Induction Linac Technology for Muon Beam Phase Rotation

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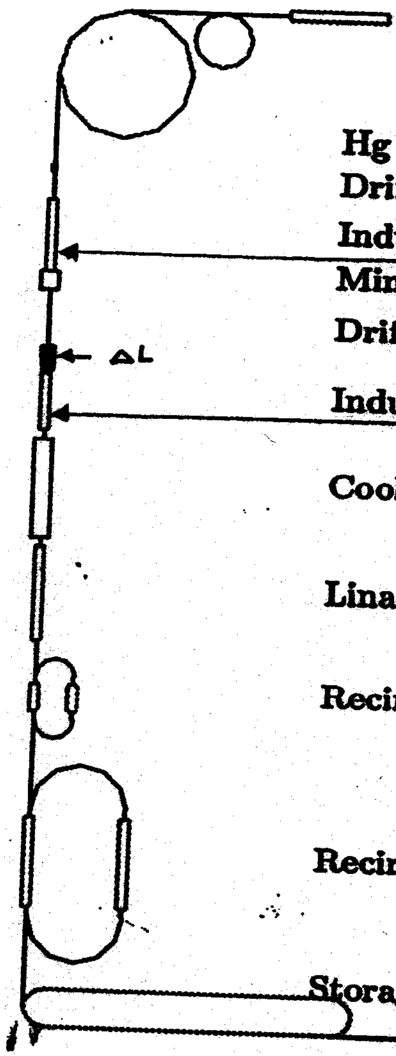
Dec.15-16,2000 – BNL

Acceleration Scheme

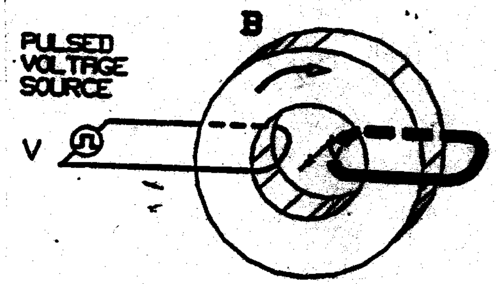


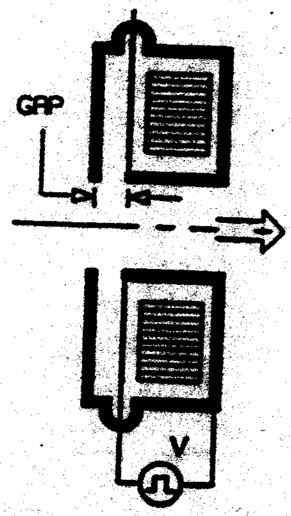
Proton Driver	Upgraded AGS		
		Δt L	MeV/m
Hg Target	(.3 m)		
Drift	(35 m)		
Induction #1	(100 m)	125ns 100m	0-1.4 MV/m
Mini Cooling	(3.5 m H_2)		
Drift	(125 m)		
Induction #2	(80 m)	300ns 120 m	1.33 MV/m (talk to Bob Palmer)
Cooling	(142 m)		
Linac	(2 GeV)		
Recirc. Linac #1	(2-6 GeV)		
Recirc. Linac #2	(2-20 GeV)		
Storage Ring	(20 GeV)		

