Magnet Shielding at Low Fields

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HEP/Argonne

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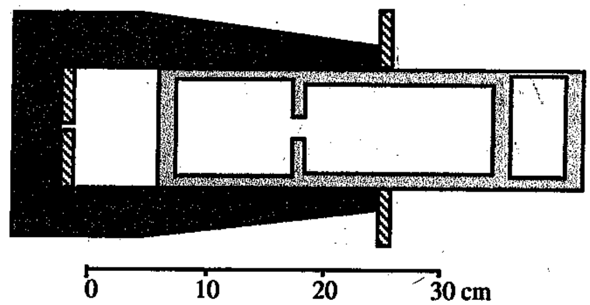
Realistic Component Dimensions

- Dipoles

  25 M lb @ 1$/lb

  A_{cond} ~ 0.001 m²

  ~ 115 m long



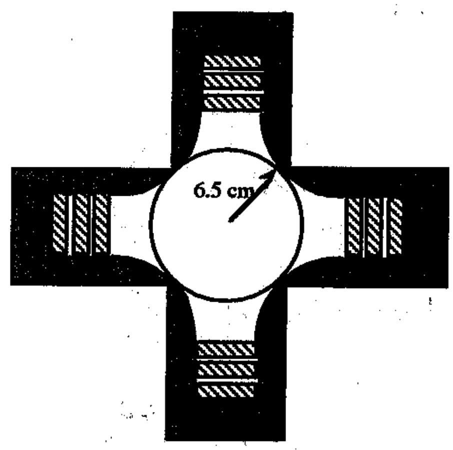
- Quadrupoles

  13 M lb

  5 turns/pole req.

