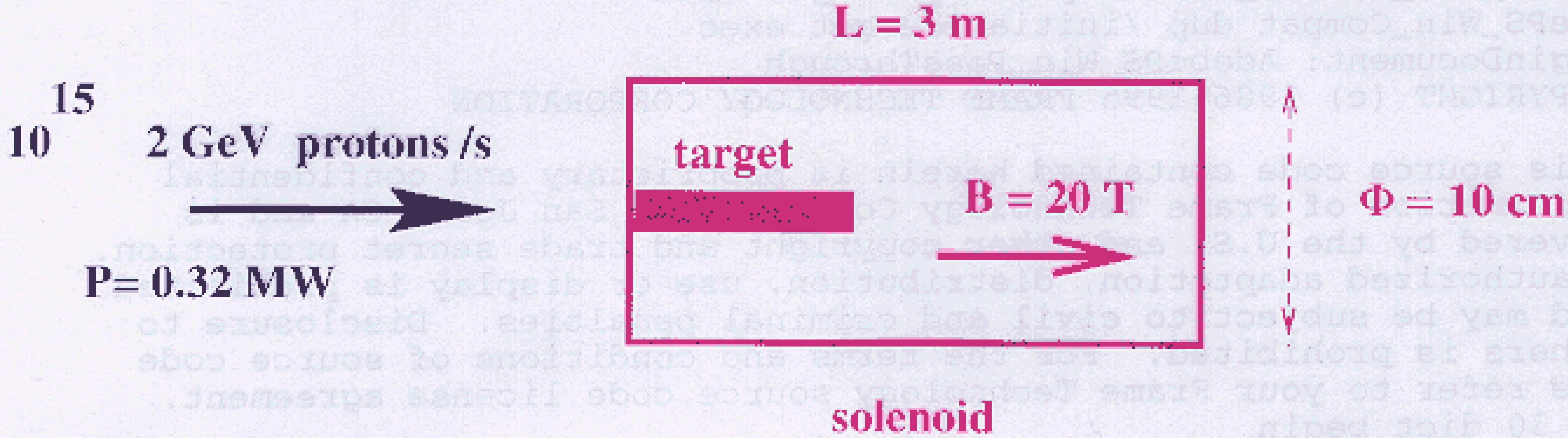
J. Collot / ISN Grenoble

November 12, 1998

Pion collection solenoid



Capture of pions with :

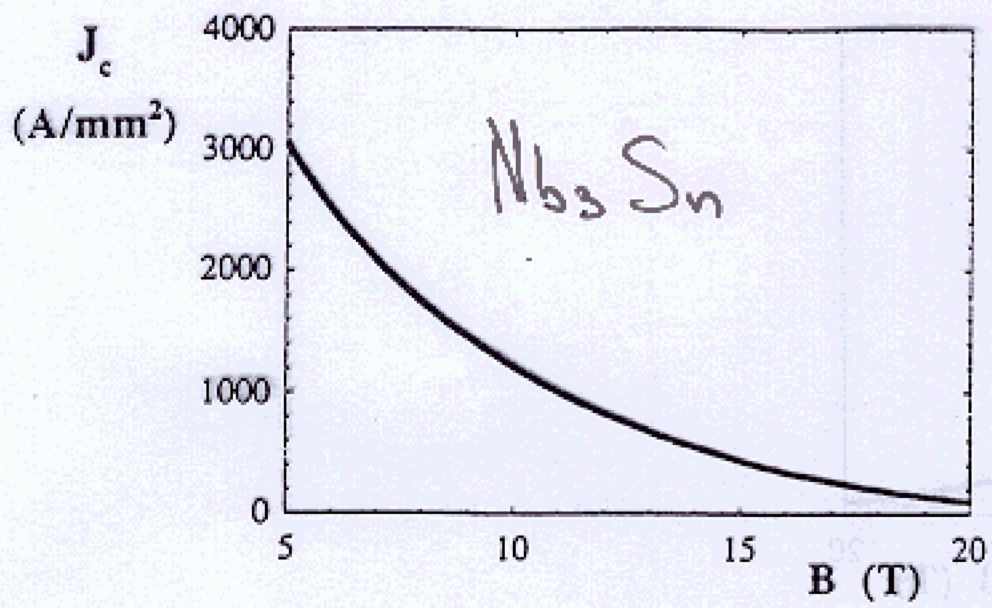
$$P_t(\mathrm{GeV}) \leq \frac{\Phi(\mathrm{m})\ B(\mathrm{T})}{13.3} = 0.15\mathrm{GeV}$$

SC or Resistive Solenoid?

SC solenoids:

	T_c (0 T)	T_c (11 T)	$\mu_0 H_{c2}$ (T=0 K)	$\mu_0 H_{c2}$ (T=1,8 K)	$\mu_0 H_{c2}$ (T=4,2 K)
NbTi	9,5 K	4,2 K	14 T	14 T	11 T
Nb_3Sn	18 K	10,4 K	25,5 T	25,5 T	23,2 T

Nb_3Sn : 21 T solenoids commercially available
but $\phi \leq 50$ mm, $l \leq 50$ cm



NbTi : B_c too low!
could be used in a hybrid magnet – 8 T, $\phi = 800$ mm

⚠ Radiation tolerance

Resistive solenoids:

- no field limit
- need high electrical power ($\geq$ 10 MW)
- limited in practice by cost of D.C. power supply & cooling system
- radiation hard (Cu, kapton)