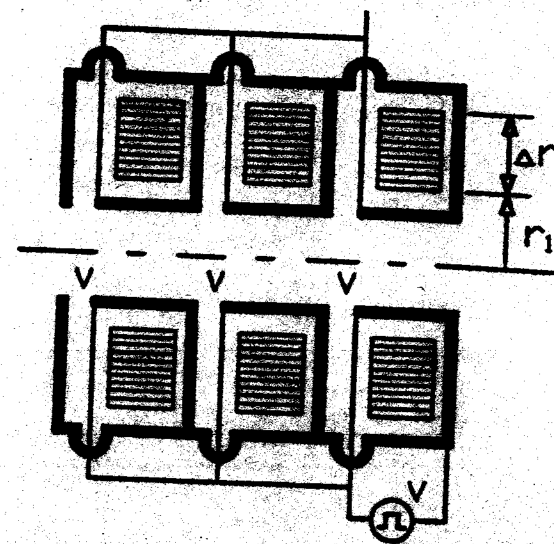
Accelerator Comparison

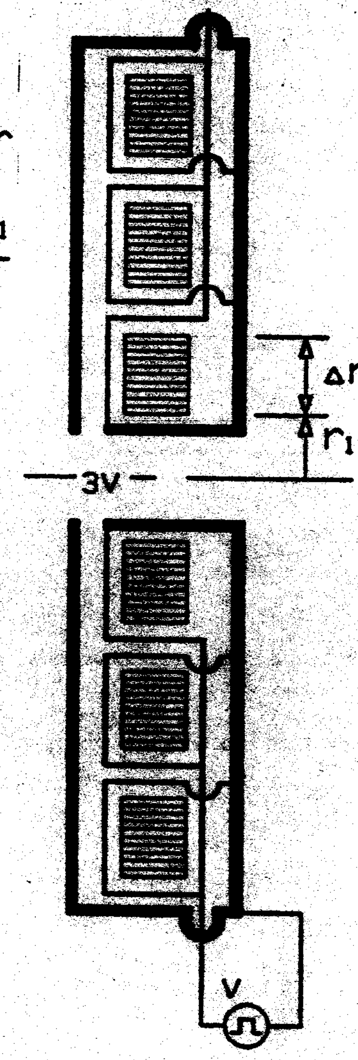
Considering the international family of linear accelerators, the LIAs have relatively low gradient but very high current capability. The two-mile Stanford Linear Accelerator (SLAC) consists of a waveguide system that transfers microwave (2856 MHz) power from klystrons to the disk-loaded accelerator structure. This structure is a high-Q (high impedance) cavity that accelerates micropulses (ps) of very low current (amperes) at very high gradients. In contrast, the LIA[1] consists of a simple nonresonant structure where the drive voltage is applied to an axially symmetric gap that encloses a toroidal ferrimagnetic material. The change in flux in this magnetic core induces an axial electric field that provides acceleration for the electrons. This simple nonresonant (low Q) structure acts as a single-turn transformer that can accelerate from hundreds of amperes to tens of kiloamperes, basically limited by the drive impedance. In principle, such a structure can also provide acceleration fields of varying time duration from tens to hundreds of nanoseconds at virtually any repetition rate. The fundamental limits on the operating parameter space are dictated by the requirements of "high current" beam transport physics.

