Induction Linac R & D

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NuFACT '00
Muon Storage Ring for a Neutrino Factory
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Present Induction Linac Design Parameters

- 200 MV (head to tail) in 100 meters
  - 100 each 2 MV induction cells

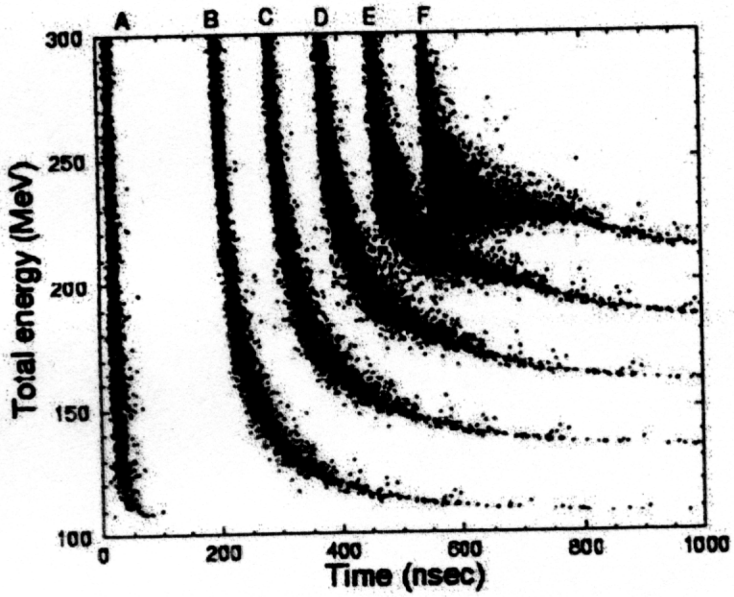
- 15 Hz

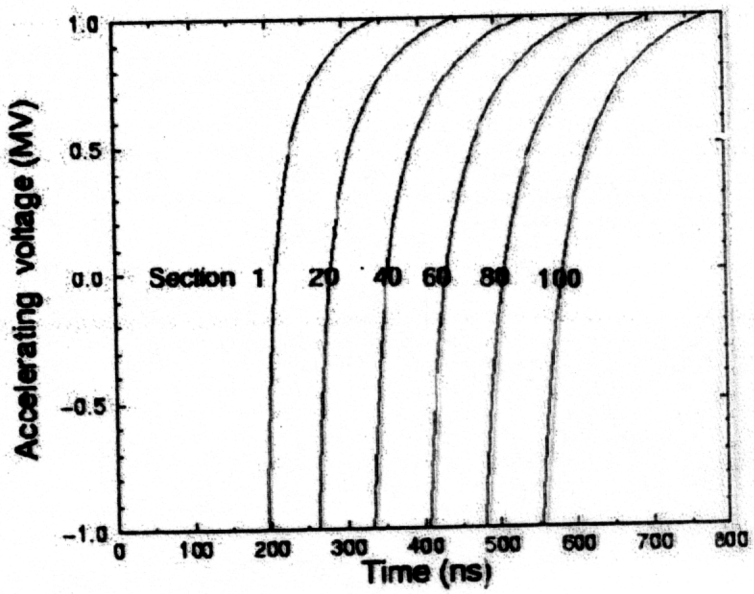
- 4 pulses / burst
  - 100 ns pulse length (hyperbolic ramp)
  - 300 ns spacing (beam off time)

- 3 x 10^8 pulses / year

- 3.0 T (90% packing) at 20 cm bore radius (or equivalent BR^2)

Induction Linacs and Long Solenoidal Channels





50 m drift before φ rotation

<u>For carbon target</u>:

0.10 μ/p between 225 - 240 MeV

0.13 μ/p between 220 - 250 MeV

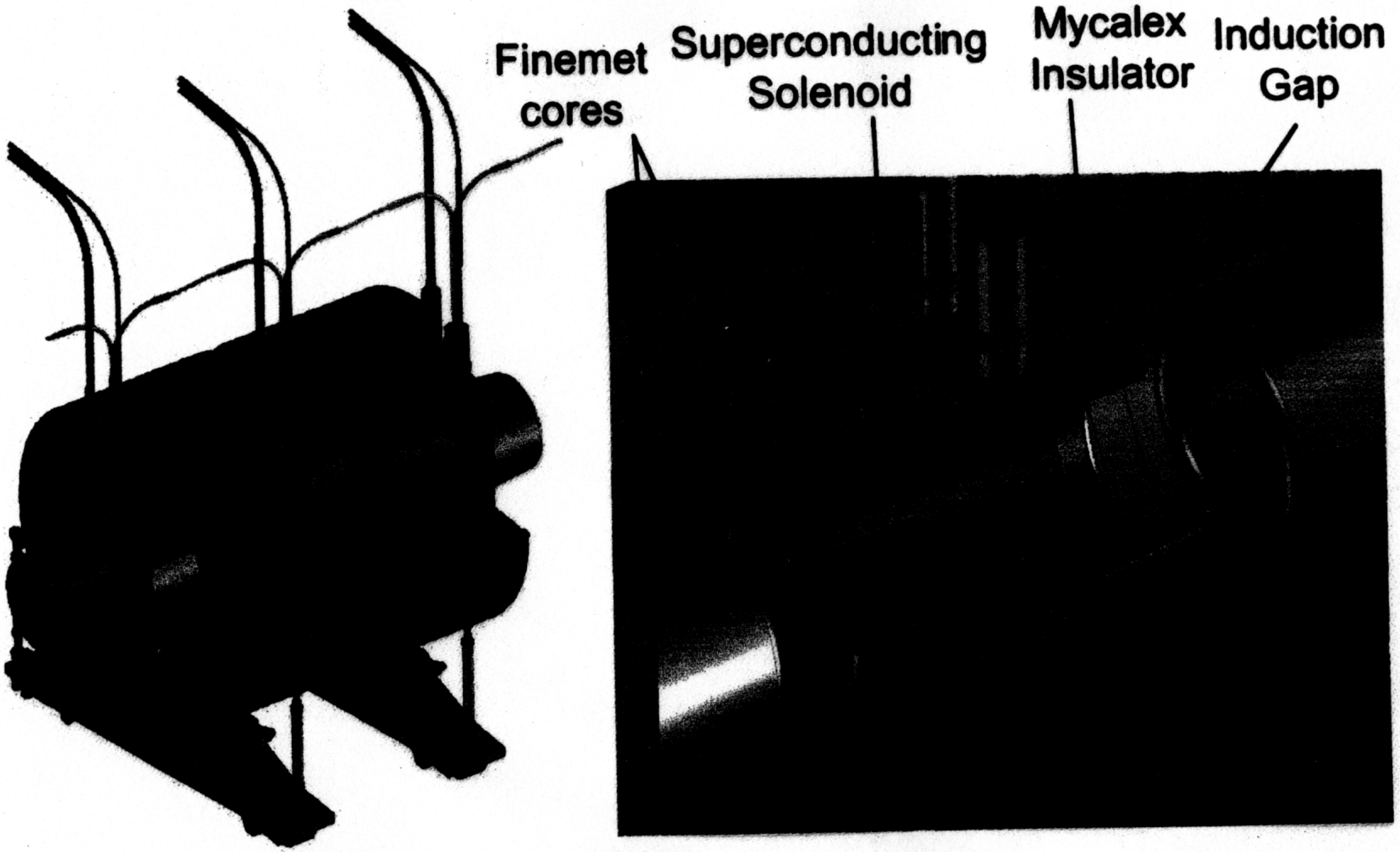
0.18 μ/p between 200 - 270 MeV

Trade off:

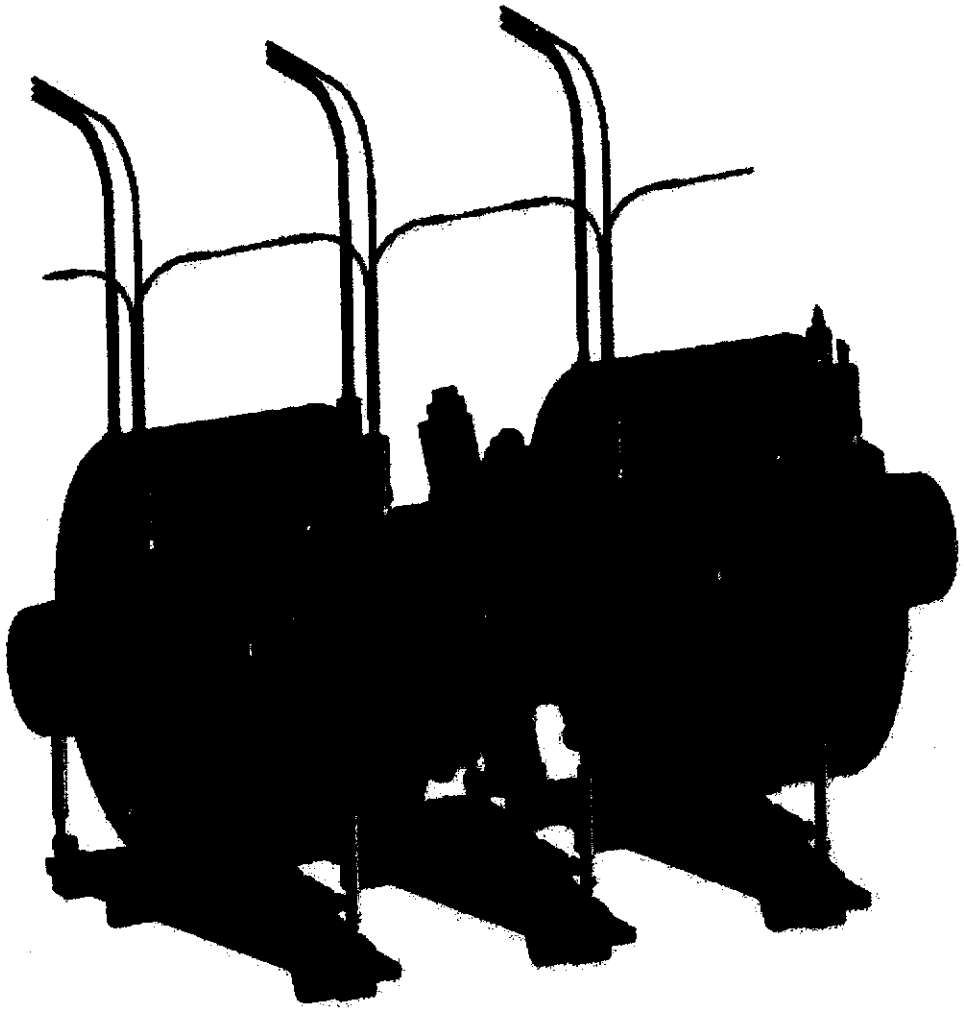
Energy Spread after rotation⇔ drift channel length [loss]

Particle capture⇔length(voltage) in induction linac [loss]