  > 10 m long

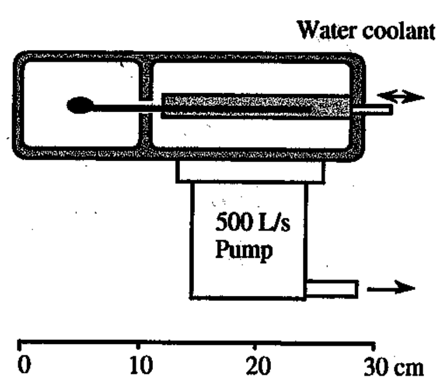
  ~ 4000 required

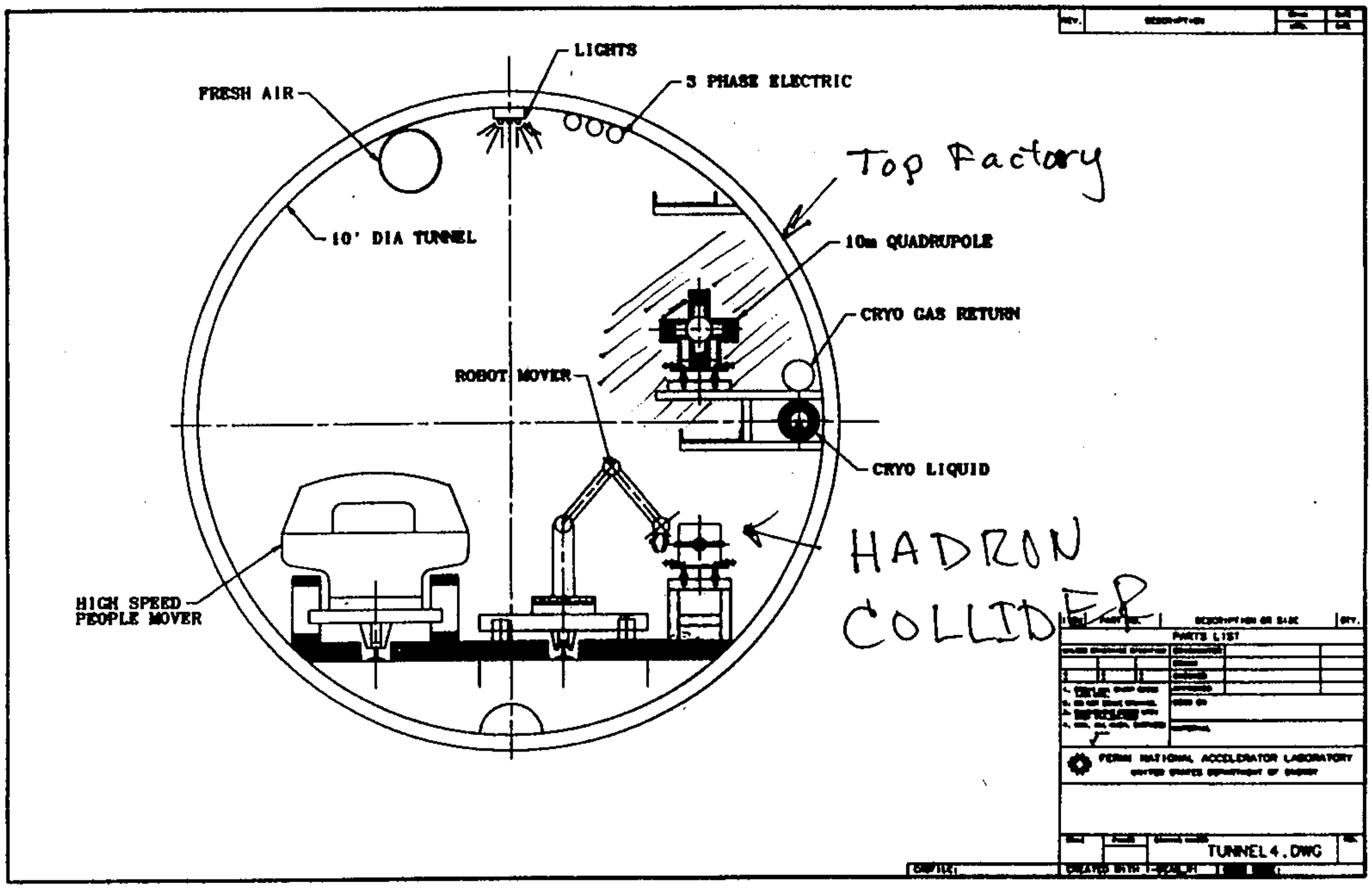


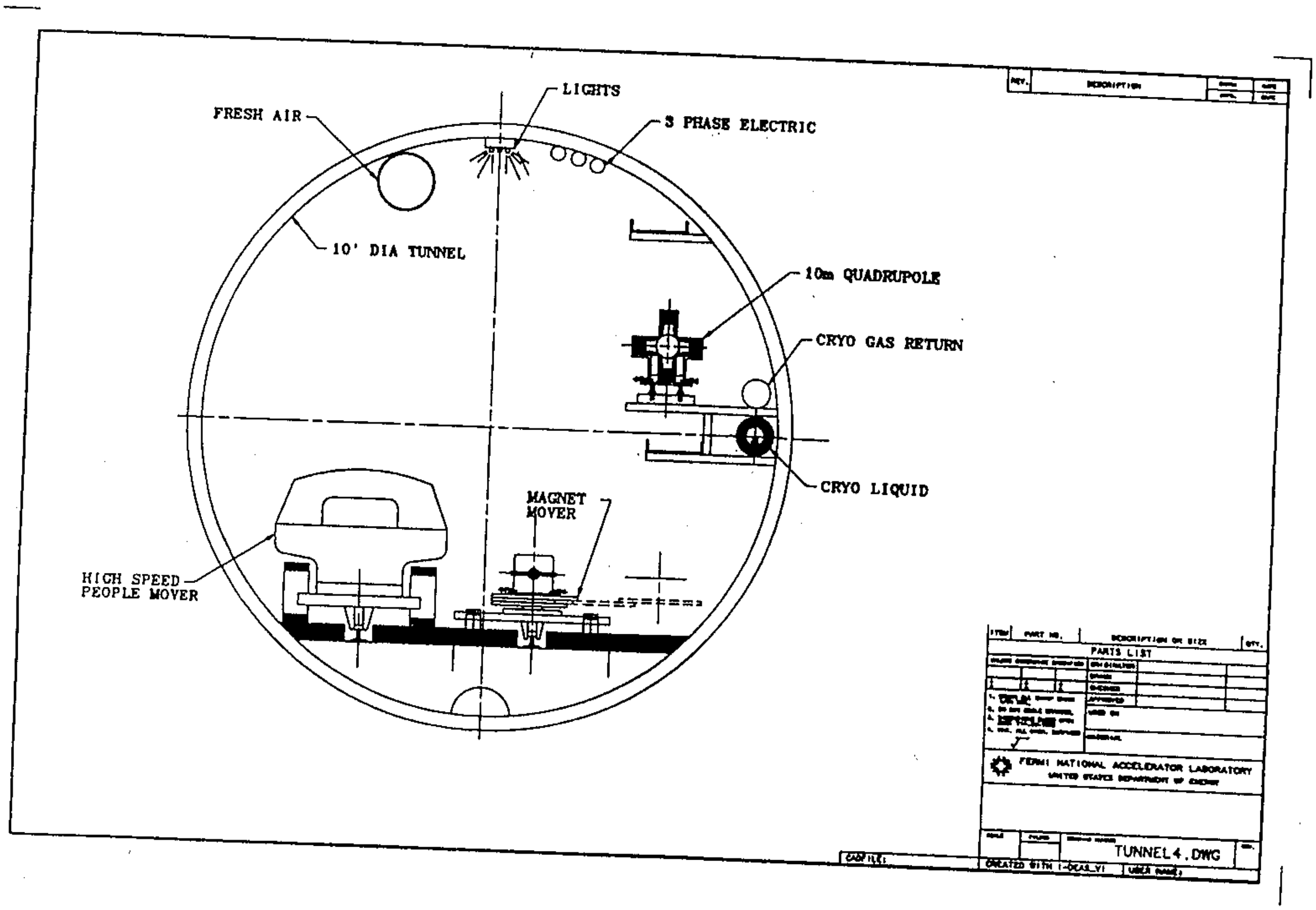
- Synchrotron radiation absorbers

  20 kW each

  Rad shielding req.




LIGHTS
FRESH AIR
3 PHASE ELECTRIC
Top Factory
10' DIA TUNNEL
10m QUADRUPOLE
CRYO GAS RETURN
ROBOT MOVER
CRYO LIQUID
HADRON COLLIDER
HIGH SPEED PEOPLE MOVER
PARTS LIST
FERMI NATIONAL ACCELERATOR LABORATORY
TUNNEL4.DWG



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FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
TUNNEL4.DWG

heat dissapation by an air cooled bus

Current =	500	A
Height =	2	cm
Width =	5	cm
Resistivity =	2.80E-08	ohm m
Air cooling =	1	mW/degC/cm^2
Circumference =	531000	m
conductors =	4	
area =	0.00100	m^2
power dep =	7	W/m/cond
Voltage =	7434	V/turn
Temperature =	5	deg C
Total power =	3.72	MW/cond
With return		
total power =	14.87	MW
total weight =	1.26E+07	lbs
cost rate =	1.6	$/lb
cost =	2.02E+07	$

Cooling the collider tunnel by conduction to the walls

Power =	100	MW	
Circumference =	531000	m	
typ Area =	6	m^2	two sides of a 3 m wide panel
typ Dist =	1	m	
Conductivity =	3	W/K/m	sandstone
Thermal Exp =	8.00E-06	/deg K	
Temperature =	10.46	degrees K	
Expansion =	8.37E-05	meters/m	