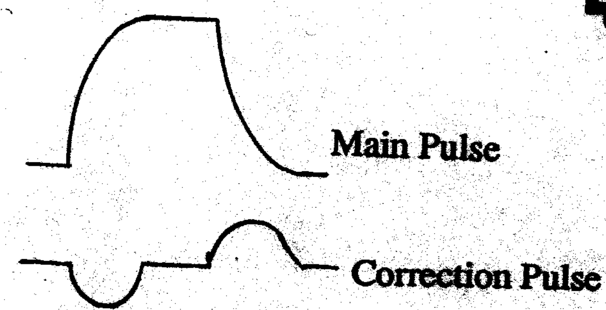
Waveform Generation





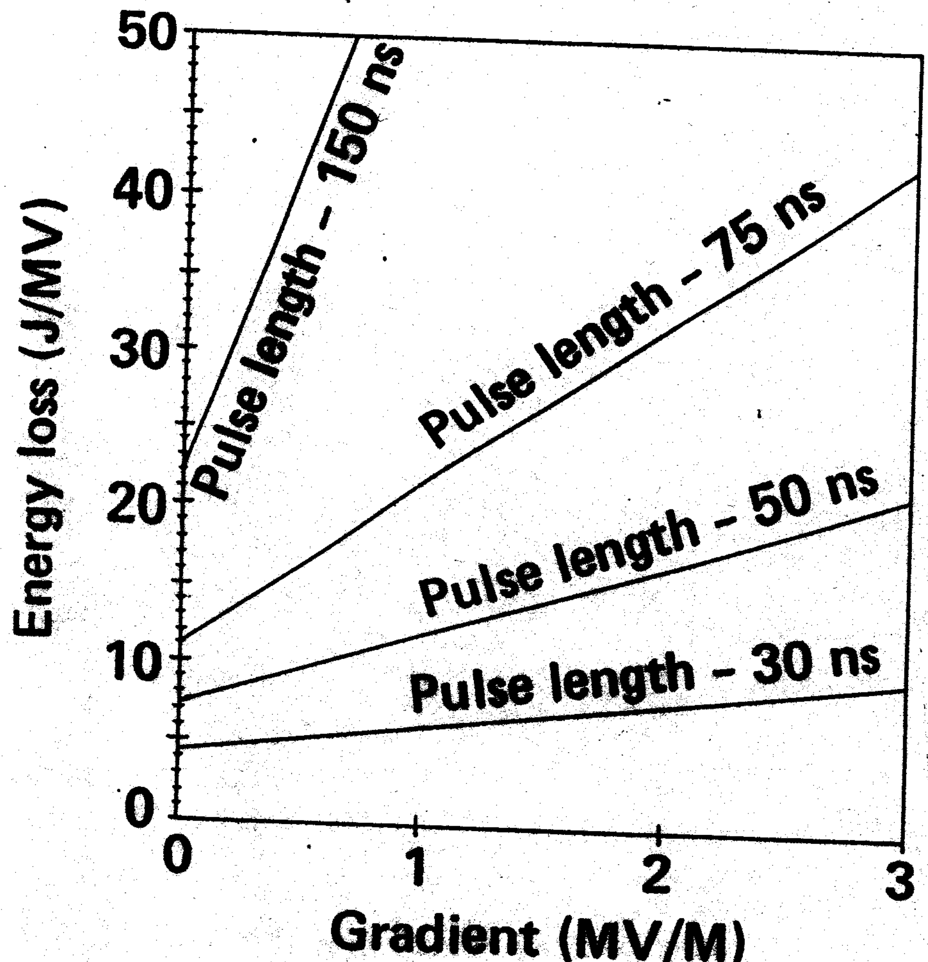


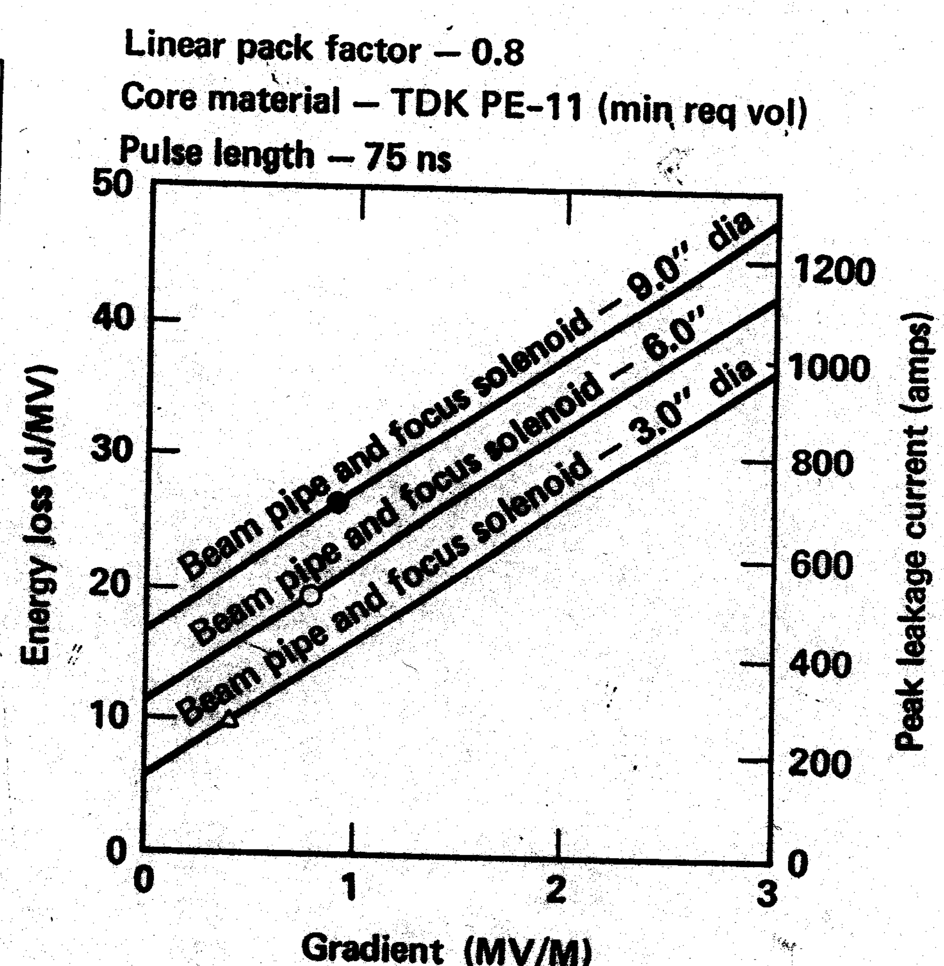




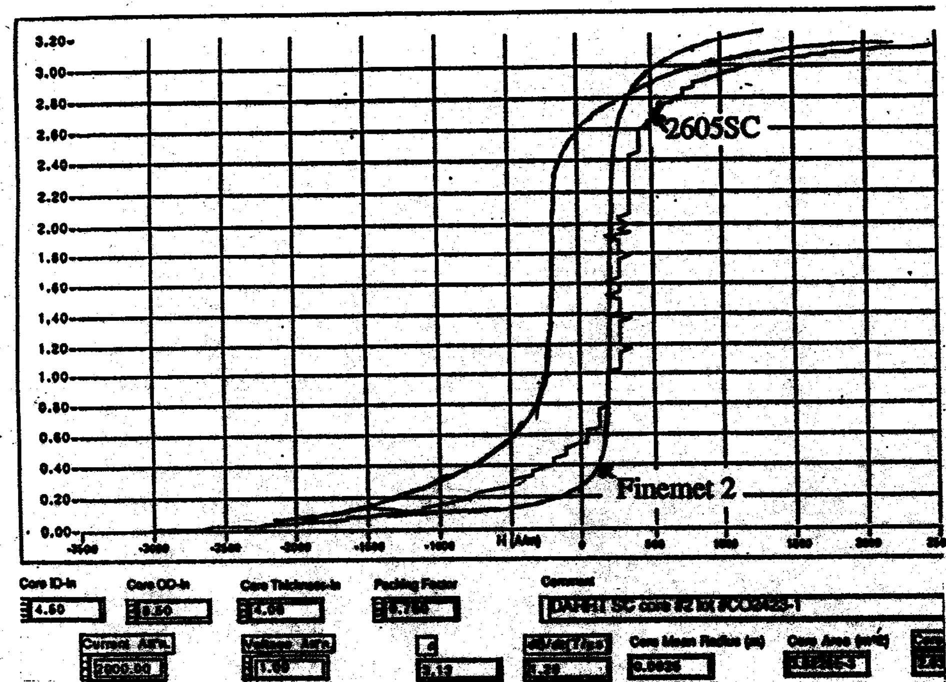
- Practically any acceleration or deceleration waveform can be generated. Wavefront or midulse correction can be applied through a separate core.
- The most economical and straight forward is the unipolar pulse.
- Reducing the gradient of Induction2 fom 2MV/m to 1.33MV/m will cut the cost of the magnetic material and the pulse power by nearly 40%.