A Pair of 1 m Long Induction Cells

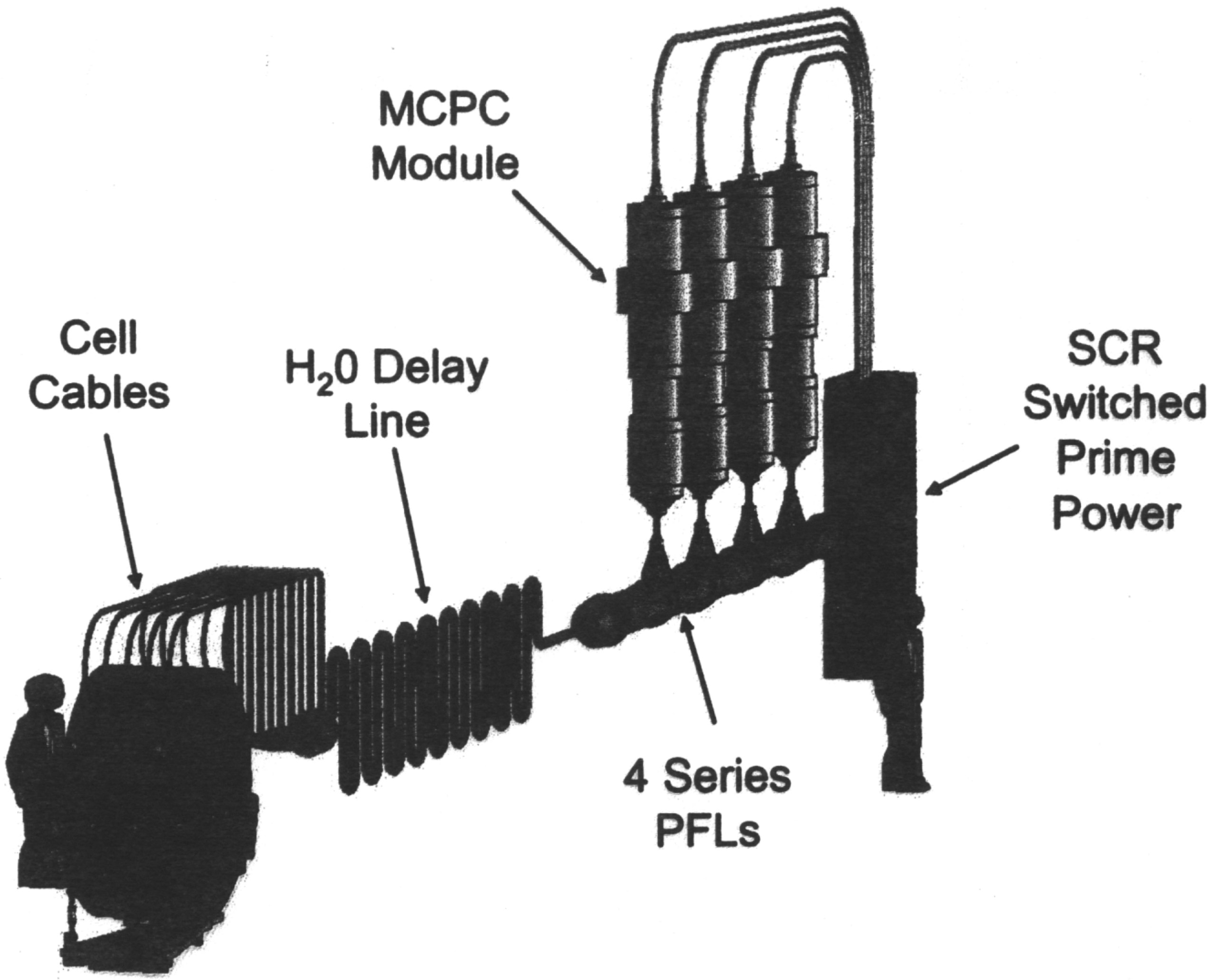


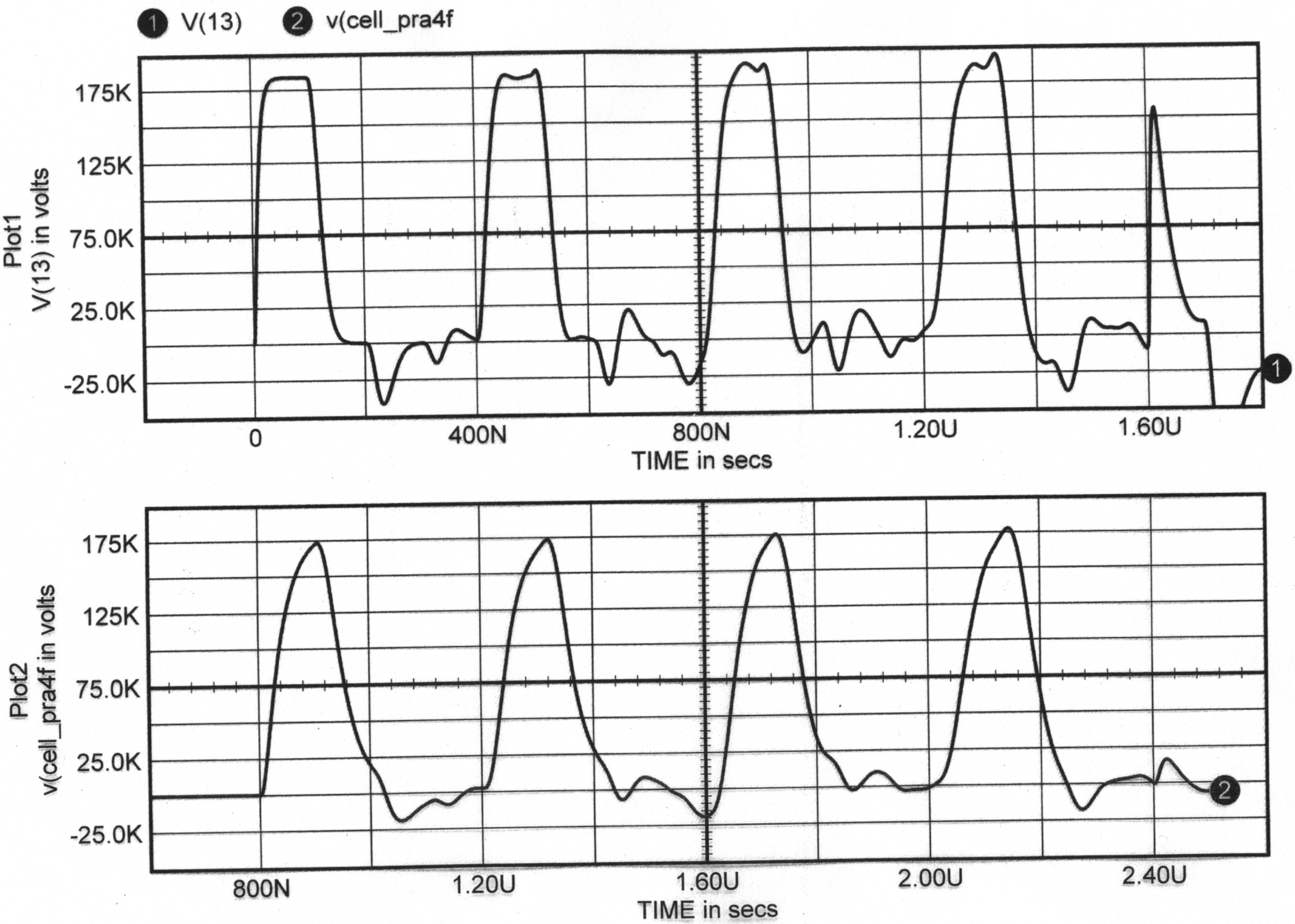
Inter-Cell Cutaway



- ¥ An Inter-Cell Module is provided every 10 cells for beam line pumping & beam position / current monitors
- ¥ A constant solenoid gap pitch is maintained