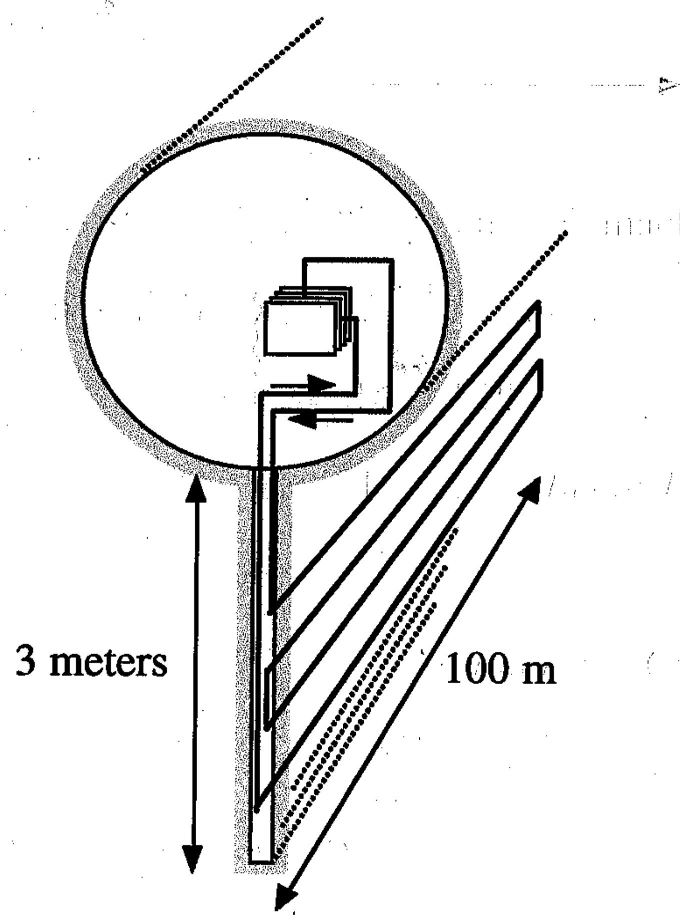
Dipole magnet yoke / mat'ls cost	LEP	RLEP			
Circumference =	26500	531000	m		
Maximum field =	0.135	0.012	T		
Pole Width =	0.225	0.225	m		
Lam thick =	0.0015	0.000635	m		
Spacers =	0.004	0.00635	m		
packing factor =	0.2727	0.0909			
return width =	0.13	0.04	m		
Max yoke field =	0.86	0.74	T		
Yoke Area =	0.1879	0.0335	m^2		see 11/25 note
Iron vol =	5.12E-02	0.0030	m^3/m		
	1.81E+00	0.1075	ft^3/m		
Density =	491.88	491.88	lbs/ft^3		
iron mass =	405	24	kg/m		
packing fr =	0.9	0.9			
weight =	2.12E+07	2.53E+07	lbs	=	12641 tons
		48	lbs/m		
cost rate =	1	1	$/lb		
Cost =	2.12E+07	2.53E+07	$		

Disposal of Waste Heat

- Heat deposited at the discrete absorbers can be conducted to the walls.
- Heat sinks would probably be large.

$$P = \kappa A \, \Delta T/\Delta x$$

Gives $\Delta T = P \, \Delta x / \kappa A \sim 10\,^{o}C$ for the following case if $\kappa \sim 3$ W/m/^{o}C, P = 200 W/m. This gradient would take weeks to develop.



Hardware

- Dipoles

  Low field implies minimal iron, light structure.

  B_{max} = ~ 0.014 T @ E_b = 300 GeV

  B_{inj} = ~ 0.0023 T @ E_b = 50 GeV

  Remanent fields and external fields are a problem at injection.

  Low currents $I = 0.5 * B\, l / \mu_0 \sim 500$ A.
  Conductors (2 - 0000 rubber insulation) ⇒ air cooled.
  Commercial connectors could be used.

- Quads

  Constraints on damping in three dimensions require long quads, $l_Q \sim 10$ m

  Pole tip fields (~50 mT), and currents are very low.

- Vacuum System

  Photodesorbed gas production / m is very low.
  2 L/s/m ⇒ 10^{-9} torr.

  The vacuum chamber can be designed so that synchrotron radiation never reaches it.
  Sagitta = 1.6 cm in 100 m. (pretty straight)

  No distributed radiation Pb shielding.

  Discrete absorbers can absorb all the gas and power loads. Heat sinks can go into the ground.

Parameterizations of the Field in a Magnet

- There are three sources on fields in magnets
  G. Fischer, SLAC-PUB 3726, (1985)
  K. Brown and J. E. Spencer, 1981 PAC, p2568
  H. A. Enge, Rev. Sci. Instr., **35** (1964) 278