General Scaling Rules

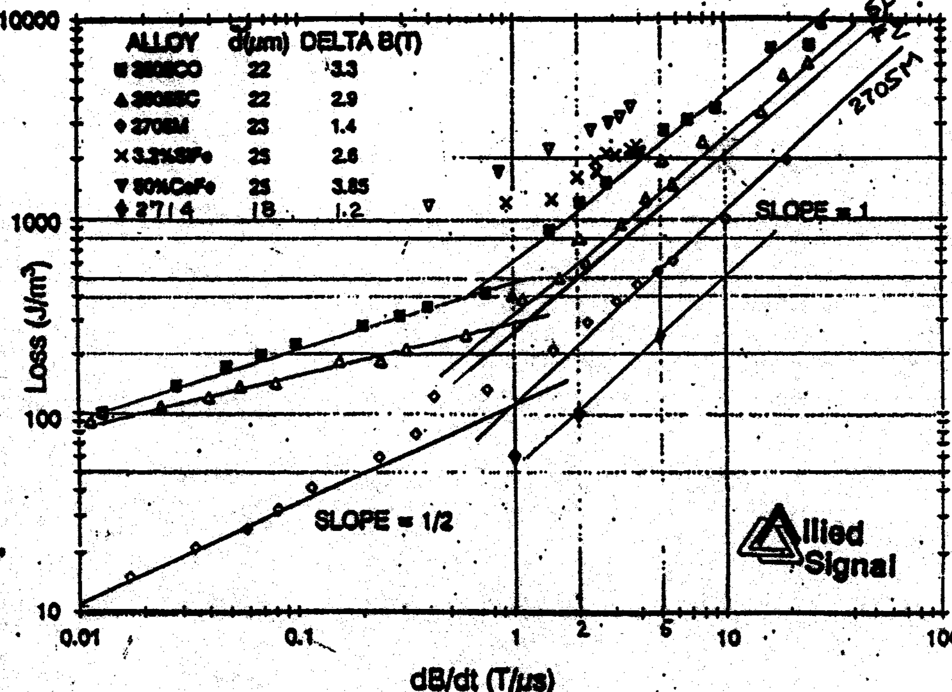




Magnetic Materials

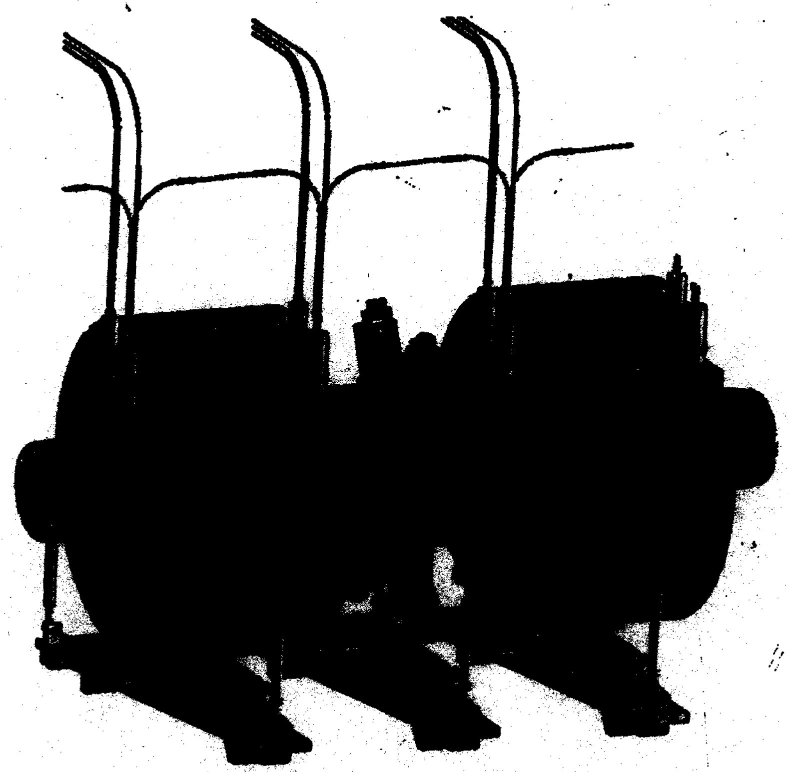


Metglas Alloys Losses



- In low current(<1000A) induction accelerators, the magnetic properties are critical to the design.
- Nearly all the energy is delivered to the core as magnetization energy and it is directly proportional to the magnetization rate or dB/dt.

Induction Module Design



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

- For Linac 1-Keep the same for now
- For Linac 2-With the reduced gradient and operating the cores at a greater dB/dt, the cells will be very similar with a slightly larger diameter

Induction Module Core Design (Study I)

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- Requirements => Size
  - 20 cm bore radius & 25 cm for B_Z magnet & Insulator => **Core IR = 45 cm**
  - 90% axial packing & allowable electric field stress => **L = 100 cm**
  - From $V * \tau = \Delta B * A$
    - 2 MV hyperbolic ramp for 100 ns => $V\tau$ = 126 mV-s
    - Balancing pulsed power & core cost => ΔB =1.0 T
    - A = 0.13 m2 , PF_r = 0.70, & PF_a = 0.58 => Core OR = 78 cm