Grenoble High Magnetic Field Lab

- founded in 1992
- jointly operated by Max Planck Institut (Stuttgart) & CNRS

	Magnetic Field Strength T	Bore diameter[1] mm	Power MW	Magnet type (from the inner to the outermost)	Remarks
M1		50	10		Test site
M2	17	50	10	1 Bitter magnet	Magnet with four radial accesses for optical purposes. Field axis horizontal.
M3	27 24	34 50	10 10	Double helix + 2 Bitter magnets	Radially cooled helices
M5	20 13 6	50 130 286	10 10 5	1 internal Bitter magnet + 2 outer Bitter magnets	
M6	24	50	10	Double helix +2 Bitter magnets	Radially cooled helices
M7	20	50	10	2 Bitter magnets	
M8	30 30 20 10	50 50 130 400	10 10 10	12 helices + 2 Bitter + 1 superconducting magnet 10 helices + 2 Bitter + 1 superconducting magnet 2 Bitter + 1 superconducting magnet 1 superconducting magnet	Hybrid magnet World record in 1987 31.3 T in 50 mm To be dismantled in summer 1998 and replaced by the new hybrid magnet.
M9	22	50	10	12 helices + 2 Bitter magnets	Field axis vertical or horizontal.
M10	34 30 20 10	34 50 130 376	20 20 10 10	20 helices + 2 external Bitter magnets 10 helices + 2 Bitter + 2 external Bitter magnets 4 Bitter magnets 2 external Bitter magnets	Operational 6/98 Operational 10/98

New hybrid magnet under construction:

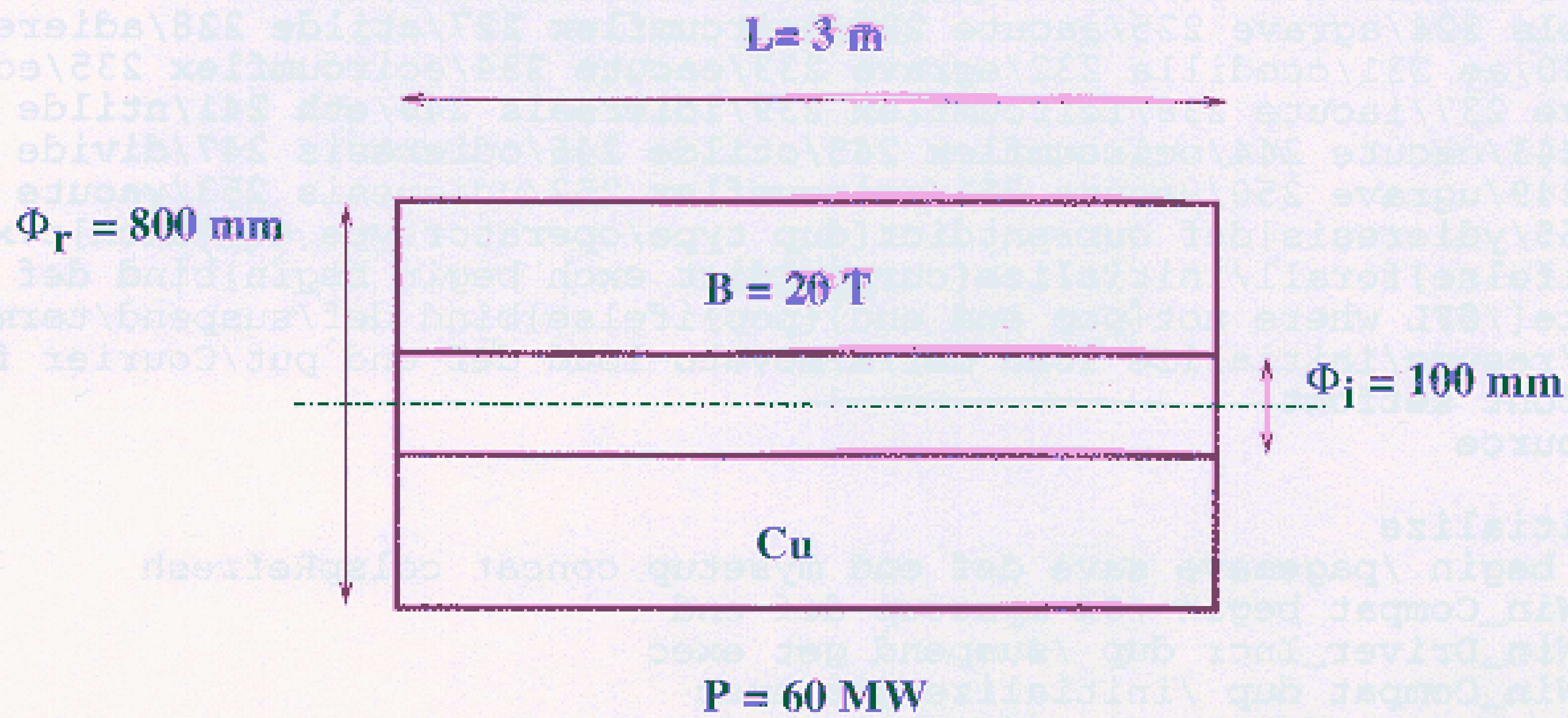
SC part { NbTi 8 T ϕ = 800 mm L = 1 m
T = 1.8 K

max. Field 41.6 T { within ϕ = 34 mm
for 24 MW.