The most detailed is Enge, who defines

$$h(s) = B_{z,0} / B_0 = 1/(1+e^S)$$

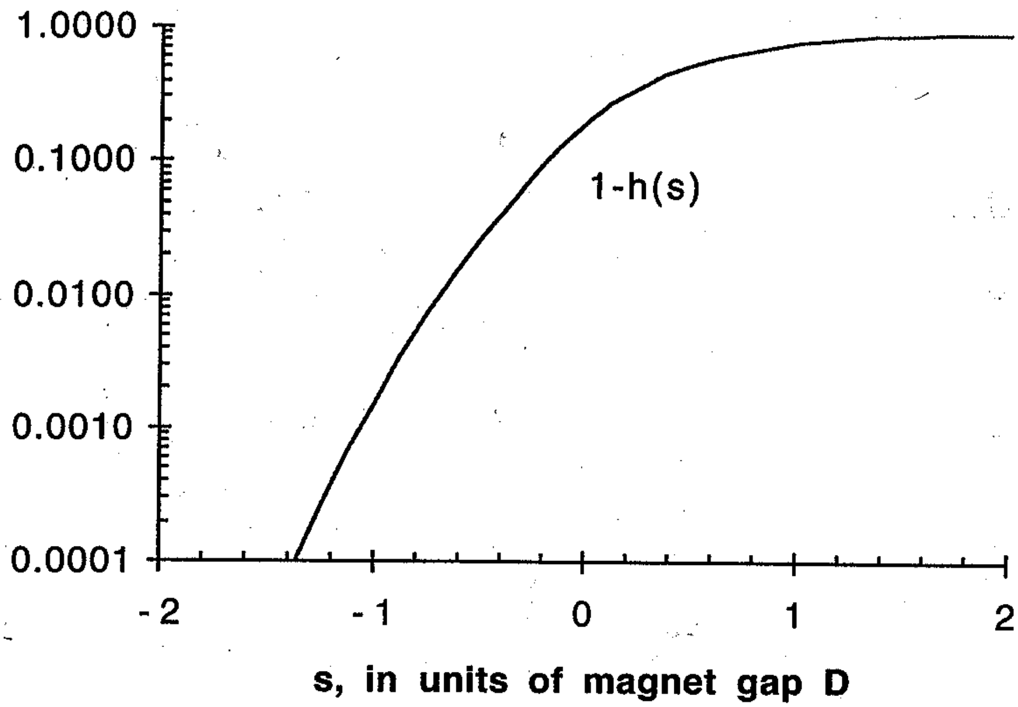
with

$$S = c_0 + c_1 s + c_2 s^2 + c_3 s^3$$

where s = the distance along the normal to the magnet gap in units of D, the gap distance. The constants depend on the geometry, but the "short tail" numbers are typical,