2 MV, 4 Pulse Pulsed Power Layout

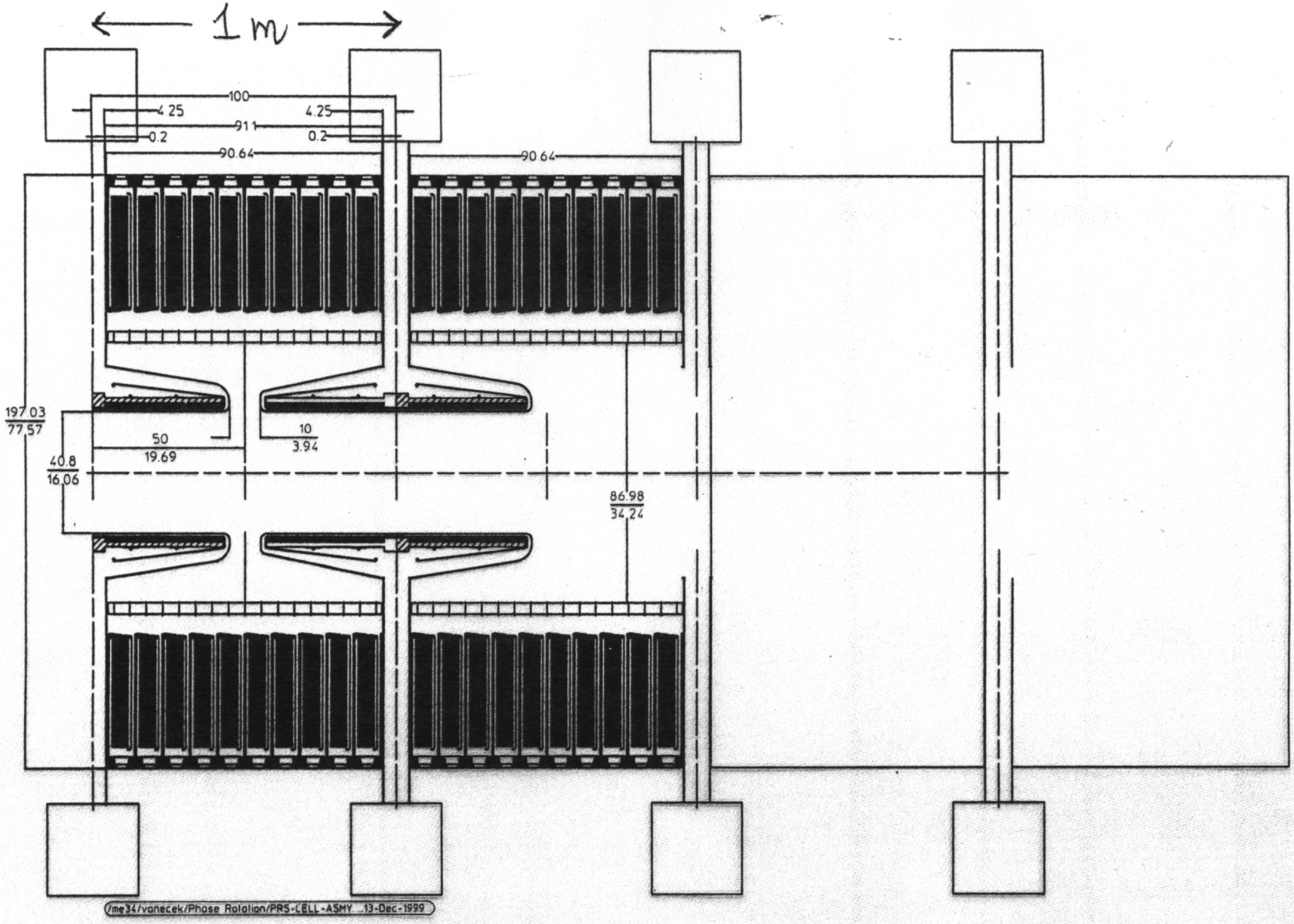




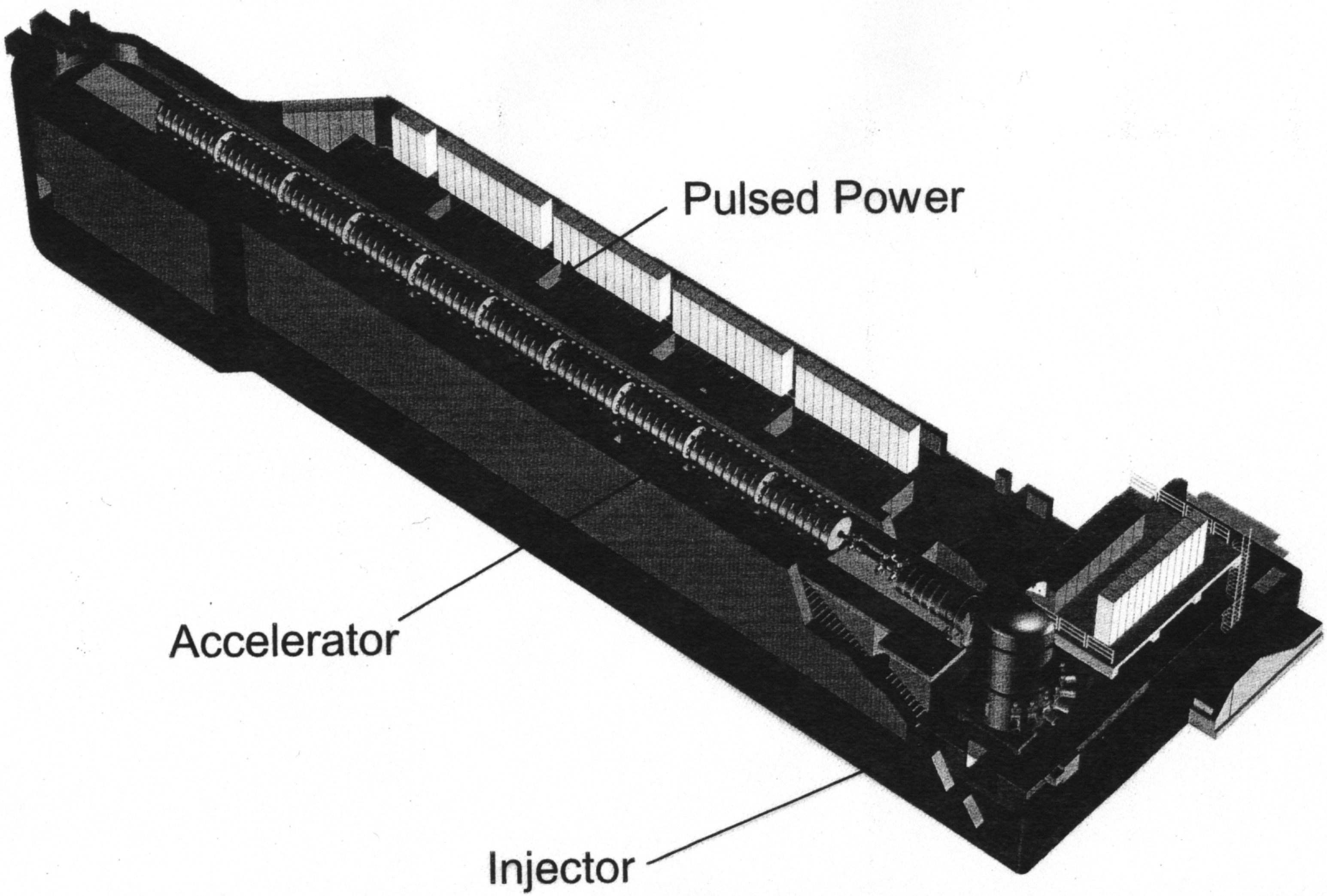
1 V(13)
2 v(cell_pra4f
Plot1
V(13) in volts
175K
125K
75.0K
25.0K
-25.0K
0
400N
800N
1.20U
1.60U
TIME in secs
Plot2
v(cell_pra4f in volts
175K
125K
75.0K
25.0K
-25.0K
800N
1.20U
1.60U
2.00U
2.40U
TIME in secs

	dates	Energy	Current	Width	Rep-rate	Location
Astron I	1960-1968	4 MeV	500 A	400 ns	5-1440 Hz	LLNL
Astron II	1968-75	6 MeV	800 A	400 ns	5-1000 Hz	LLNL
ERA	1969-74	4 MeV	1.2 kA	40 ns	1 Hz	LBNL
ETA	1978-88	5 MeV	10 kA	50 ns	1-1000 Hz	LLNL
FXR	1981---	15 MeV	5 kA	50 ns	1/3 Hz	LLNL
ATA	1982-90	50 MeV	10 kA	70 ns	1-1000 Hz	LLNL
ETA II	1988-92	6 MeV	1 kA	70 ns	1-5000 Hz	LLNL
MBE-4	1985-91	1 MeV	0.4 A(Cs^+)	4-.4 μs	1/5 Hz	LBNL
RTA	1995-	1 MeV	1 kA	300 ns	1 Hz	LBNL
DARHT-I	1999	20 MeV	4 kA	80 ns	1/60 Hz	LANL
DARHT-II	1999-	20 MeV	2 kA	2 μs	1/60 Hz	LANL
MUON PHASE ROTATOR		±100 MeV	16 A	100 ns	15 Hz (x 4 pulses)	