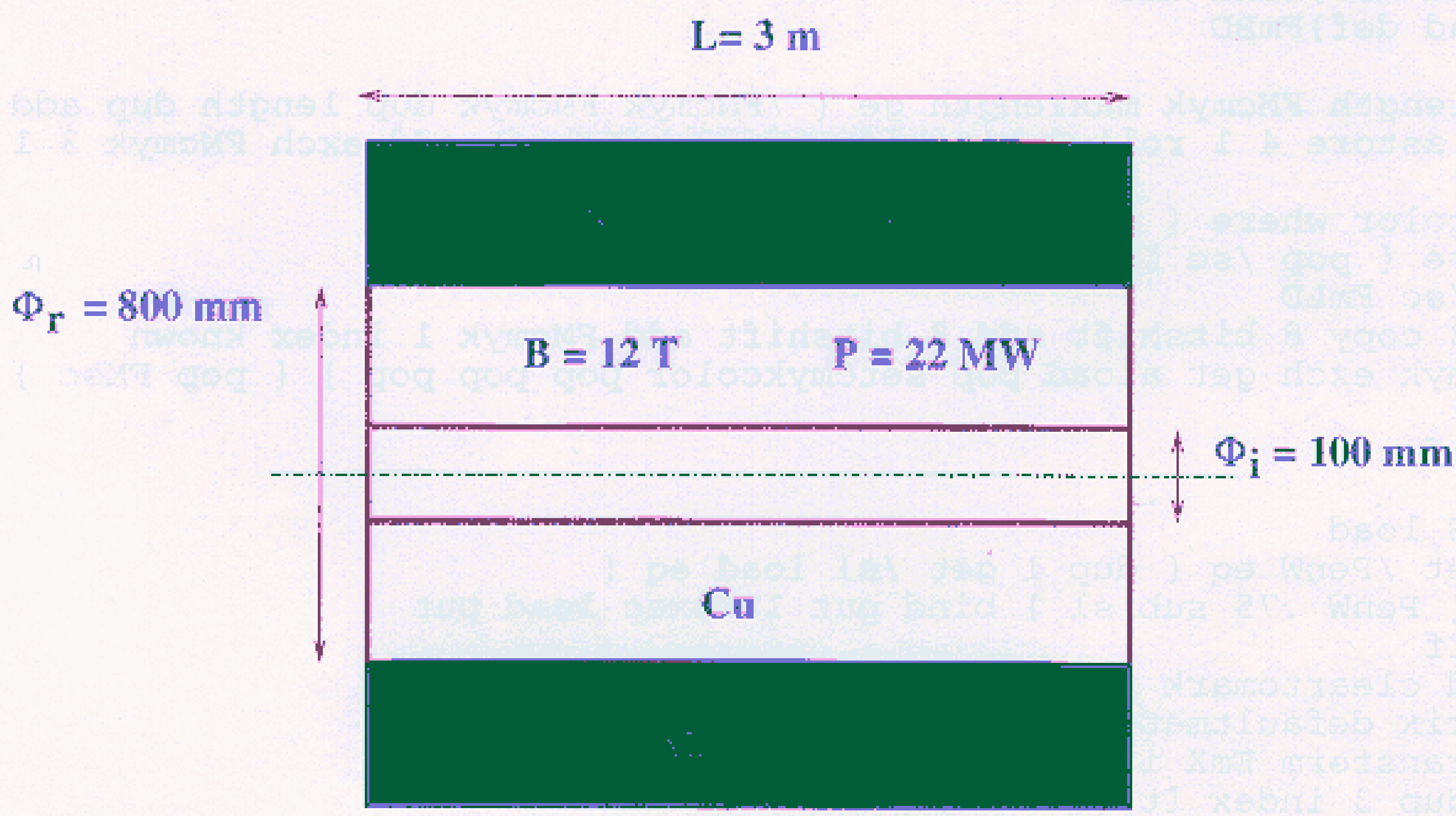
Proposals

Made under guidance of Walter Joss from GHMFL

Bitter magnet:

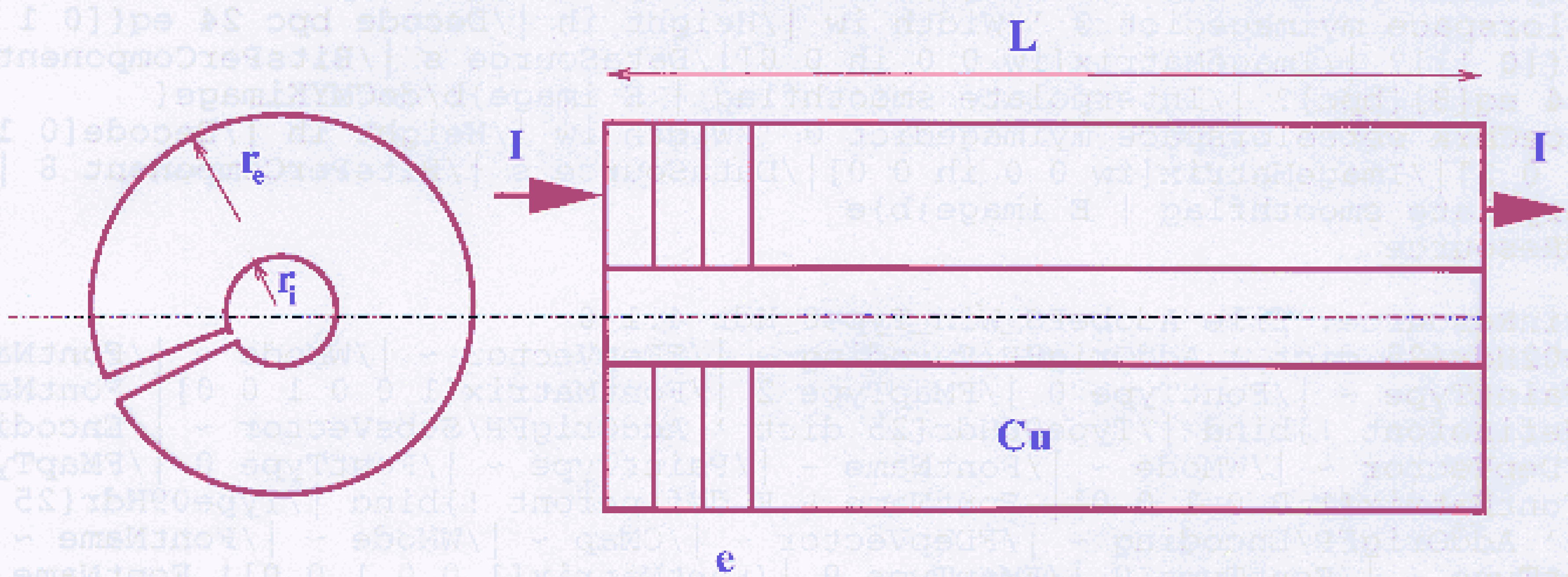


Hybrid magnet:



Understanding the resistive solenoid features

Magnet simplified model



$B = \mu_0 \, NI$ **N number of windings or turns per m**

$NI = 0.8 \, B(T) \, (MA \, turns/m)$

I=16 kA , B=20 T then N=1000 turns/m → e=1mm

R/turn $= \left(\int_{r_i}^{r_e} \frac{1}{\rho} \frac{e \, dr}{2\pi \, r}\right)^{-1} = \frac{2\rho\pi}{e} \frac{1}{Ln(r_e/r_i)}$

Power: $P = R.N.L \, I^2$

Field: $B = \mu_0 \sqrt{\frac{N.P}{R.L}}$

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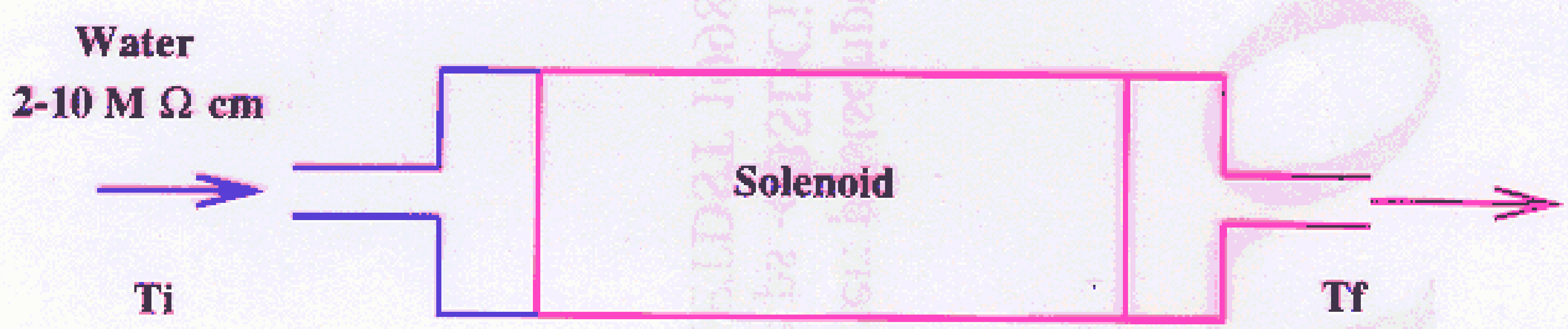
B= 20 T , e= 1 mm , r_i= 5 cm

r_e= 25 cm , ρ= 2.1 10^{-8} Ω m

R/turn= 82 $\mu\Omega$ $\rightarrow$ P = 63 MW (1 TGV = 6 MW)