$c_0 = 0.383$
$c_1 = 2.388$
$c_2 = -0.817$
$c_3 = 0.200.$

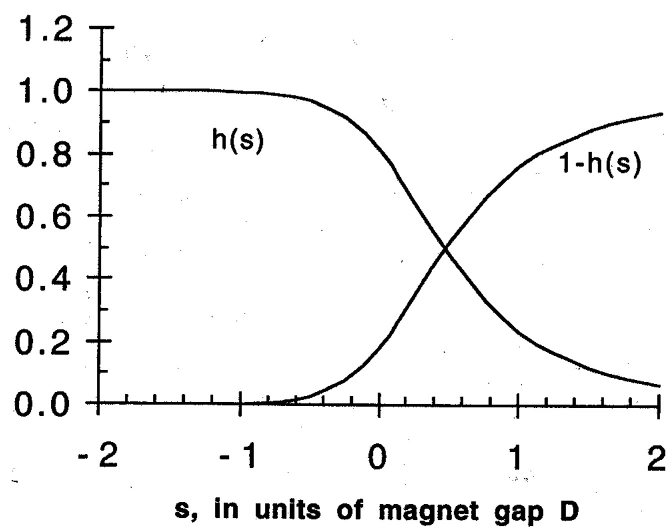
Penetration by External Fields



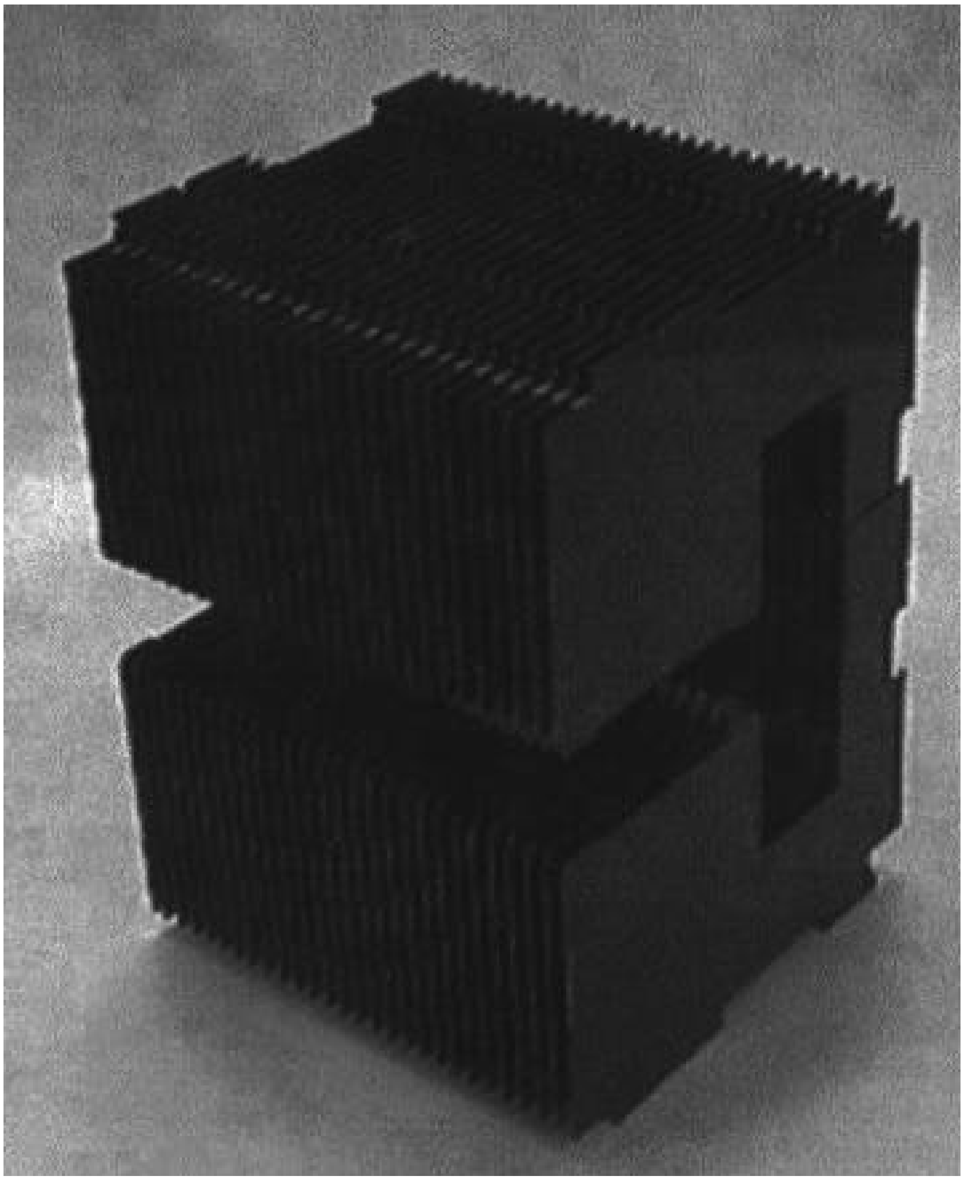
The penetration is primarily dependent c_0, which changes slightly with geometry.

