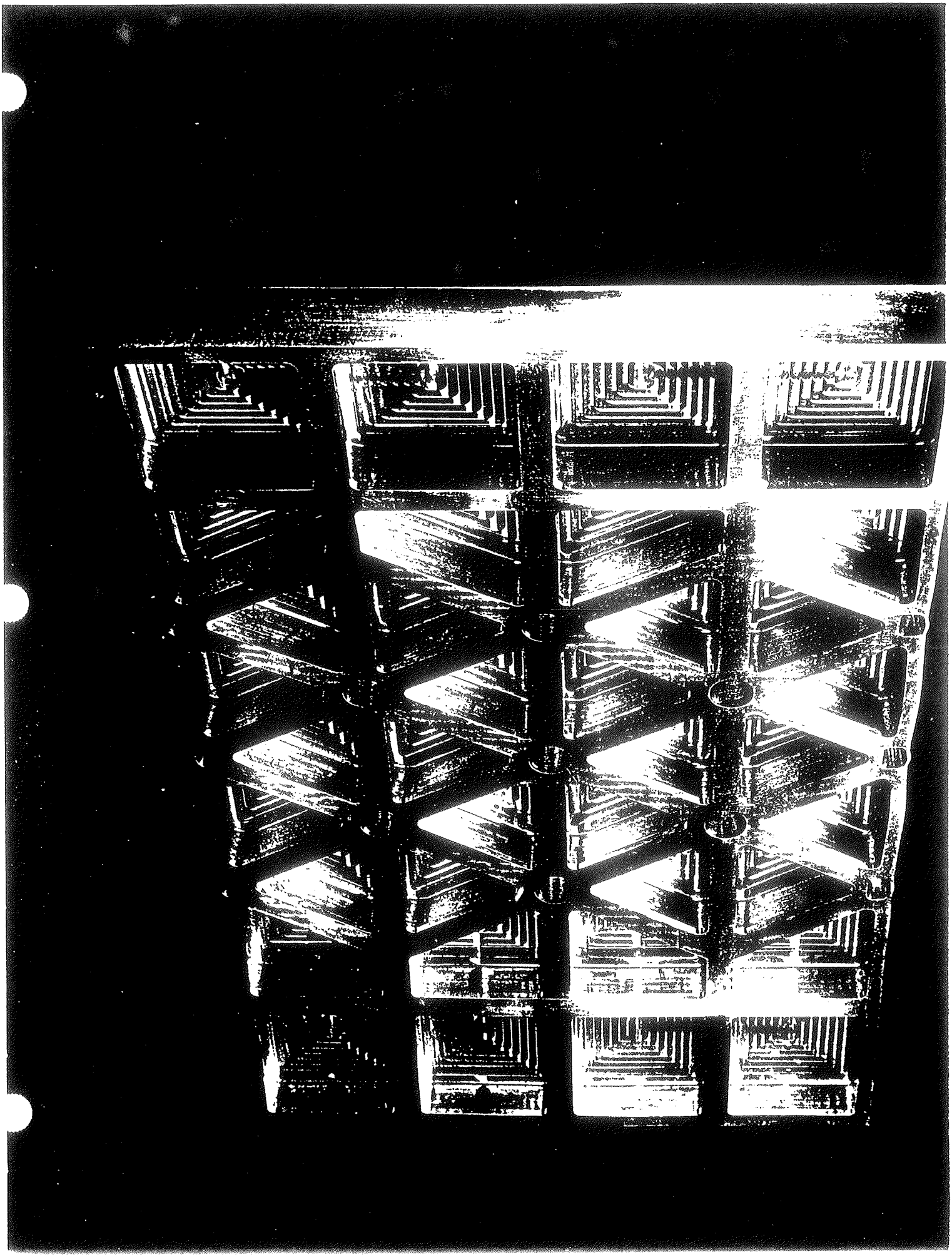


Table 5-17

Overall schedule for the prototype solenoid and the production solenoid. The Japanese fiscal year begins April 1 of the year indicated.

JFY1991	Prototype Magnet Development
	—Superconductor fabrication (by May) '92
	—Winding machine development (by July)
	—Outer support cylinder fabrication
	—Isogrid vacuum wall development
JFY1992	—Coil winding (Sept ~ Dec)
	—Cryostat element fabrication
JFY1993	—Assembly of the magnet
	—Cool-down and excitation in air
JFY1994	Production Magnet Fabrication
	—Superconductor fabrication
	—Cryostat element fabrication
JFY1995	—Coil winding
	—Magnet assembly
JFY1996	—Magnet assembly continued
	—Cool-down and excitation test in air
	—Transportation to SSCL
JFY1997	—Cool-down and excitation in iron
	—Field mapping

SUMMARY

DESIGN STUDY

- THE LATEST DESIGN BOUNDARY CONDITION OF B=2.0T AT X=1.2Xo WITH Z(Fe-END)=4.783 m , ΔZ(Fe-COIL)= 0.62m AND Fz(COIL)=1300 tonnes WITHIN ACCEPTABLE FORCE LEVEL.

- THE SUPERCONDUCTING COIL MAY BE SUPPORTED WITH 2 x 6-FOLD RADIAL SUPPORTS AT BOTH AXIAL ENDS AND WITH 14 (=12+2) AXIAL SUPPORTS AT THE CHIMNEY END. THE AXIAL SUPPORTS REQUIRE X_{max} =3.6Xo AROUND η=1.5 WITH IN A REGION OF 6% OF CIRCUMFERENCE.

- CRYOSTAT MAY BE SUPPORTED WITH 8-FOLD SUPPORT-BAR FROM THE BARREL CALORIMETER, ALTHOUGH 16 FOLD SUPPORT WAS PREFERRED. STIFFNESS OF THE SUPPORT-BAR AGAINST ΔFz = 40 tonnes AND ΔF/ΔZ=15 ton/cm SHOULD BE IMPORTANT.

PROGRESS ON PROTOTYPE R&D

- SUPERCONDUCTOR OF 6km HAS BEEN NEARY COMPLETED. IT MAY SATISFY TO HAVE $\sigma 0.2=67MPa$ AT 4.2K

- COIL WINDING MACHINE IS BEING DEVELOPED. THE PROTOTYPE COIL IS TO BE WOUND BY THE END OF THIS YEAR.

- EPOXY BOUNDING SHEAR-STRENGTH MEASURED USING SAMPLES TAKEN FROM THE FIRST WINDING TEST WAS $\geq$ 5MPa AND LARGER BY A FACTOR 10 THAN EXPECTING IN FEM ANALYSIS.

- VACUUM VESSEL WITH ISOGRID IS IN PROGRESS. BRAZED HONEYCOMB CYLINDER IS BEING DEVELOPED IN PARALLEL.

- PROTOTYPE MAGNET ASSEMBLY IS TO BE CARRIED OUT IN 1993.