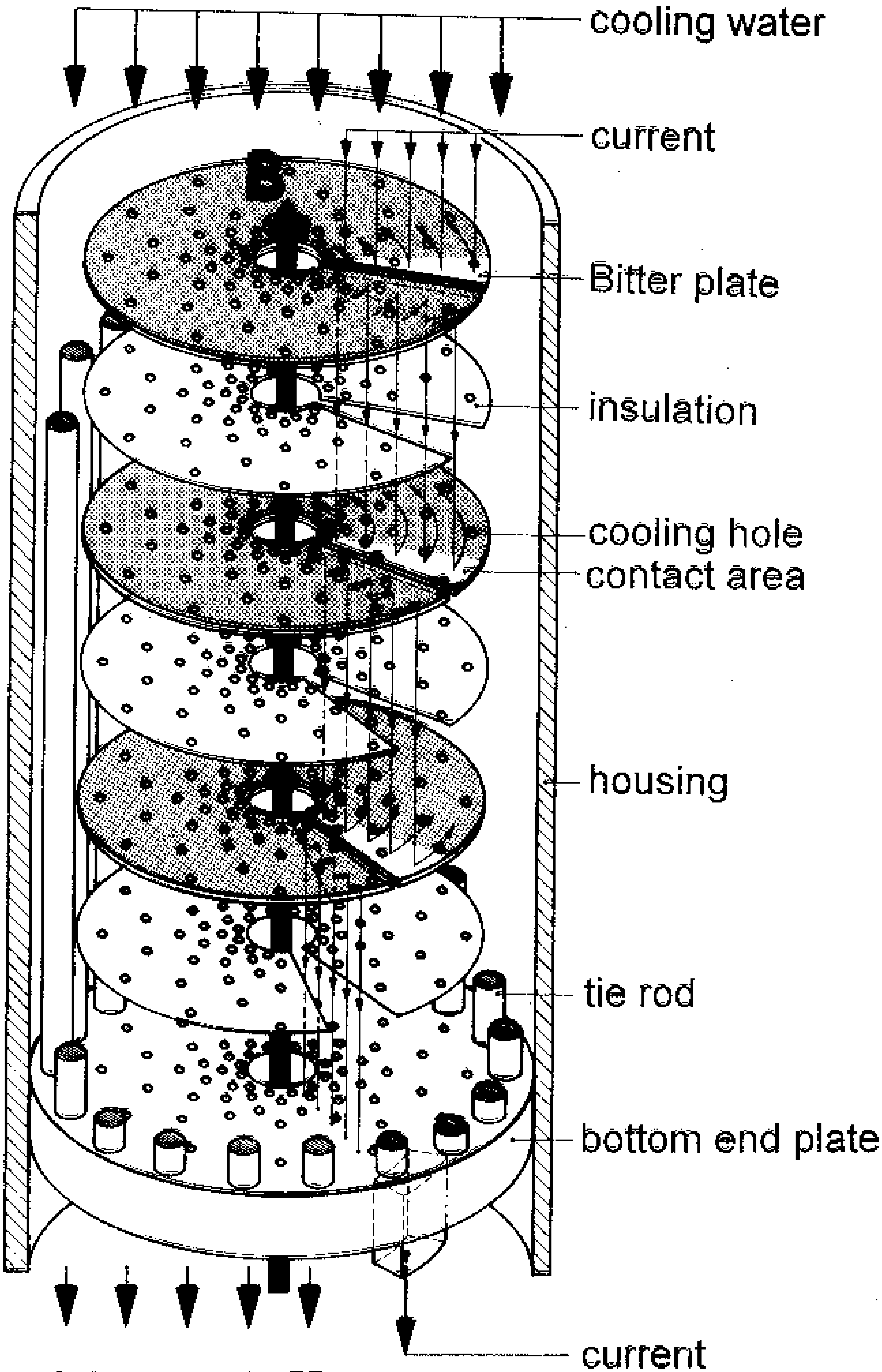
If P= 20 MW $\rightarrow$ B= 11.3 T

Cooling

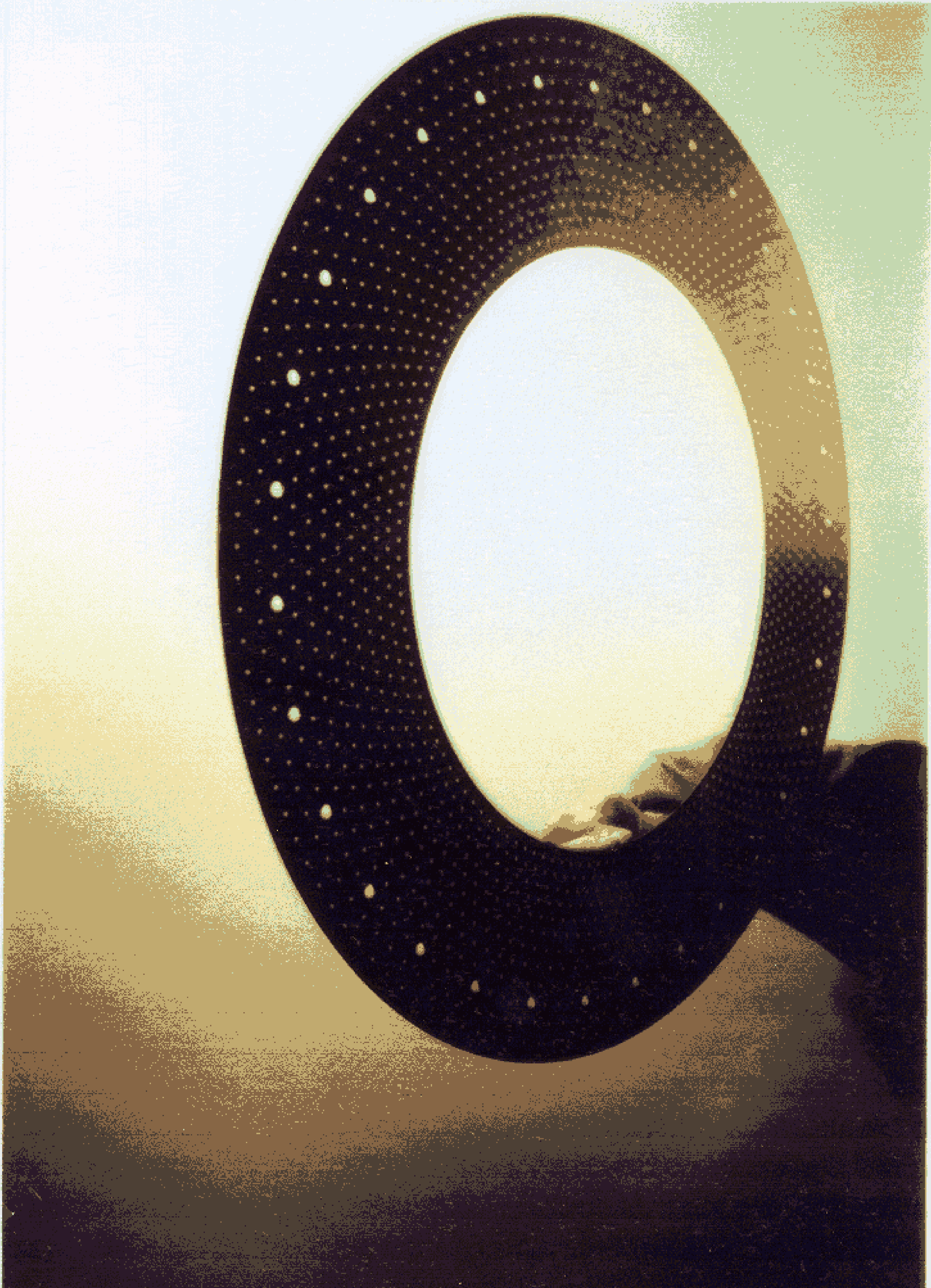


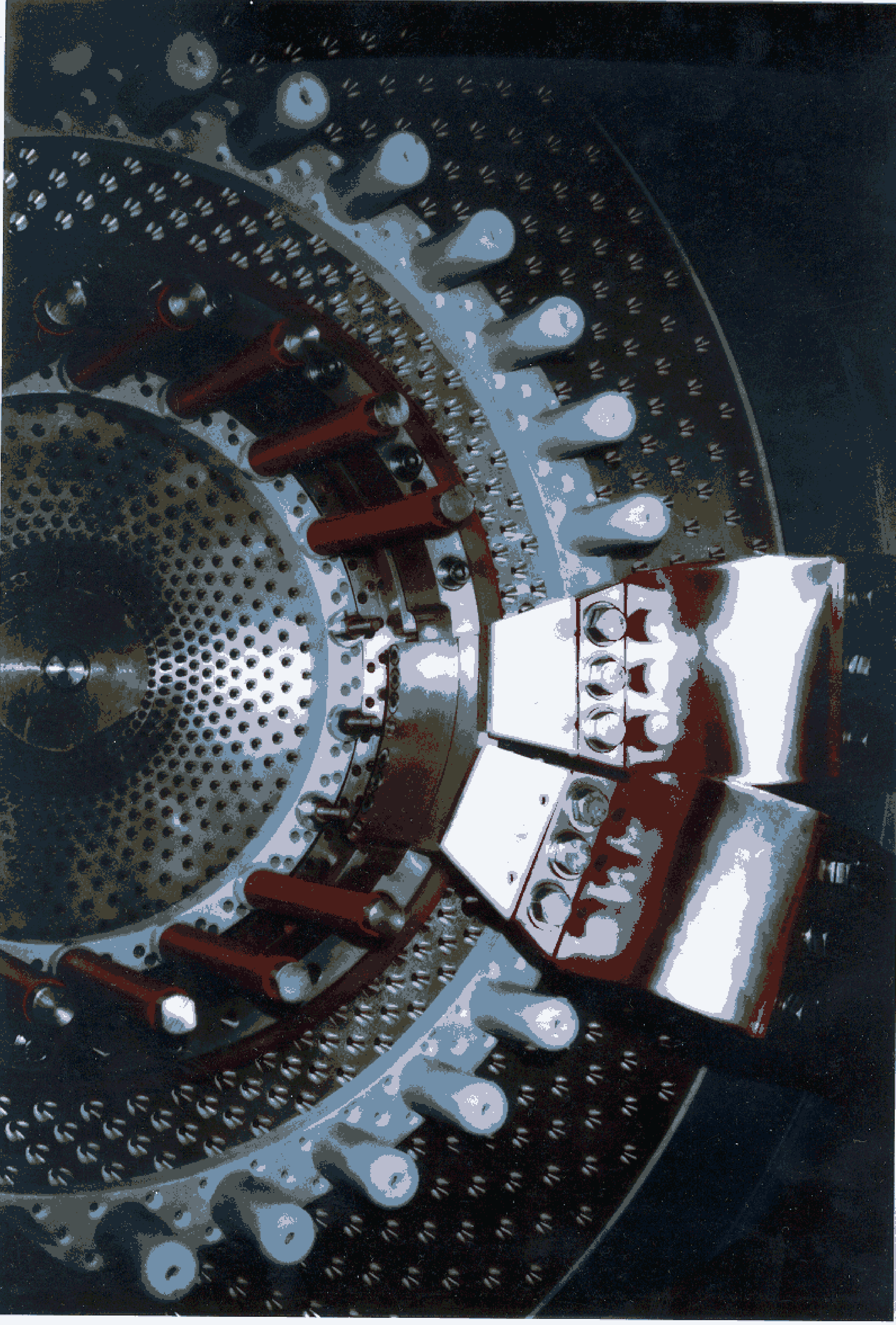
$$\Delta T = T_f - T_i = 20K$$

$$V = \frac{63\ 10^6}{4.18 \times 1000 \times 20} = 750\ l/s$$

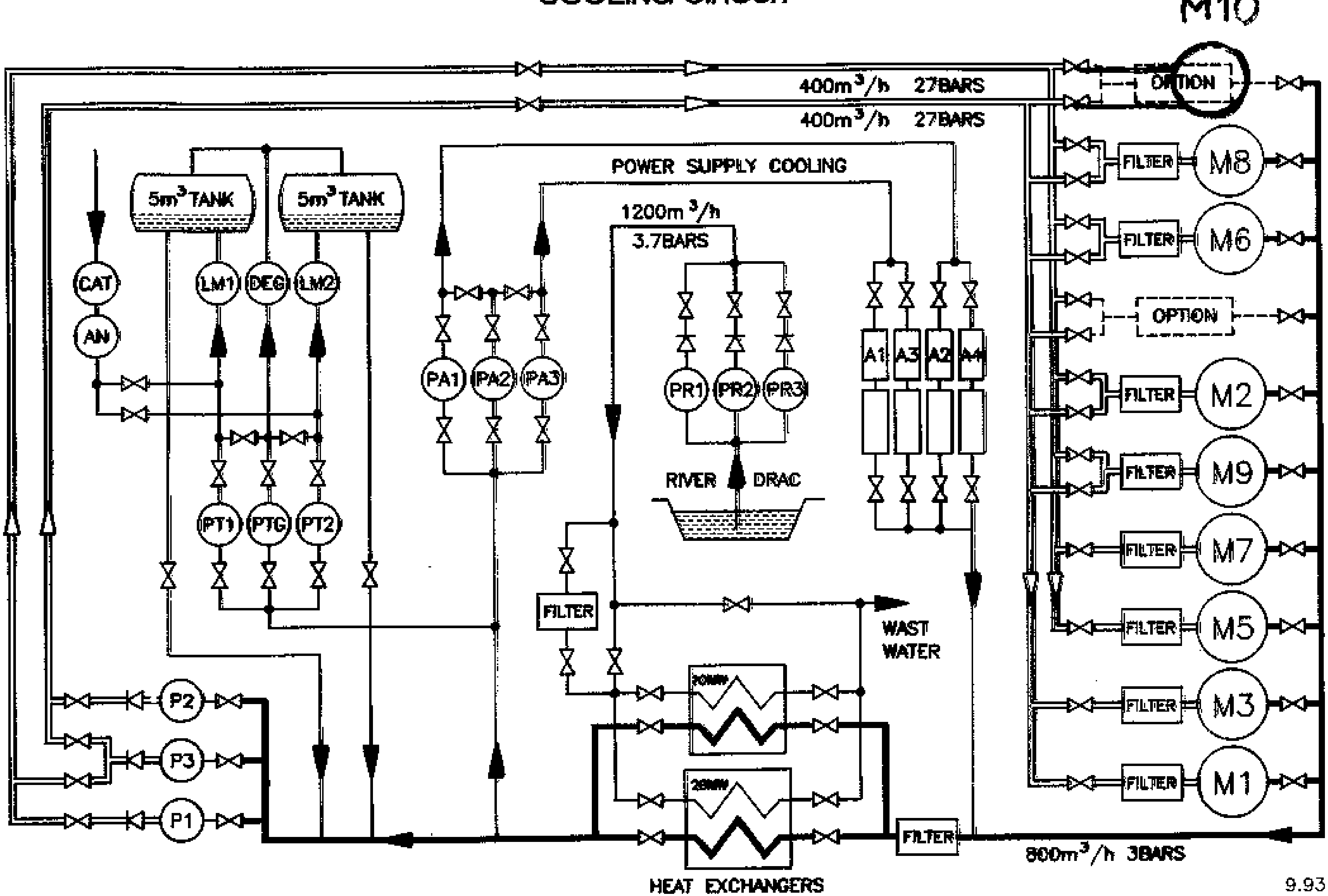


BITTER MAGNET

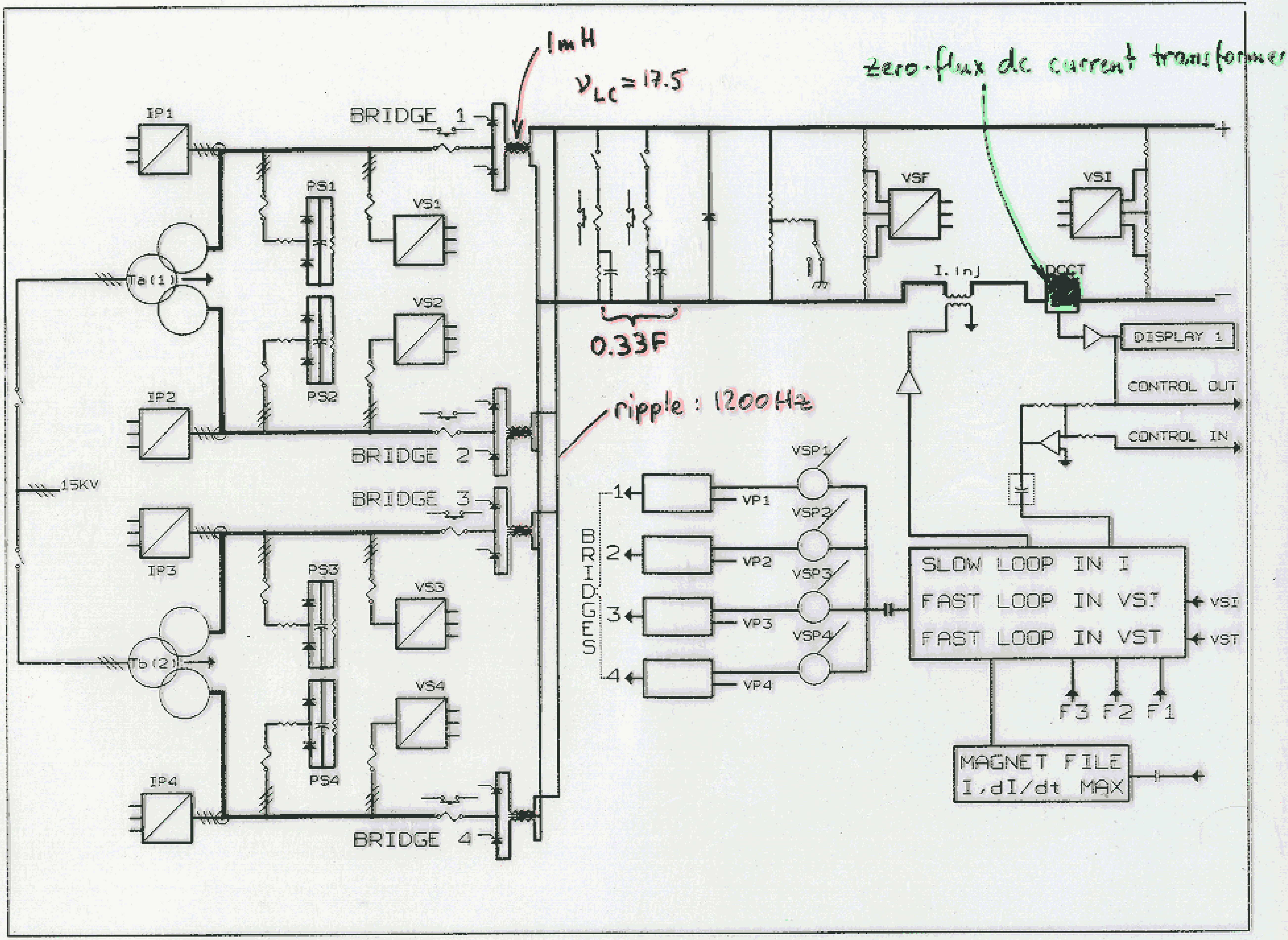




COOLING CIRCUIT



9.93