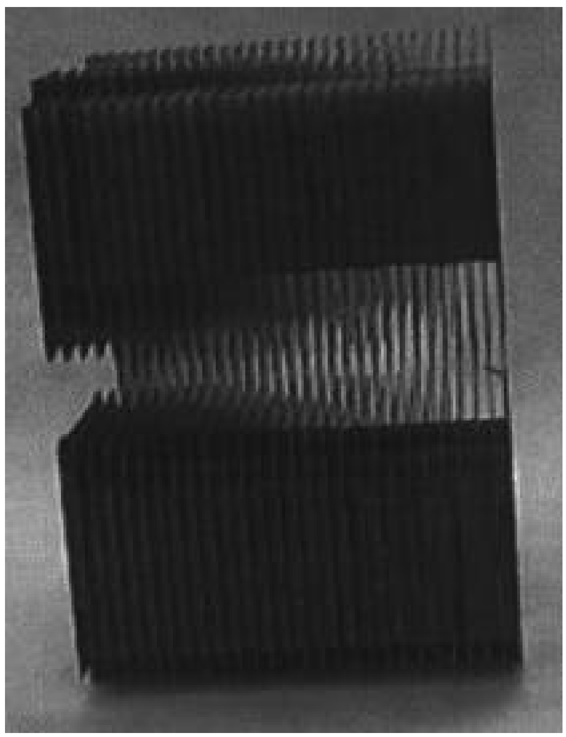
Fields in Gap

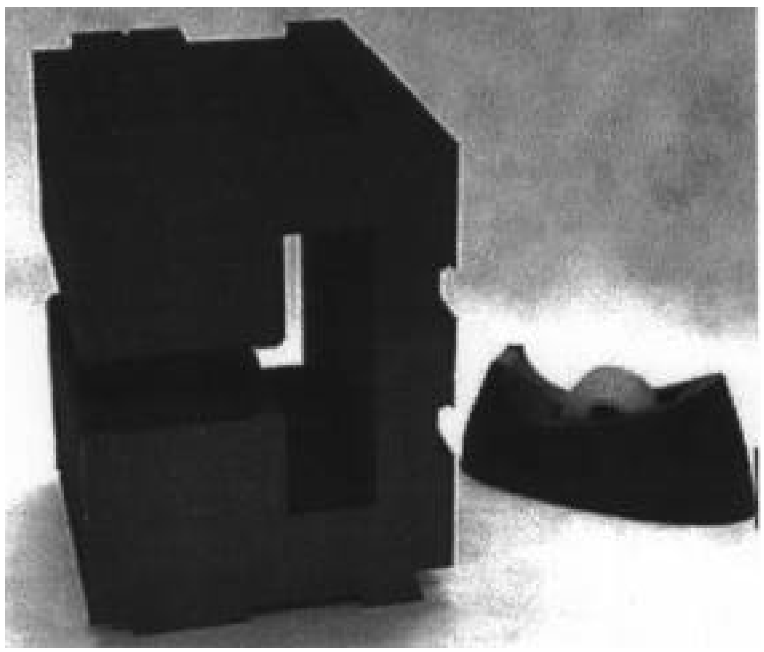
The resulting fields, when the physical gap is adjusted to be at zero look like,



Assuming the zero is arbitrary, one can consider *1-h(s)* as an error field penetrating a gap.







Error Fields

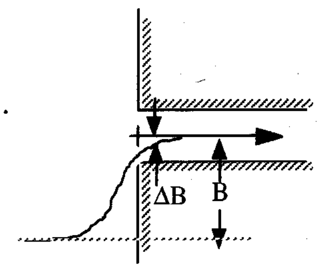
- Penetration of external fields can be estimated by comparing $\Delta B/B$ in the special case when $B_{ext} = 0$.