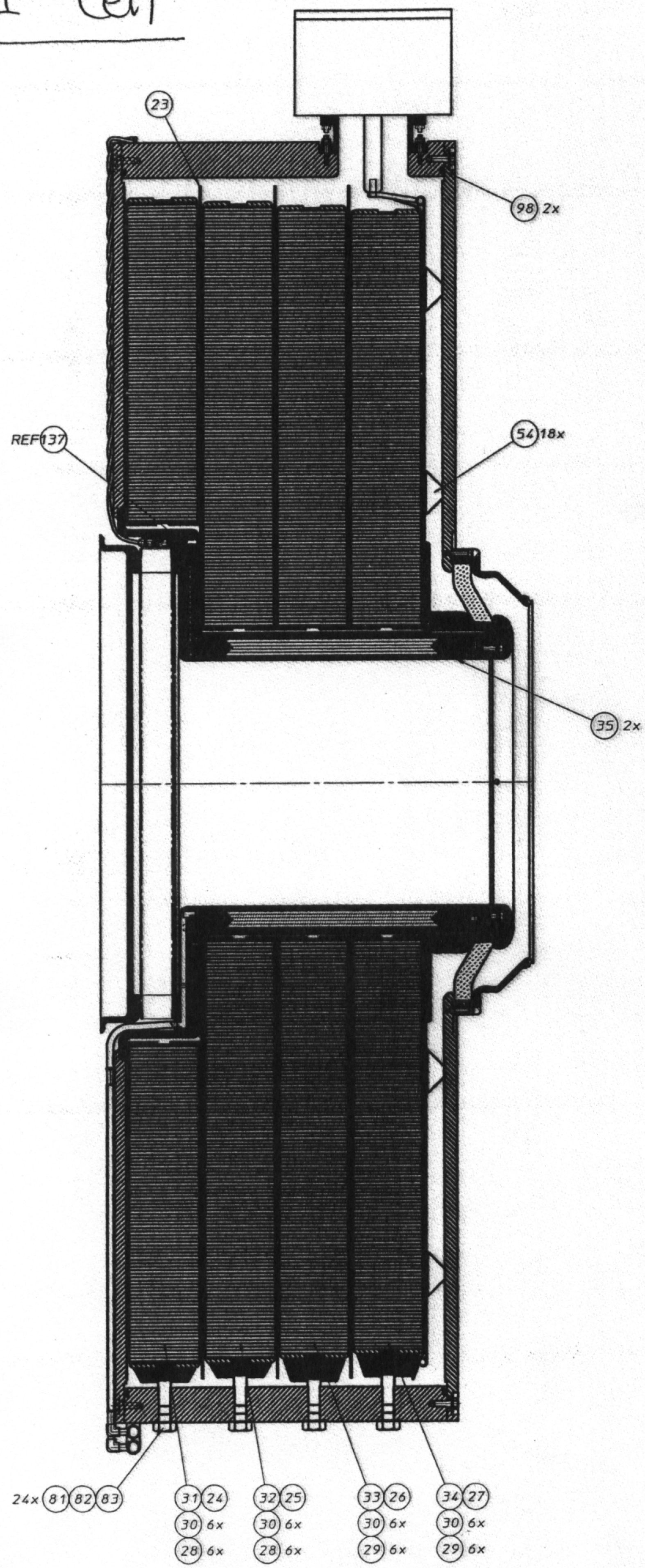
MUON PHASE ROTATOR



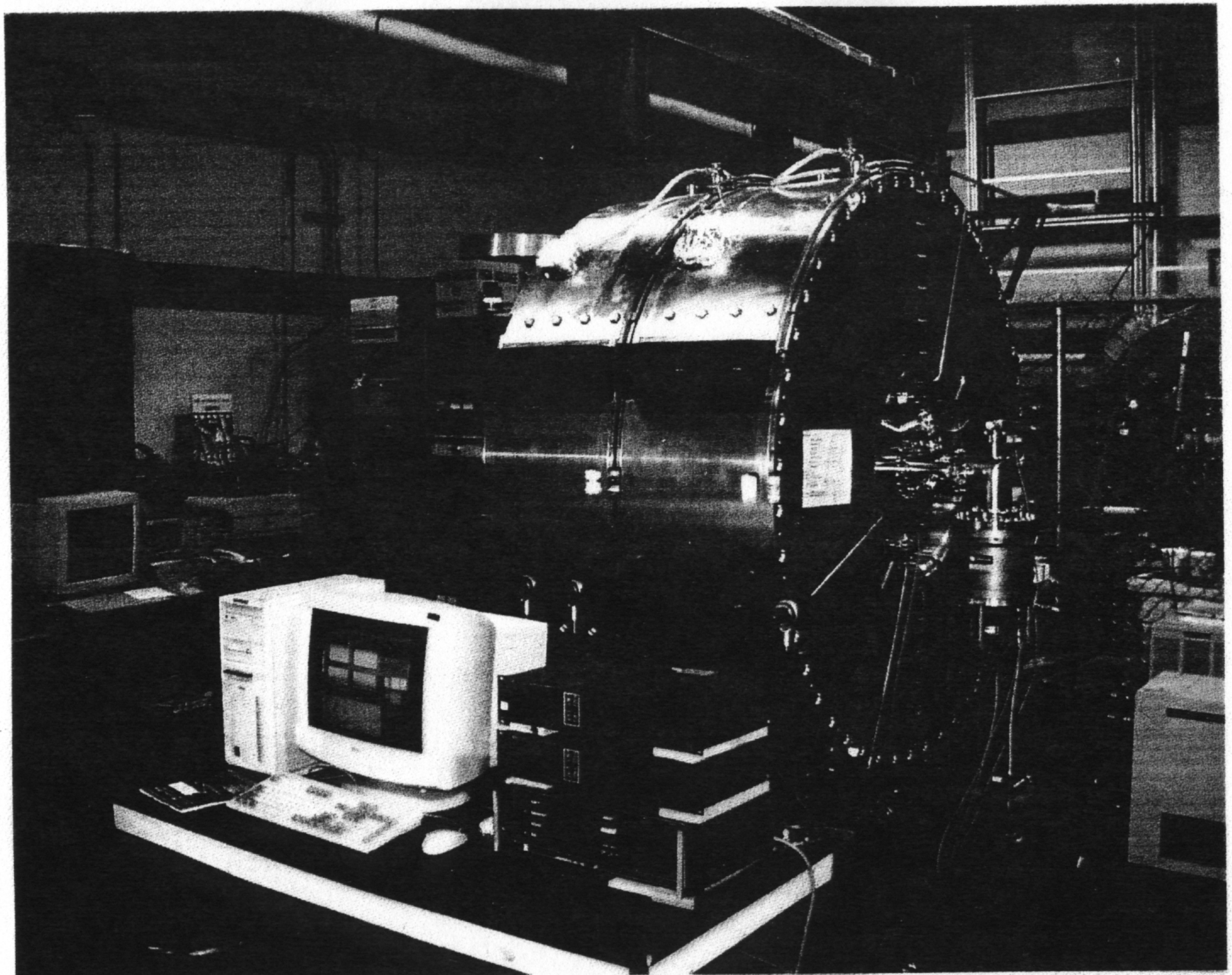
DARHT Second Axis



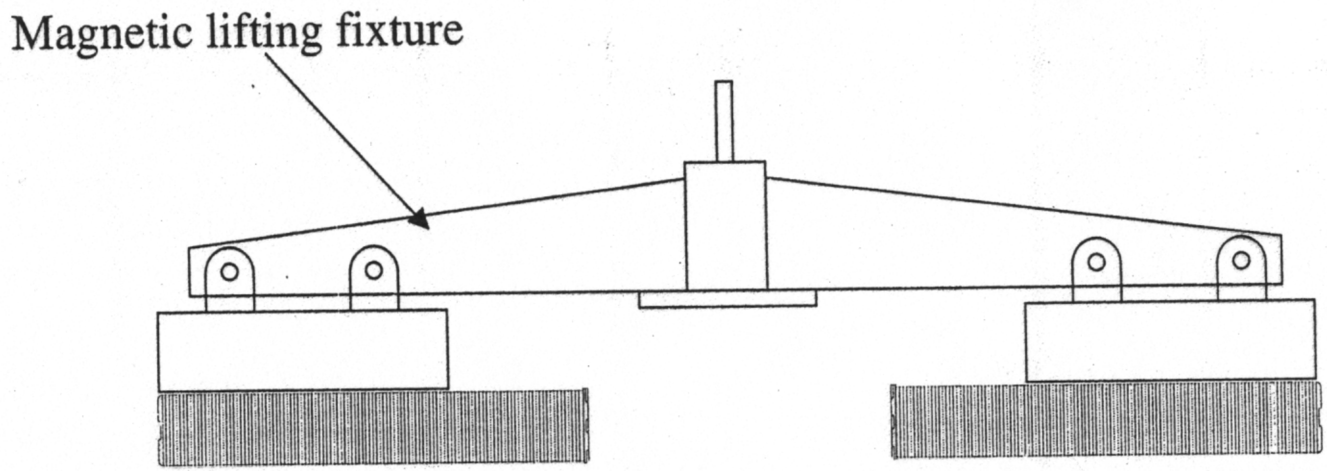
DARHT-II Cell

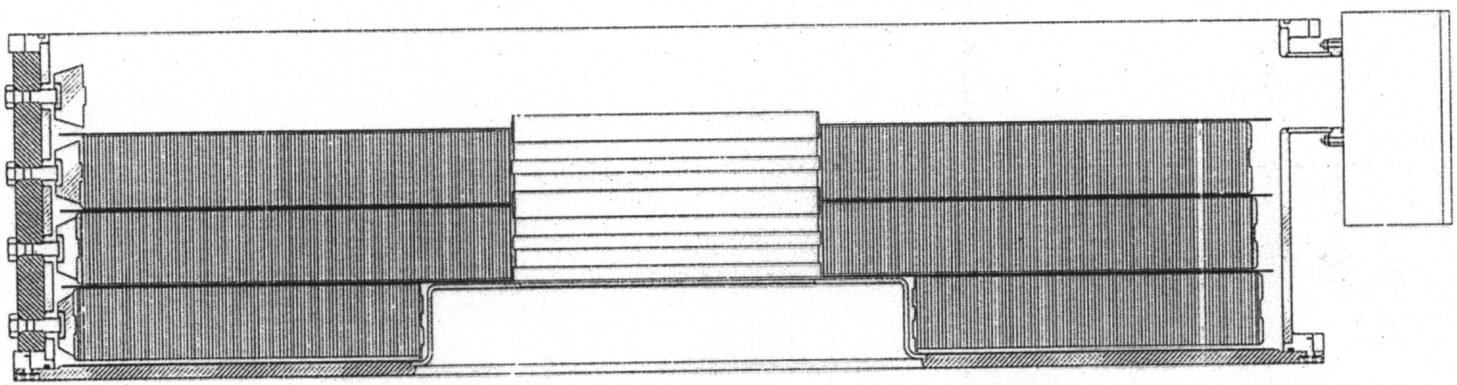


Two Cell Vacuum Testing

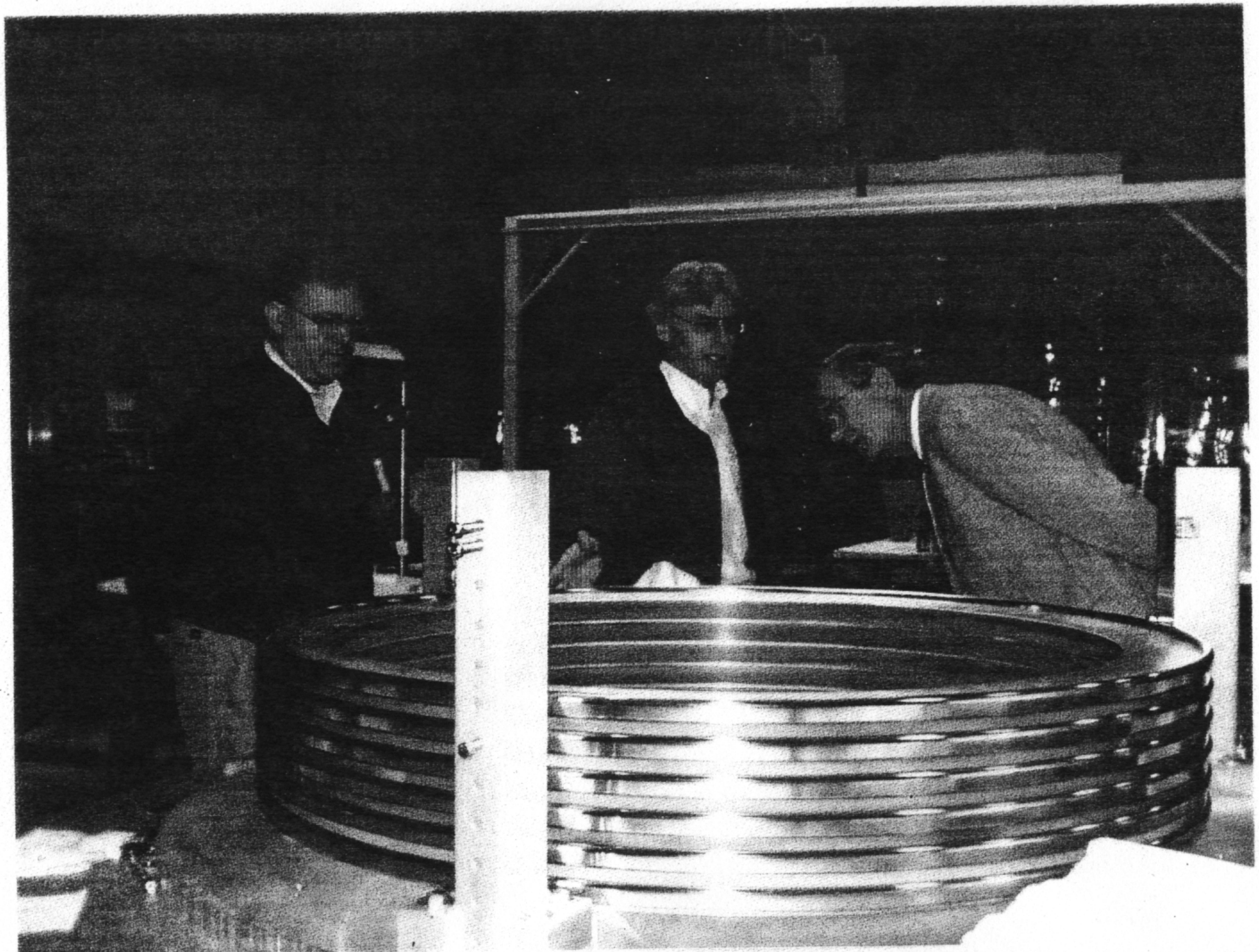


Cell assembly

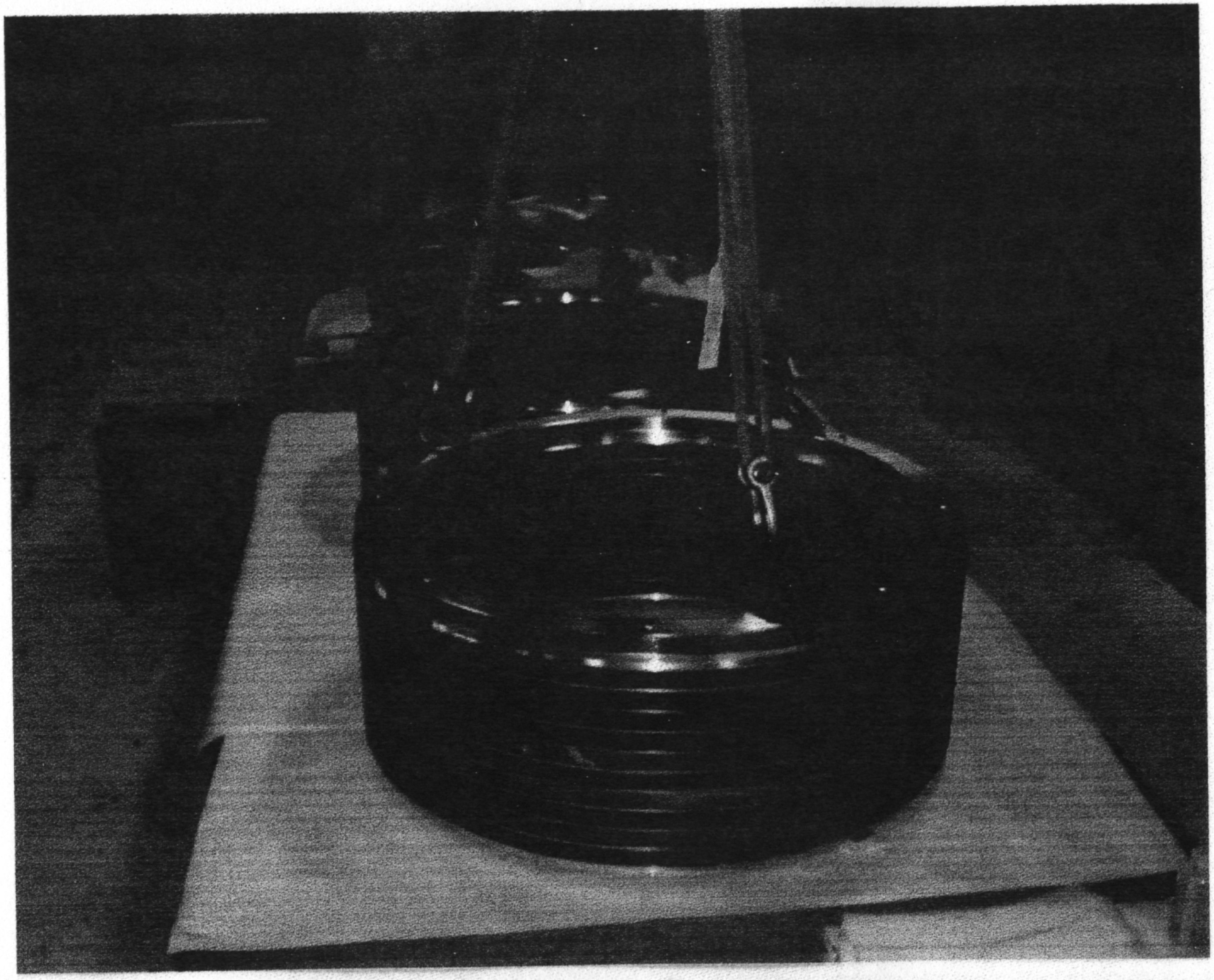




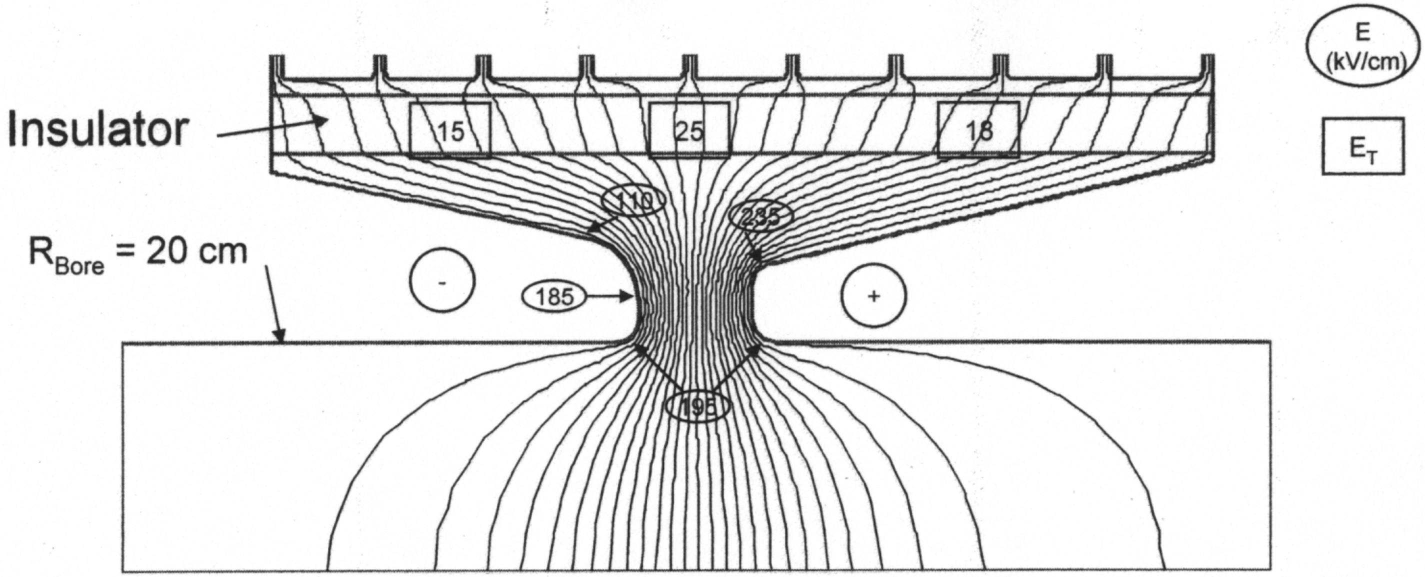
HV Column - Mycalex Stack



High Voltage Column: Mycalex Stack 3 and 4 Completed



Induction Cell Field Stress



- Field are conservative
  - @ V = 1600 kV