1mH
$v_{LC} = 17.5$
zero-flux dc current transformer
0.33F
ripple : 1200Hz
BRIDGE 1
BRIDGE 2
BRIDGE 3
BRIDGE 4
IP1
IP2
IP3
IP4
PS1
PS2
PS3
PS4
VS1
VS2
VS3
VS4
Ta(1)
Tb(2)
15KV
VSF
VSI
I.inj
DCCT
DISPLAY 1
CONTROL OUT
CONTROL IN
VSP1
VSP2
VSP3
VSP4
VP1
VP2
VP3
VP4
BRIDGES
SLOW LOOP IN I
FAST LOOP IN VST
FAST LOOP IN VST
VSI
VST
F3 F2 F1
MAGNET FILE
I,dI/dt MAX

MAIN CHARACTERISTICS OF THE HYDRAULIC PUMPS

Circuit	Cooling purpose	Number of pumps	Type	Outlet pressure bar	Flow m^3/h	Speed rpm	Power kW	Control
Primary	Heat exchanger	3	Vertical immersed	3.7	600	1500	85	Automatic motor starter
Secondary	Magnets	3	Horizontal water cooled	27	400	1000 – 3000	450	Electric speed variators
Secondary	Power supplies	3	Vertical	8.0	50	2900	20	no
Secondary	Water treatment	3	Vertical	3.0	22	2900	3	no