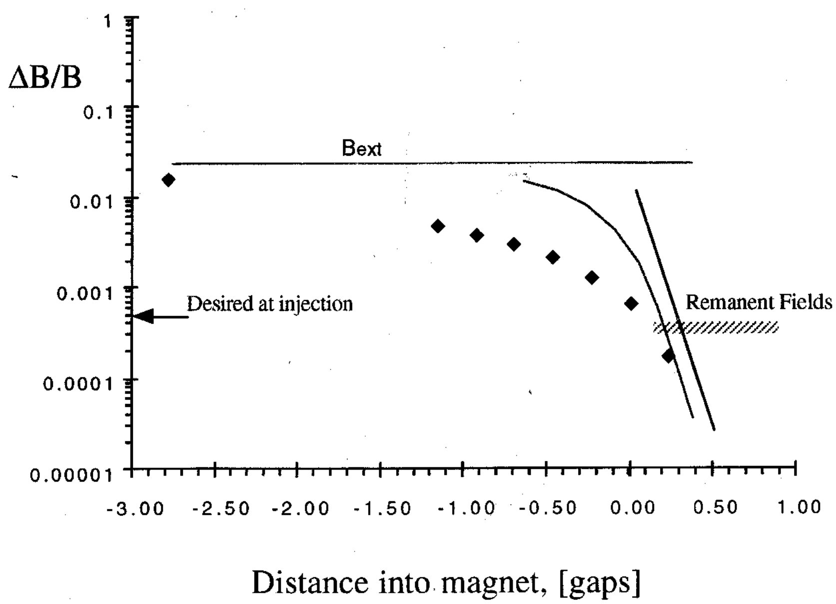
Brown and Spencer

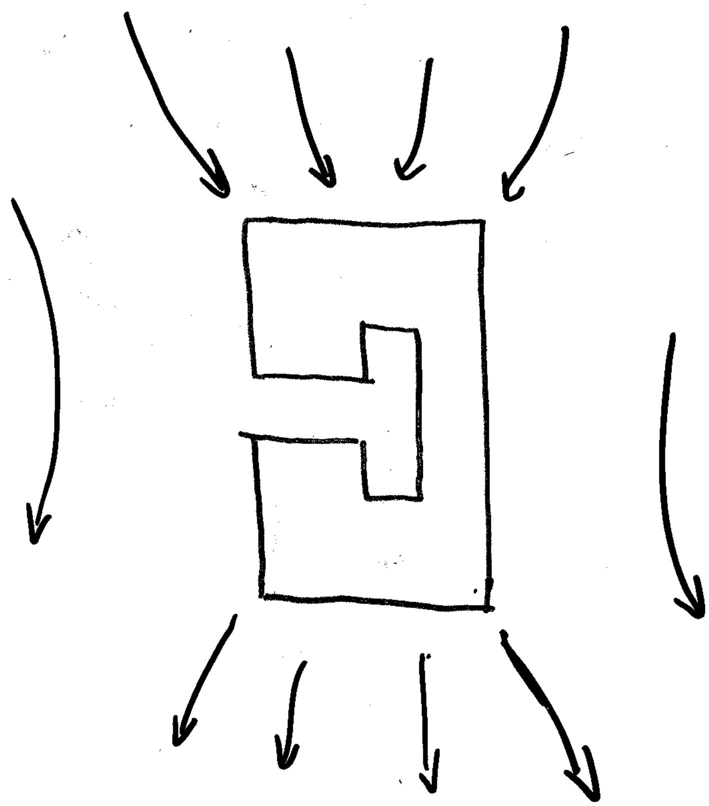
$$\Delta B/B \sim 1 / (1 + e^S)$$
$$S = c_0 + c_1 x + c_2 x^2 + \ldots$$

Fischer

$$\Delta B/B \sim 10^{-ax}$$







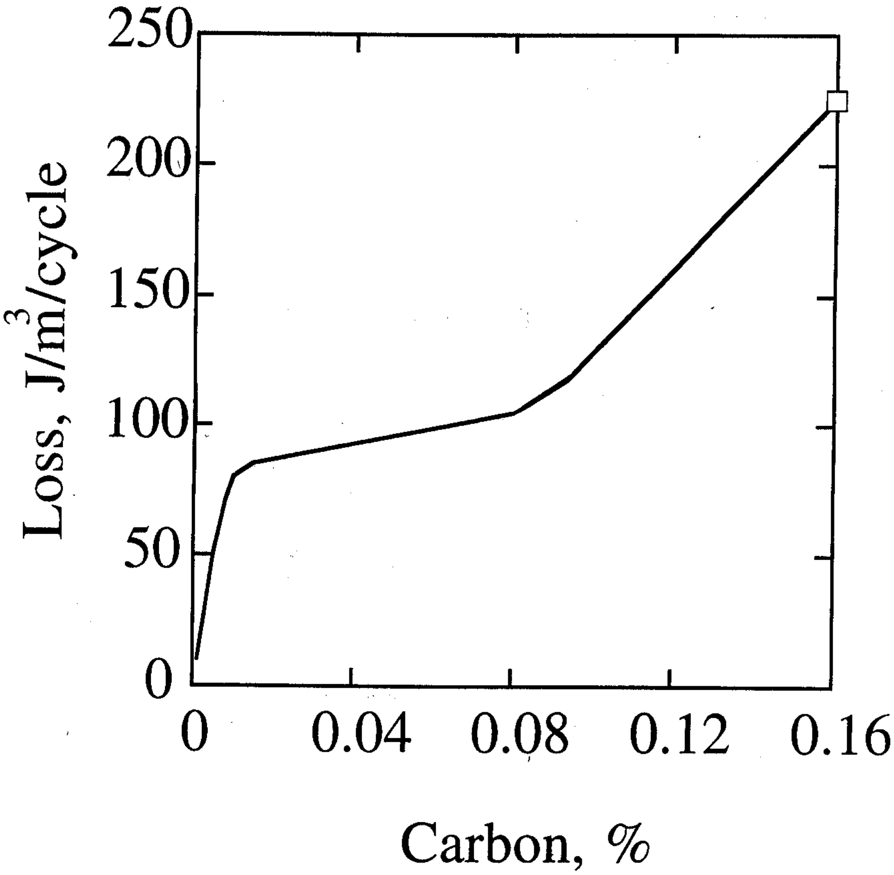
Summary

The external fields outside the magnet are attenuated by two effects:

- The external fields are shunted around by the magnet yoke so that the field external to the gap is ~0.1 times the ambient field.

- The field in the gap is attenuated by the gap geometry and dies off rapidly within the gap.

The remanent fields in the gap were significant. The test magnet was not efficiently degaussed due in part to power supply limitations. The measured remanent fields were dependent on the probe location, and degaussing.



250
200
150
100
50
0
Loss, J/m3/cycle
0
0.04
0.08
0.12
0.16
Carbon, %