  - 160 kV/cm in Oil
  - 25 kV/cm along insulator
  - 193 kV/cm

Diode Region E-Field Stresses

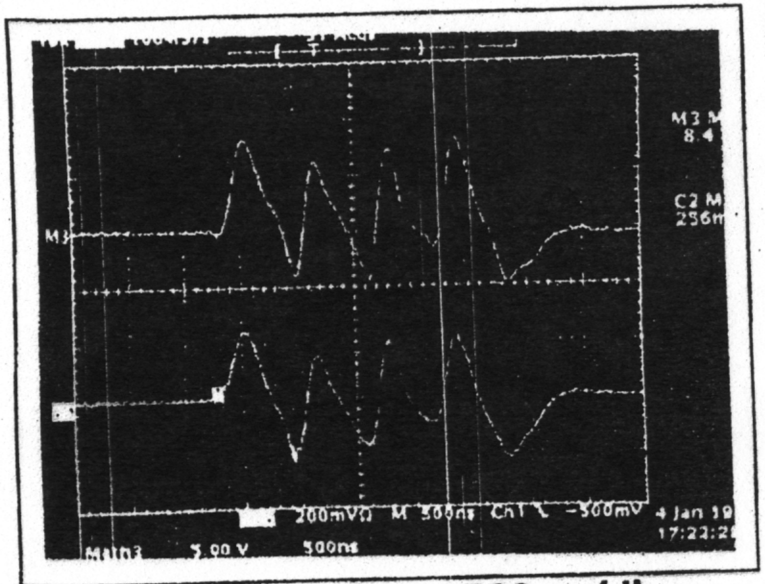
(1) ITS Injector at 3.75 MV and 17.8 cm A-K Gap:

A-K Gap - 210 kV/cm
Radial Field across Insulator - 76 kV/cm
Peak Cathode Shroud Field - 295 kV/cm

(2) 4-Pulse Injector at 4.0 MV and 32 cm A-K Gap:
Plastic Fields Derated by $T^{-1/6} \sim 0.80$

	Design Baseline	Design Achieved
A-K Gap:	150 kV/cm	150 kV/cm
Radial Field across Insulator:	50 kV/cm	45 kV/cm
Peak Cathode Shroud Field:	200 kV/cm	170 kV/cm