ΔV	V_{eff}	τ_r	τ_{flat}	τ_{eff}	$V\tau$	Type	δ	PF_r	ΔB_{max}	Cost	
kV	kV	µs	µs	µs	mV-s	*	gm/cc	*	T	Norm	
200	142	0.070	0.030	0.07	12.6	Finemet	7.32	0.70	1.96	1.00	<-- Finemet
200	142	0.070	0.030	0.07	12.6	2605SC	7.32	0.70	2.90	0.36	<-- 2605SC
200	142	0.070	0.030	0.07	12.6	2605SC	7.32	0.70	1.10	2.00	<-- 2714A

ΔB	A_{Met}	A_{Core}	$\Delta B/\Delta t$	L		Δr	r_i	r_o	r_o/r_i	r_{Mean}	H	I_{Core}	E_{Core}	k	U_{Met}	V_{Met}	W_{Met}	System $
T	cm²	cm²	T/µs	*	cm	cm	cm	cm	cm	cm	kA/m	kA	J	J-µs/T-m³	J/m³	cm³	kgm	Norm
0.97	130	185	13.2	2.28	5.8	32.0	45	77	1.71	61.0	0.65	2.50	31.5	107	634	49670	363.6	1.00
0.82	154	220	11.1	2.28	5.8	37.9	45	83	1.84	64.0	0.55	2.23	28.1	107	454	61744	452.0	1.02
1.48	85	122	20.1	2.28	5.8	21.0	45	66	1.47	55.5	0.98	3.41	42.9	107	1445	29888	217.3	1.07
0.82	154	220	11.1	2.28	5.8	38.0	45	83	1.84	64.0	0.98	3.94	49.6	282	801	61946	453.4	1.13
2.20	57	82	28.8	2.28	5.8	14.1	45	59	1.31	52.1	2.53	8.28	104.4	282	5571	18736	137.1	2.07
0.82	154	220	11.1	2.28	5.8	38.0	45	83	1.84	64.0	0.37	1.50	18.9	41	306	61946	453.4	1.35
0.86	147	209	11.7	2.28	5.8	36.1	46	82	1.79	64.1	0.39	1.59	20.0	41	339	58981	431.7	1.33

- Linac 1-Same projected hardware as study I but with one pulse.
- Linac 2-Will require 25-50% more energy than Linac 1.
- Correction Pulser- Will require an additional 10% if it is needed.

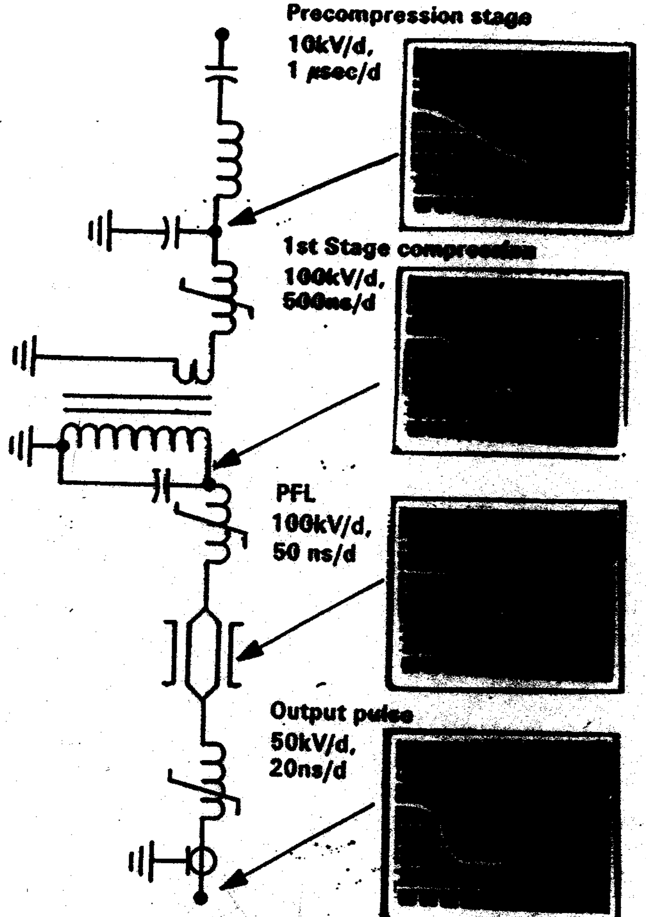
Cost Optimization

- The cost optimization process in selecting the magnetic material will factor in the following:
  - -Cost of the drive energy with the new topology ($/J)
  - -The cost of the magnetic material ($/kg)
  - -The magnetic material losses (J/m3) and the flux swing(ΔB) at the optimized dB/dt.