RATING OF POWER SUPPLIES

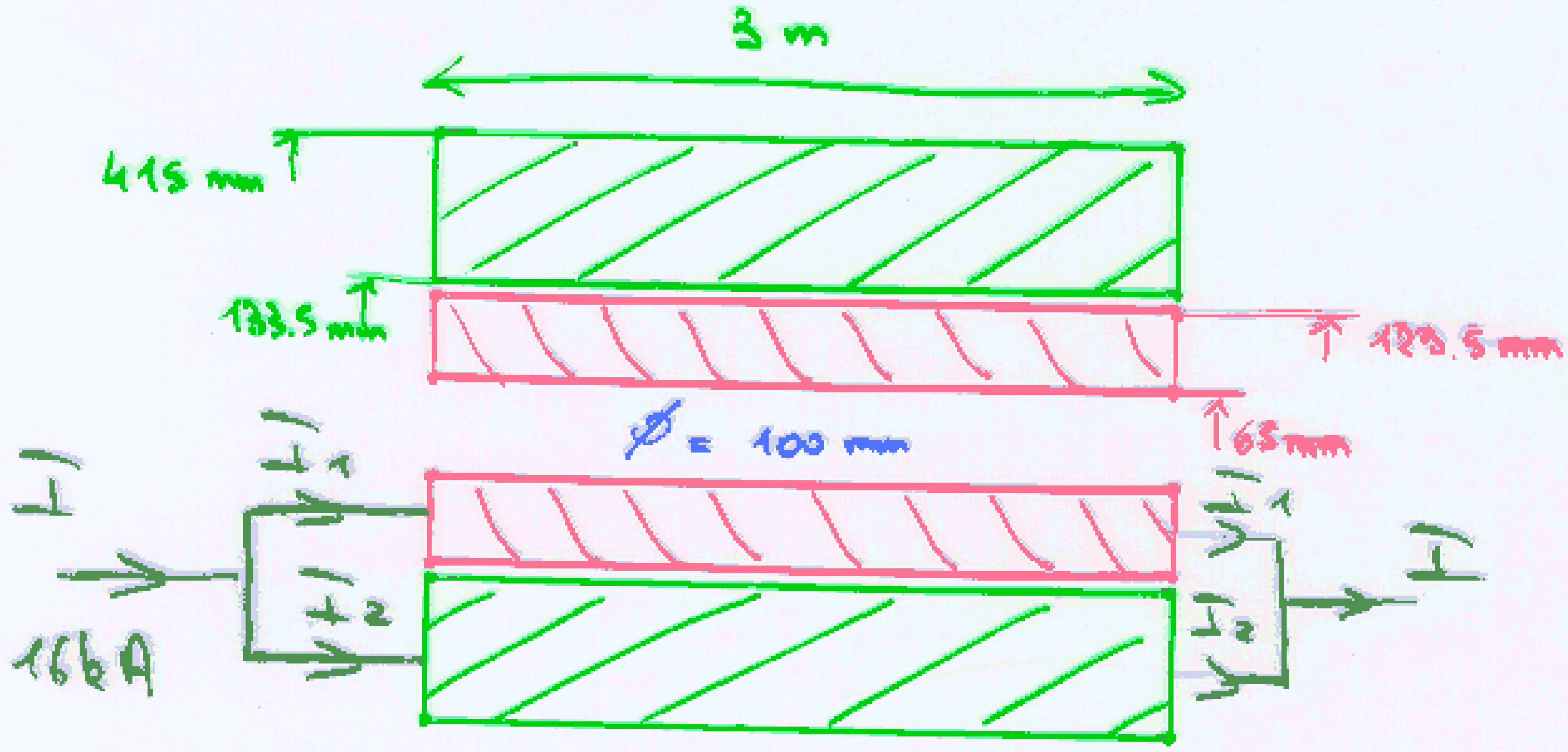
	Number of Units	Power MW	Current kA	Voltage V
Nominal	4	6.3	15	420
Short period (<10 min)	4	6.93	16.5	420

PERFORMANCE OF POWER SUPPLIES

Ripple and noise 0 – 10 kHz peak to peak	50 ppm
Resolution of current command	4 ppm
Current calibration	100 ppm

Bitter magnet proposed by Walter Joss

2 solenoids : to reduce strains due to Laplace Forces



N = 1000 turns/m

R_1/turn = 192 μΩ
R_2/turn = 116 μΩ
) R''/turn = 72 μΩ

P = 55 MW

$$\frac{B_1}{B_2} = \frac{I_1}{I_2} = \frac{R_2}{R_1} = \frac{7.5\,T}{12.5\,T}$$

if $B = B_1 + B_2 = 12\,T \Rightarrow P = 20\,MW$
(hybrid magnet)

Cost

Bitter magnet:

Magnet:	2.5 MCHF	$(\propto L)$
D.C. supply + cooling:	25.0 MCHF	$(\propto LB^2)$
Consumption: 37 CHF/MWh, 7 month/year, 10 years	110.0 MCHF	$(\propto LB^2 t)$
	137.5 MCHF	

Hybrid magnet

Bitter magnet:	2.5 MCHF	$(\propto L)$
SC magnet: (He cryogenics included) Industrial contract	12.5 MCHF	$(\propto L)$
D.C. Supply + cooling:	7.5 MCHF	$(\propto LB^2_{res})$
Consumption: 37 CHF/MWh, 7 month/year, 10 years	35. MCHF	$(\propto LB^2_{res} t)$
	57.5 MCHF	

Conclusion

- Technical solutions exist to build a 3m _ 20T solenoid
- A hybrid solution looks much cheaper
- The SC magnet may be ordered in industry
- The Bitter magnet could be done @ GHMFL
- Check radiation levels and tolerance in SC magnet
- Optimize ϕ & $\vec{B}$