Electrode Field Stress for multi-pulse

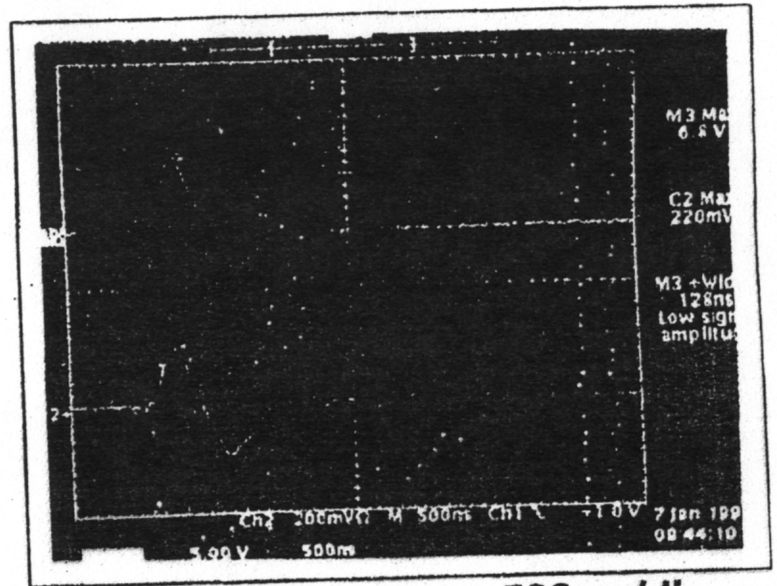


500 ns/div

With 4 pulse train threshold 210±20 kV/cm

Voltage

Charge through monitor

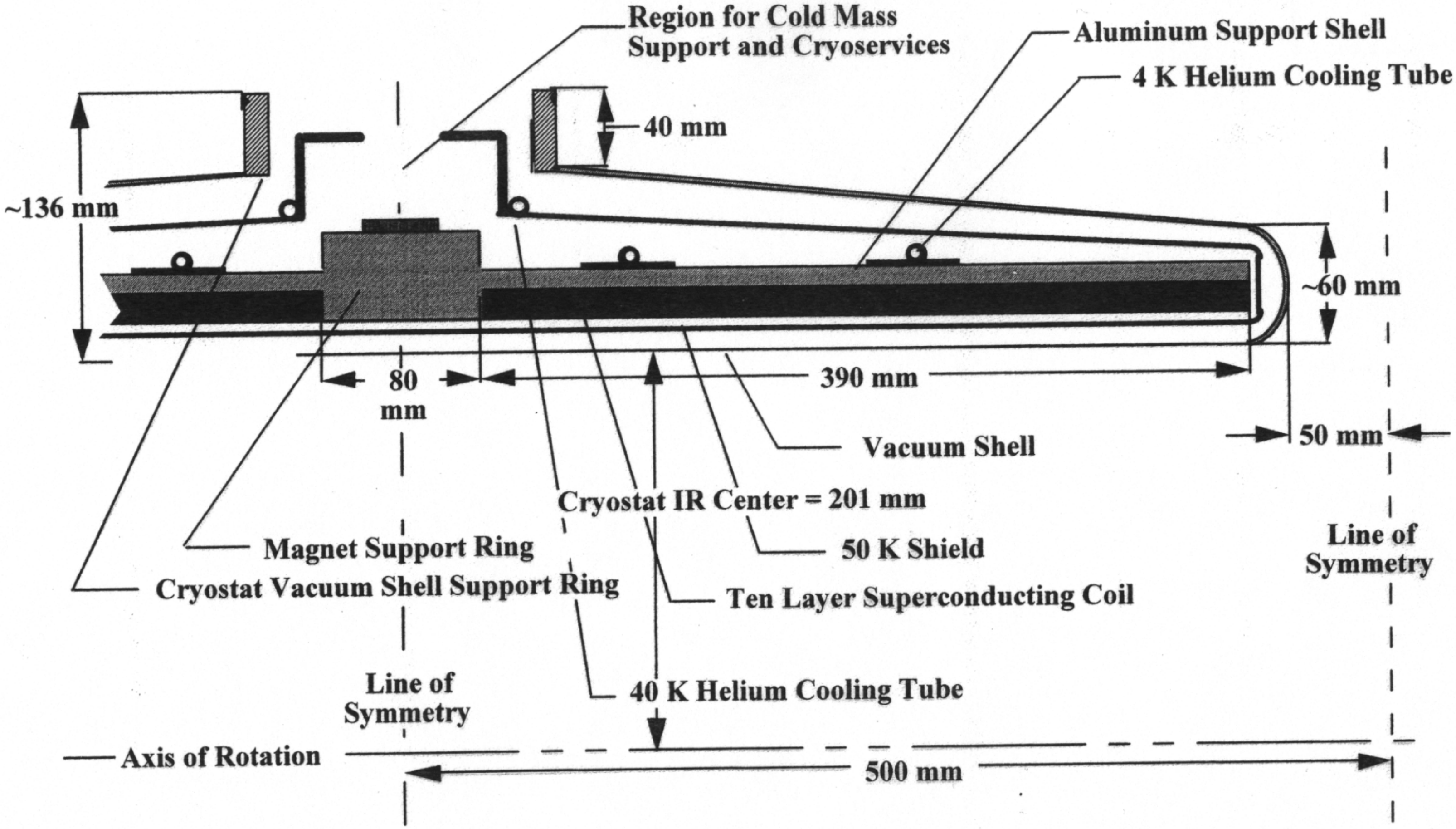


500 ns/div

With single pulse threshold 230±20 kV/cm

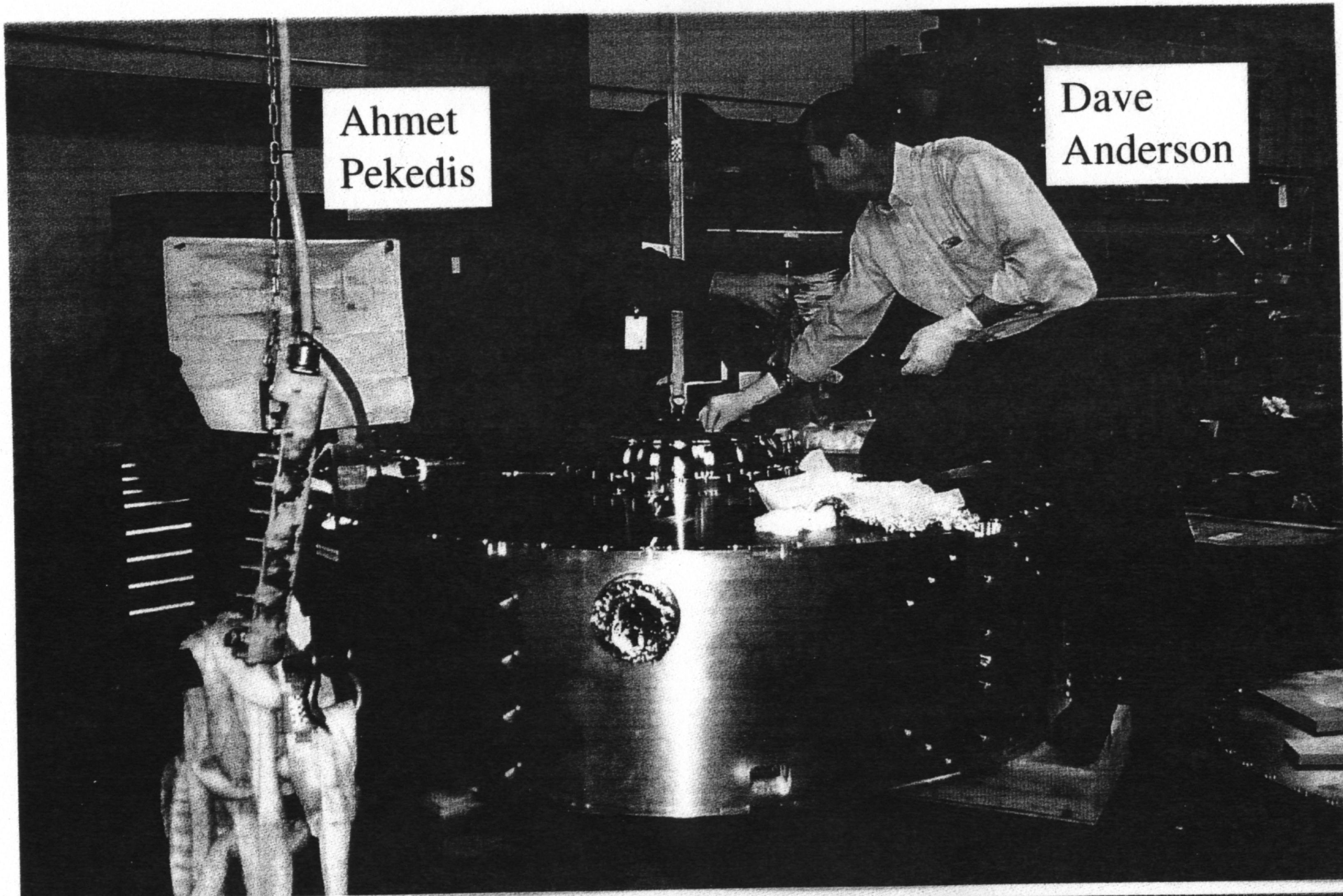
Gap spacing ~1.5 mm
30 cm diameter aluminum plates

Ruduction consistent with $(Nt_p)^{-1/5}$ scaling



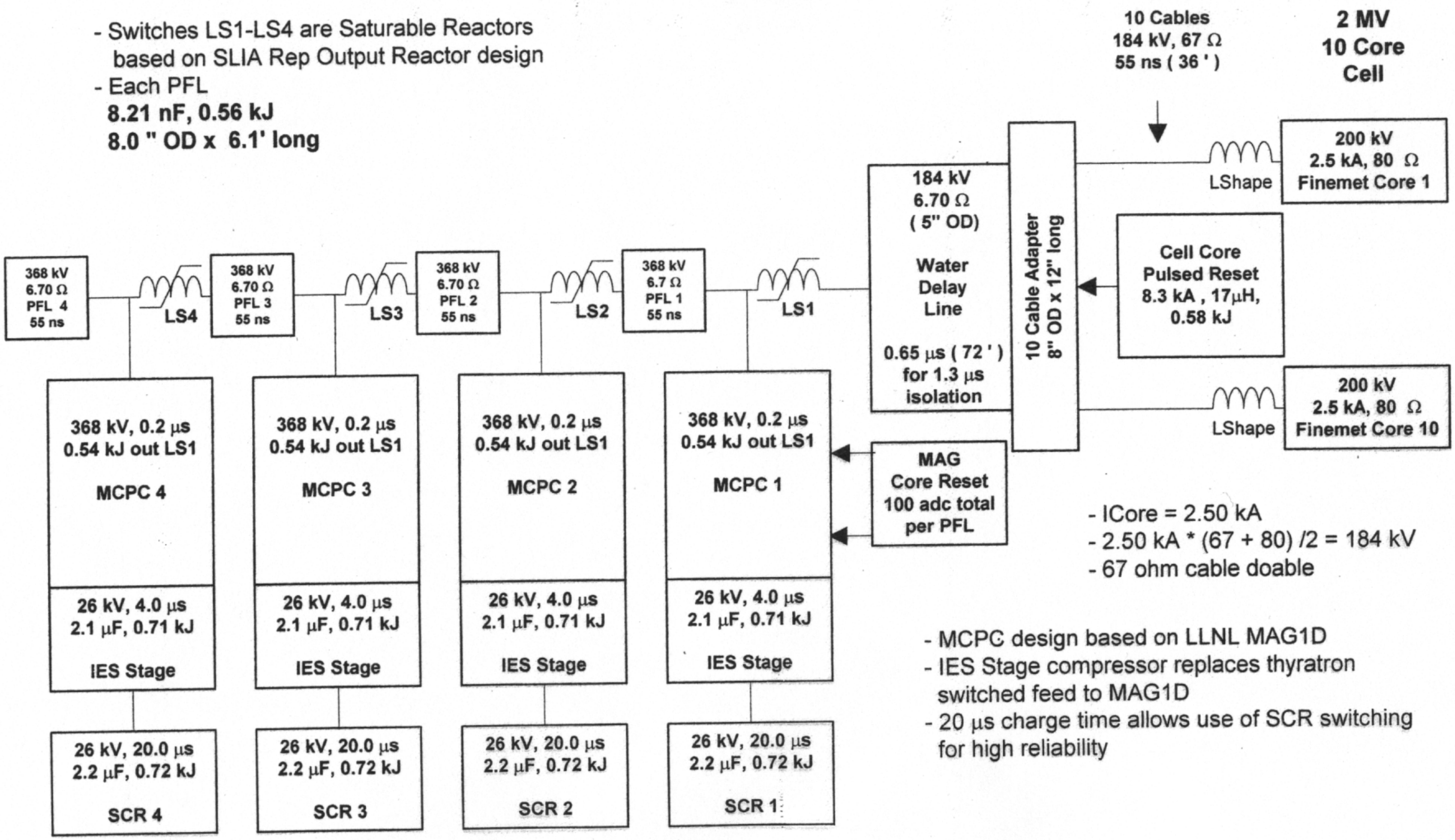
Quarter Section of a 3.0 T Solenoid for the Phase Rotation System