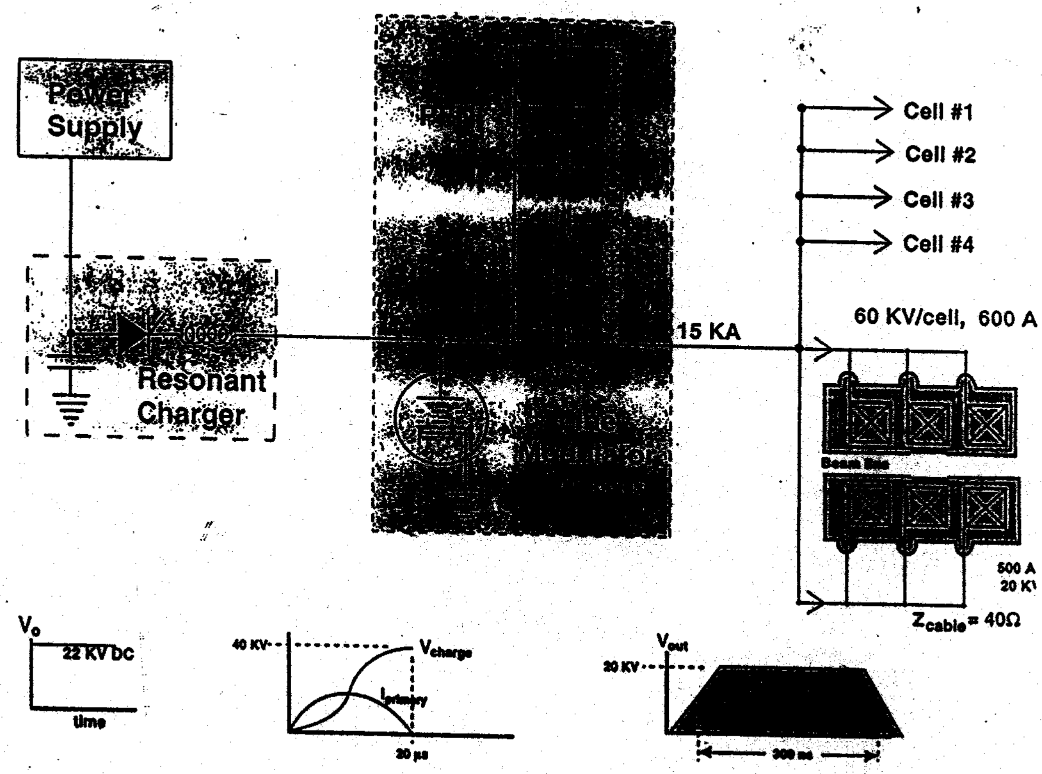
Drive Architecture

- The single unipolar pulse is considerably simpler to generate than the multipulse burst.
- Lower gradient(1.33MeV/m-vs-2.0MeV/m) in the second induction accelerator will further reduce the cost.
- A waveform correction core can be included in the acceleration scheme if the physics of beam transport requires it.
- Direct drive and nonlinear magnetic pulse compression shuold be reviewed since the single unipolar pulse will make the modulator easier and less expensive.