Solenoid insertion



4 Pulse Pulsed Power System
4 Series PFLs

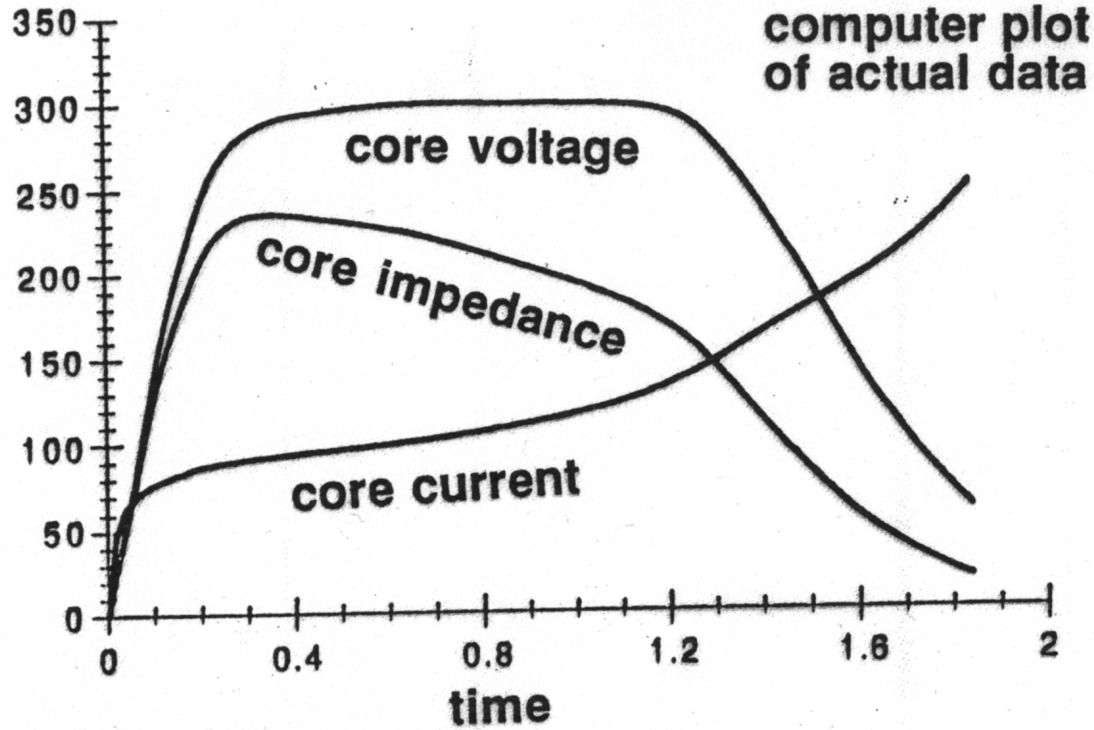
- Switches LS1-LS4 are Saturable Reactors based on SLIA Rep Output Reactor design
- Each PFL
  8.21 nF, 0.56 kJ
  8.0 " OD x 6.1' long



- ICore = 2.50 kA
- 2.50 kA * (67 + 80) /2 = 184 kV
- 67 ohm cable doable

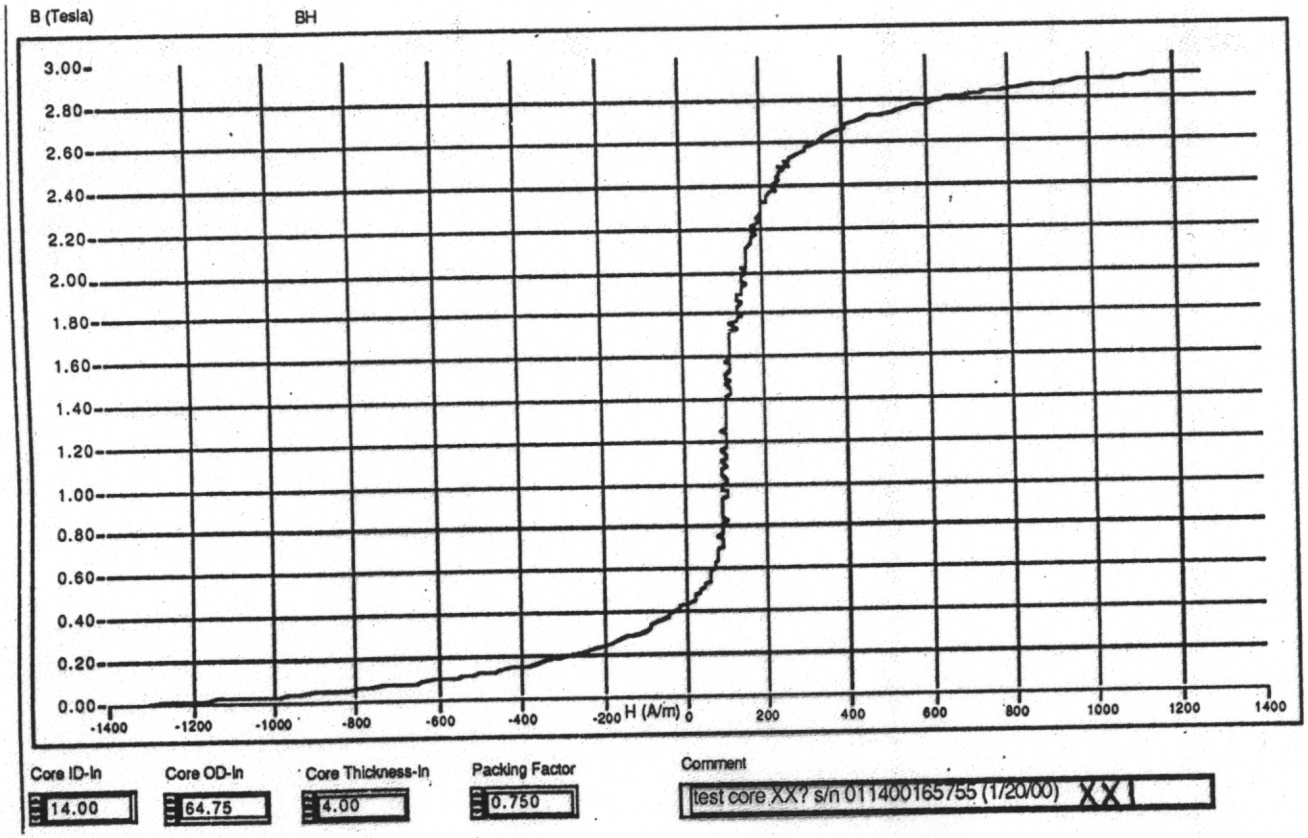
- MCPC design based on LLNL MAG1D
- IES Stage compressor replaces thyratron switched feed to MAG1D
- 20 μs charge time allows use of SCR switching for high reliability

Core Current Varies by a Factor of Two



Top Trace: Core voltage ÷ 10
Middle Trace: |Z| Core x 75
Bottom Trace: Core current