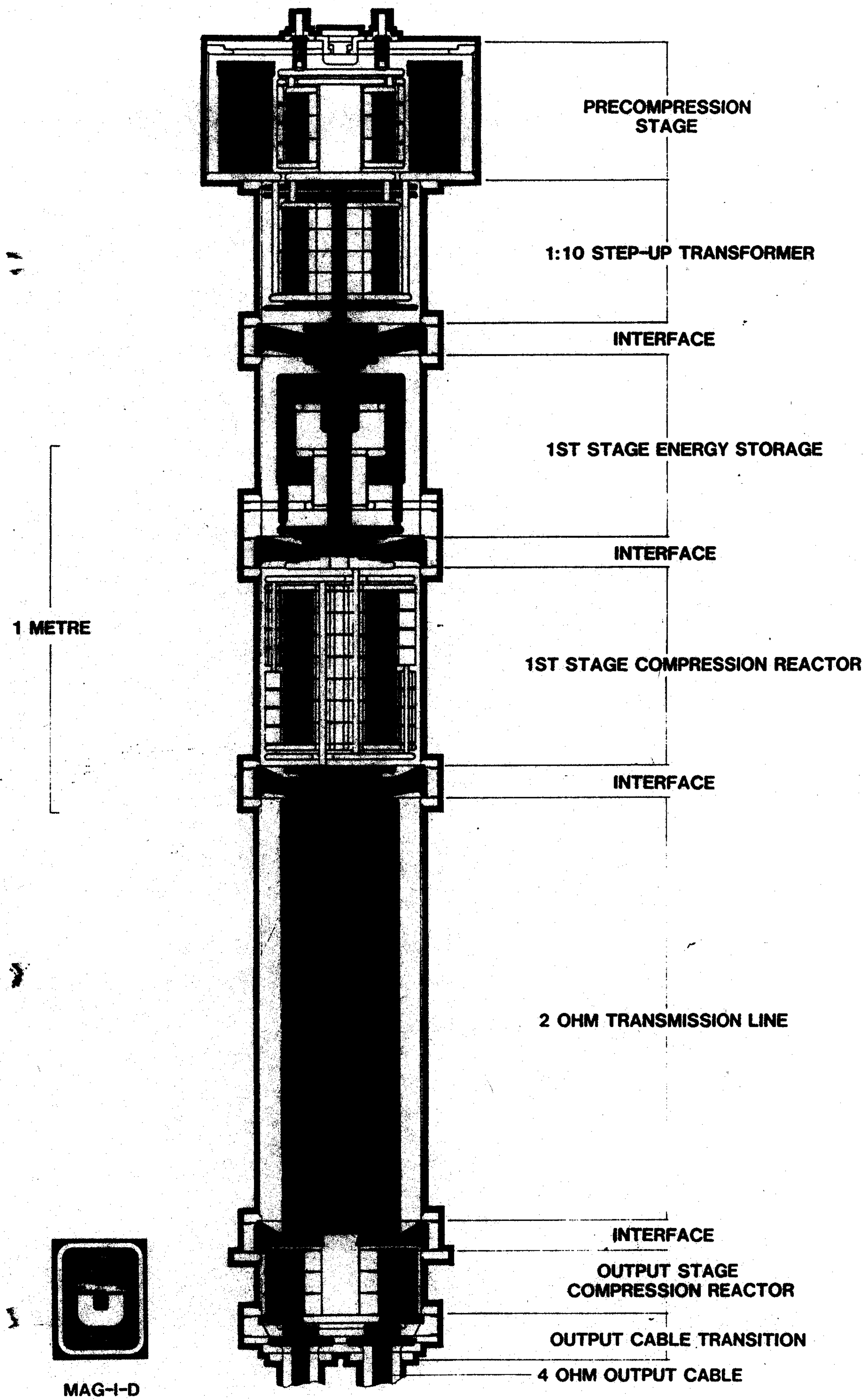
Direct Drive-vs-Pulse Compression



Pulse Compression



Direct Drive



MAG-I-D
60-C-06/85-121C

Simplified Schematic of 8MV Single Pulse

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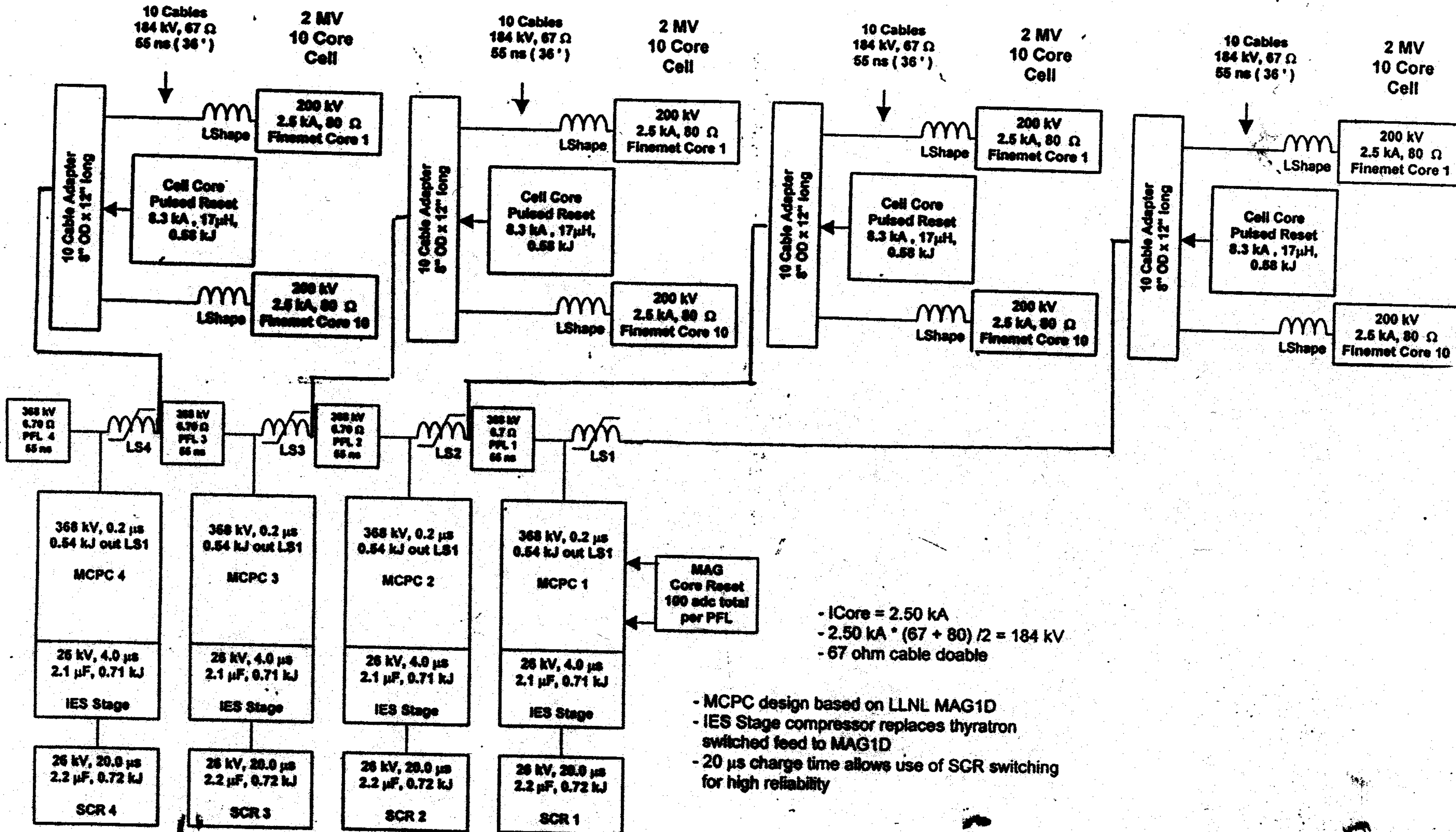
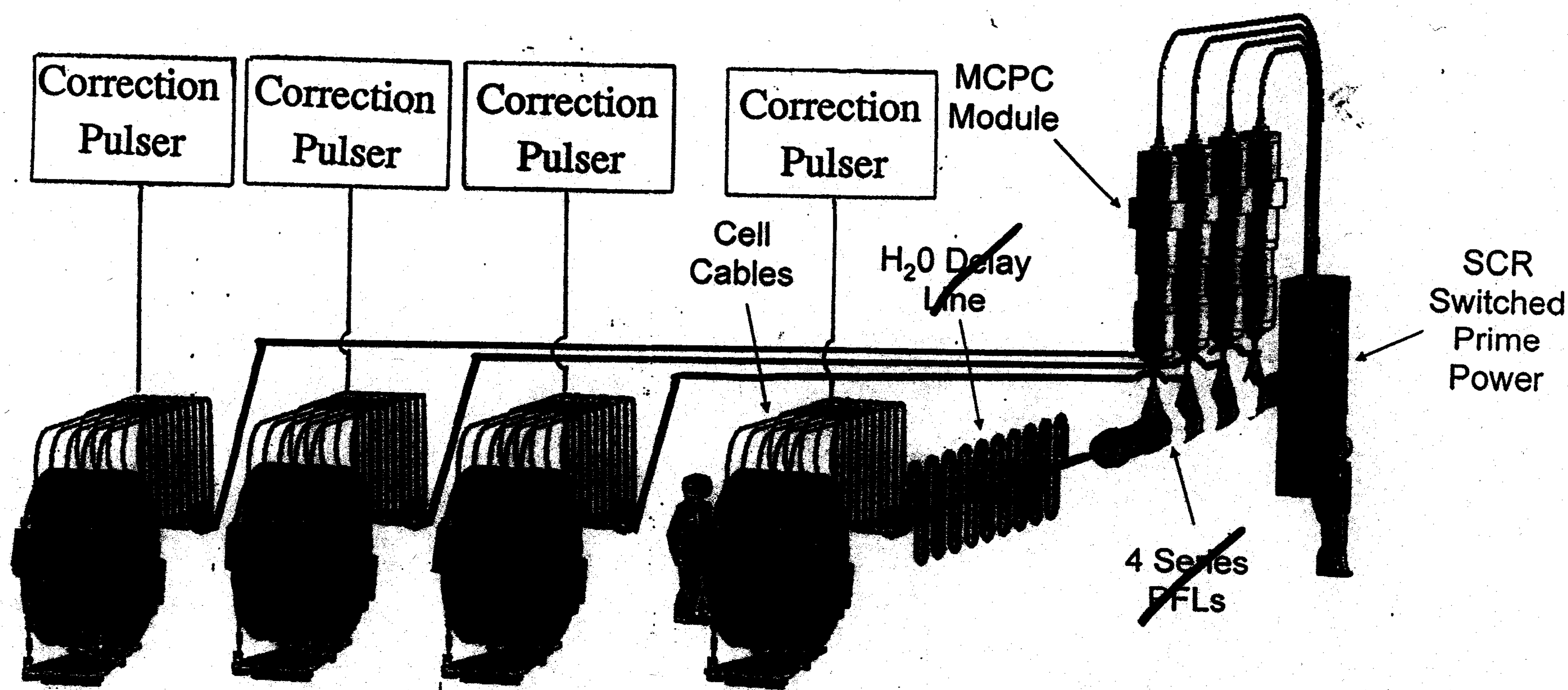