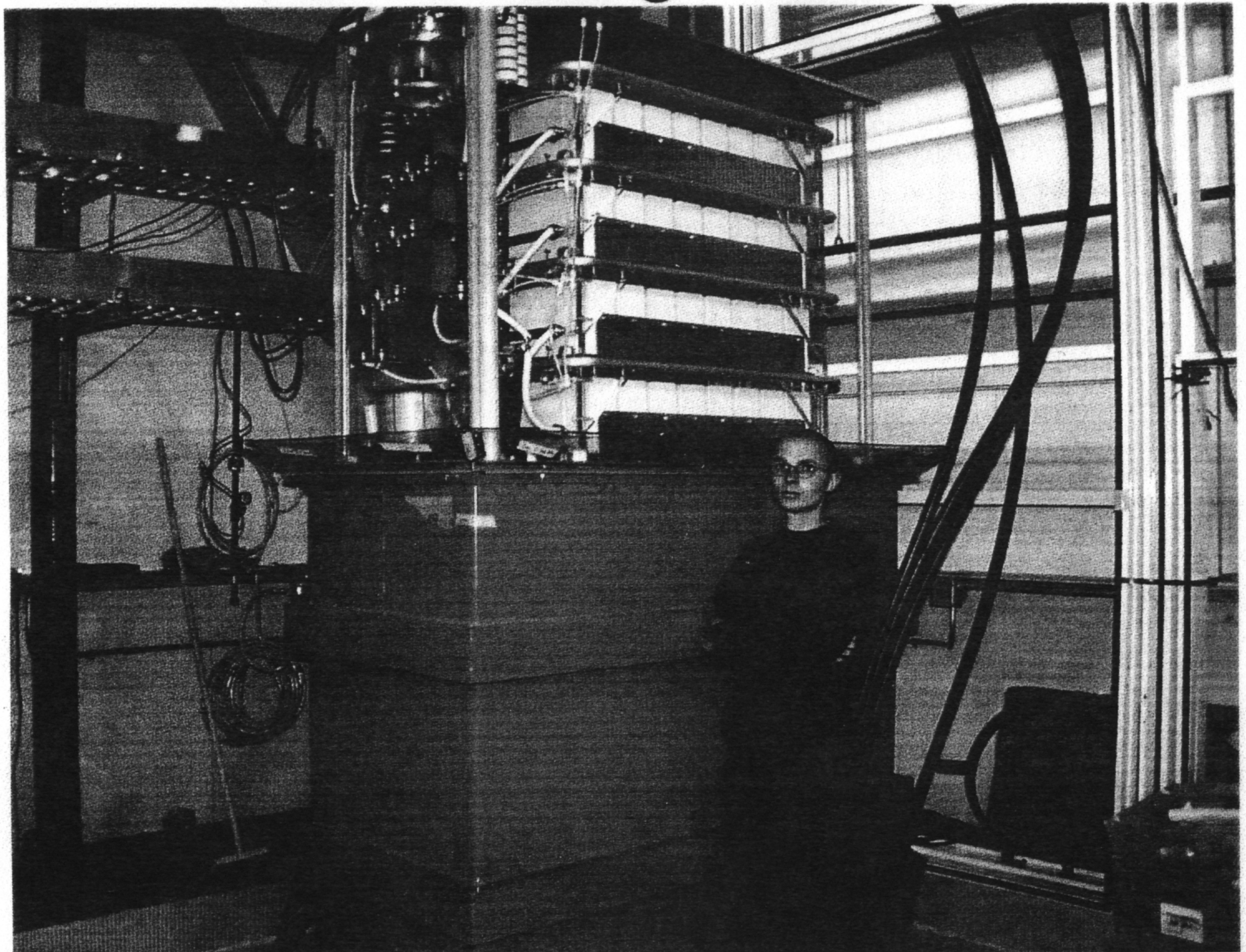
Test Cores



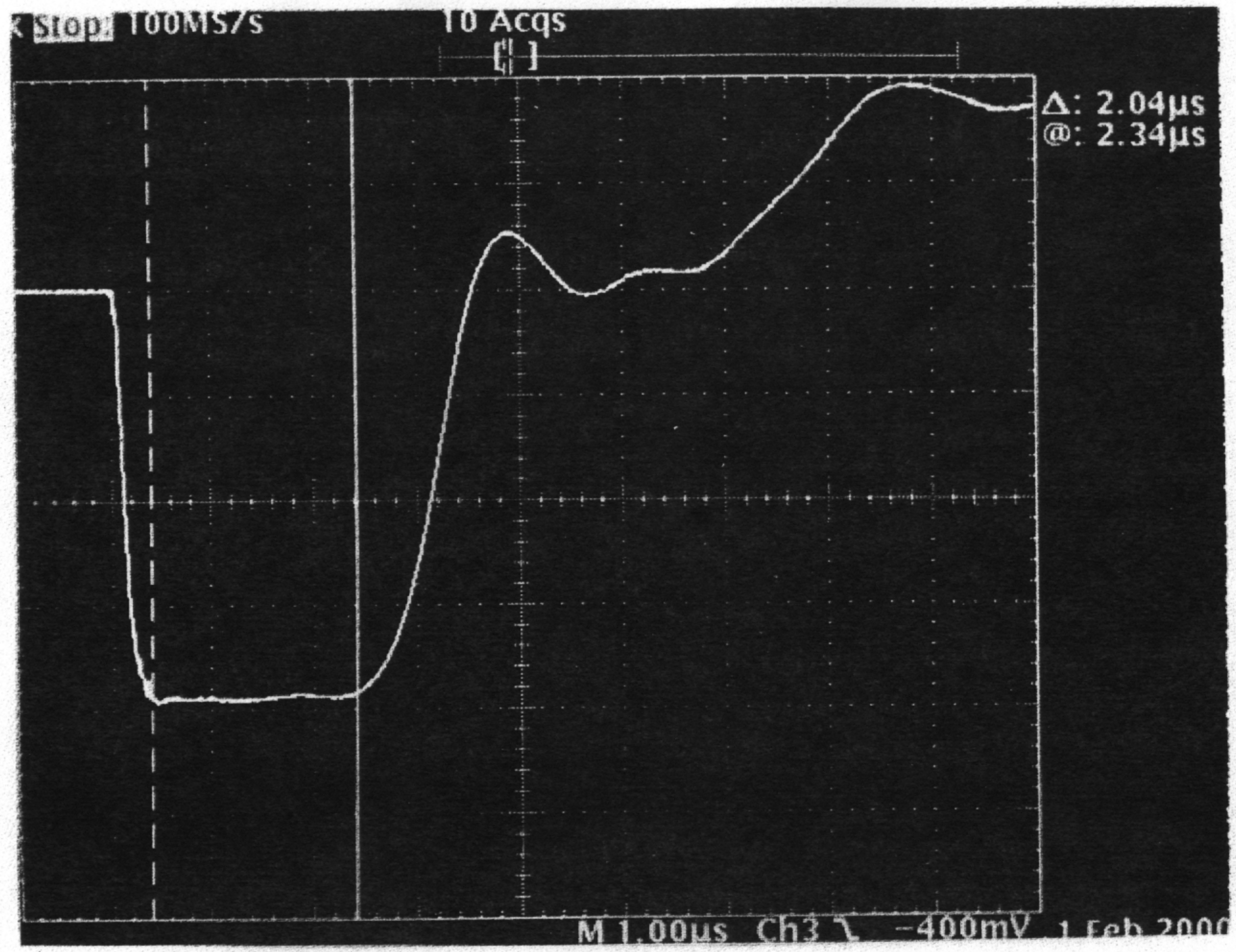
Usable ΔB = 2.675T @ ΔH = 1200A/m

Energy Loss = 350J/m^3 for 0.42T/us magnetization rate

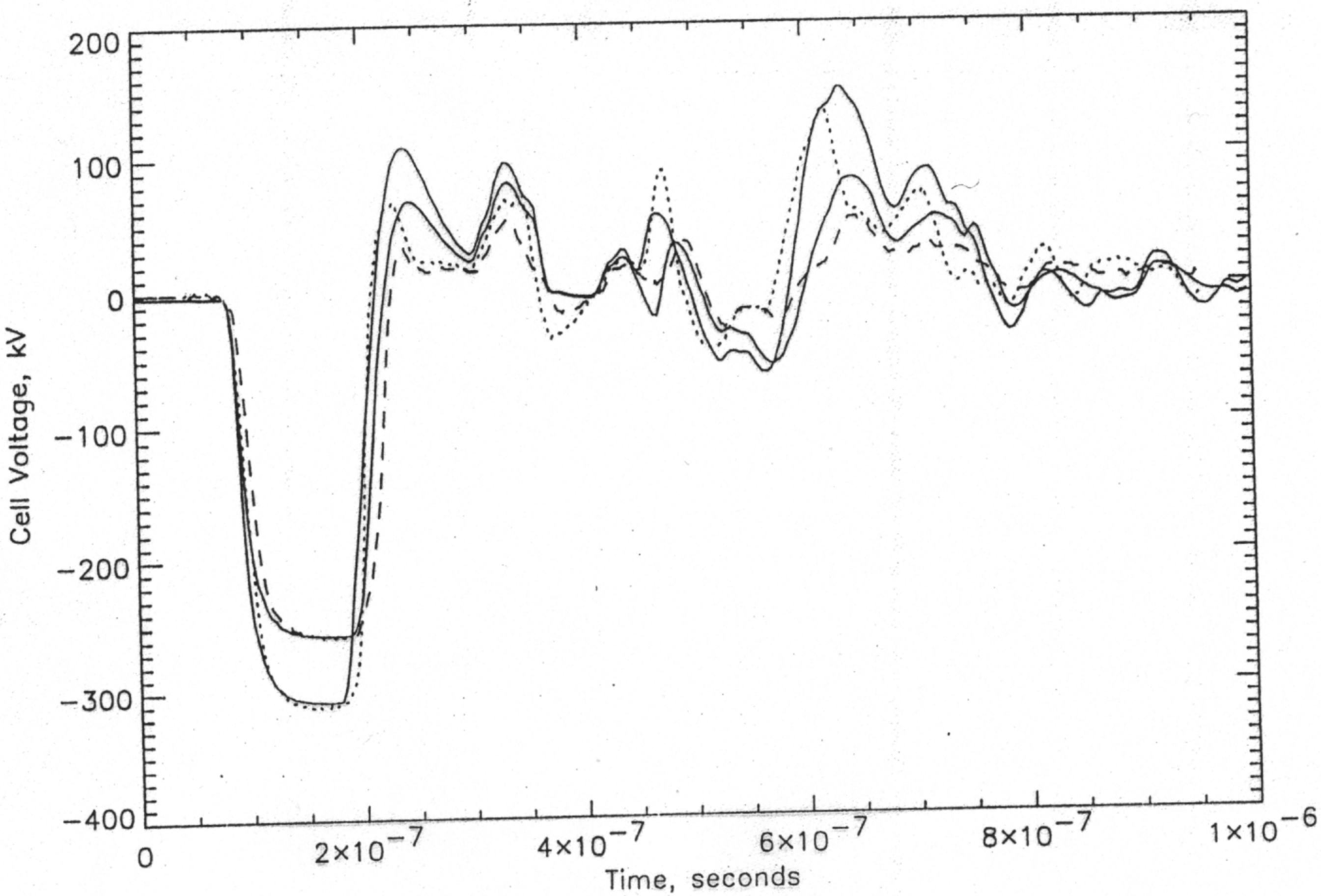
Pulse Forming Network



Sample PFN waveform

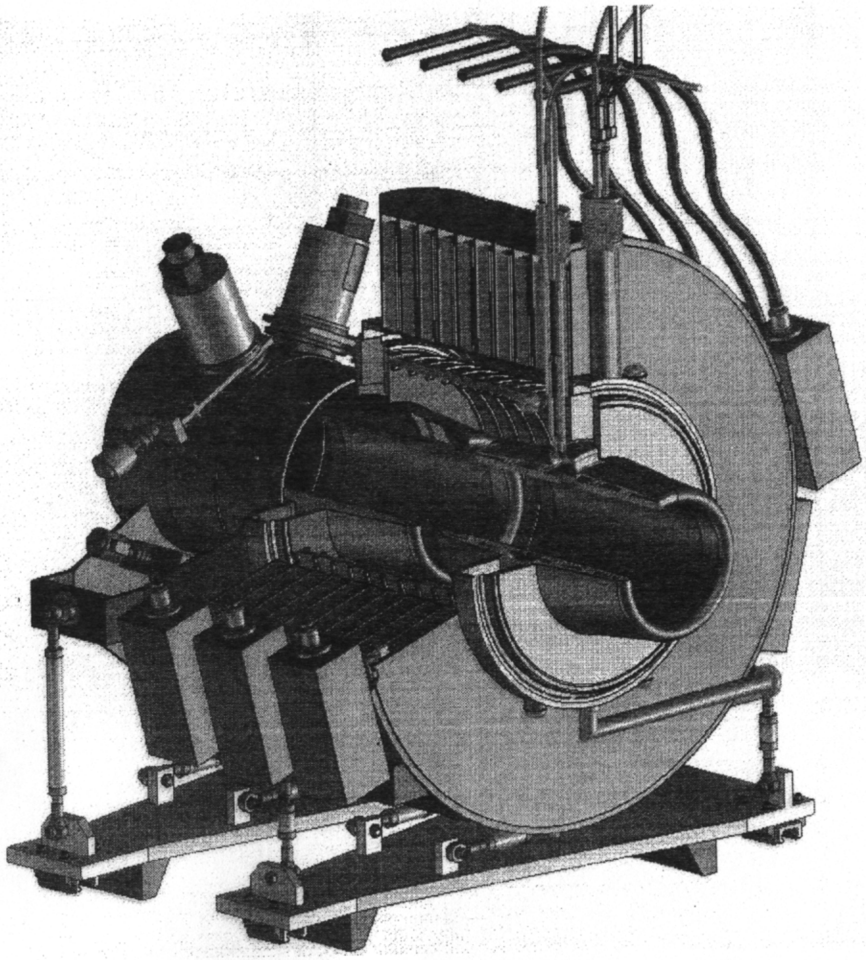


Comparison of Actual and Predicted Waveforms Shows Good Agreement



Prototype Module Cell

- Consists of
  - 1 m Induction cell
  - Single Superconducting Solenoid Magnet



Conceptual Design Tasks

- Get Induction Linac design consistent with the system beam dynamic requirements
- Induction Cell
  - Choose insulator material
  - Resistive grading and/or MOV protection
  - Optimize topology for minimum electrical stress
  - Core material selection (Finemet or Metglas 2605SC) & tests
    - Small core samples (FNLA provided cores, LBNL pulser)
    - Full size single core (may spill over to year 2)
- Superconducting magnet
  - Further design development
  - mechanical forces

Conceptual Design Tasks (cont.)

- Pulsed Power
  - Explore alternate circuit topologies to reduce cost
  - Optimize waveshape with circuit simulation model
    - Incorporate cell core model and normalize with core test results
    - Add detail and develop tuning knobs
  - Optimize magnetic compressor design
  - Explore alternate switch technologies & test
    - Improved Thyristor
    - IGBT, FET

3 Year Program Plan

- Complete testing of a prototype 4 pulse module in 3 years
- Prototype module consists of:
  - 4 Pulse Pulsed Power Module
  - 2 MV, 1 m Induction Cell
  - Single Superconducting Solenoid Magnet
- Schedule
  - Months 1-10 _ Conceptual Design ending with CDR
  - Months 11-20 _ Detailed Design ending with FDR
  - Months 21-30 _ Fabication & Assembly
  - Months 31-36 _ Test Prototype Module