- ICore = 2.50 kA
- 2.50 kA * (67 + 80) /2 = 184 kV
- 67 ohm cable doable

- 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

8MV Single Pulse Layout



- Main pulse generator provides over 90% of desired pulse.
- Pulse correction generator provides 10% or less.

Conceptual Design Tasks

- Work closely with the physics team to estabilish the optimum waveform requirements to achieve the performance at the minimum cost.
- Optimize the cell topology for minimum energy loss and minimum electrical stress.
- Test thinner magnetic materials at the required magnetization rate and make the selection to minimize overall cost.
- Explore other circuit topologies such as direct drive and compare with magnetic pulse compression.
- Evaluate all switch technologies such as thyratron, thyristors, IGBT and test.

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Preliminary Cost for Single Pulse

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	Phase Rotation Pulse Power System	QUANTITY	COST M$		
1	Power Supplies	5640 kw	$3.95		
2	SCR Prime Power	100 ~~400~~	.75 ~~$3.00~~		
3	MČPC Reset	100	$0.06		
4	Output Section	100	$0.83		
5	Cell Core Reset	100	$0.33		
6	INSPECTION (15%)		$1.23		
7	COORDINATION & SUPPORT (15%)		$1.23		
8	IES Reactor	100 ~~400~~	1.76 ~~$7.04~~		
9	MCPC & PFL	100 ~~400~~	7.26 ~~$20.04~~		
10	Prepulse Generator	100	$3.00		
11	Correction Core		.90		
	GRAND TOTAL		~~49.70~~ *	Cont	~~72.01~~
			21.30	~~.45~~ .25	26.63
	Note: No inspection or coordination is needed in item #8 thru #10				

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* Very preliminary cost projections in going to single unipolar pulse.

Program Plan

- Complete the Conceptual Design in months 1-12.
- Complete Detail Design of prototype in months 13-24.
- Complete Fabrication and Testing in months 25-36.