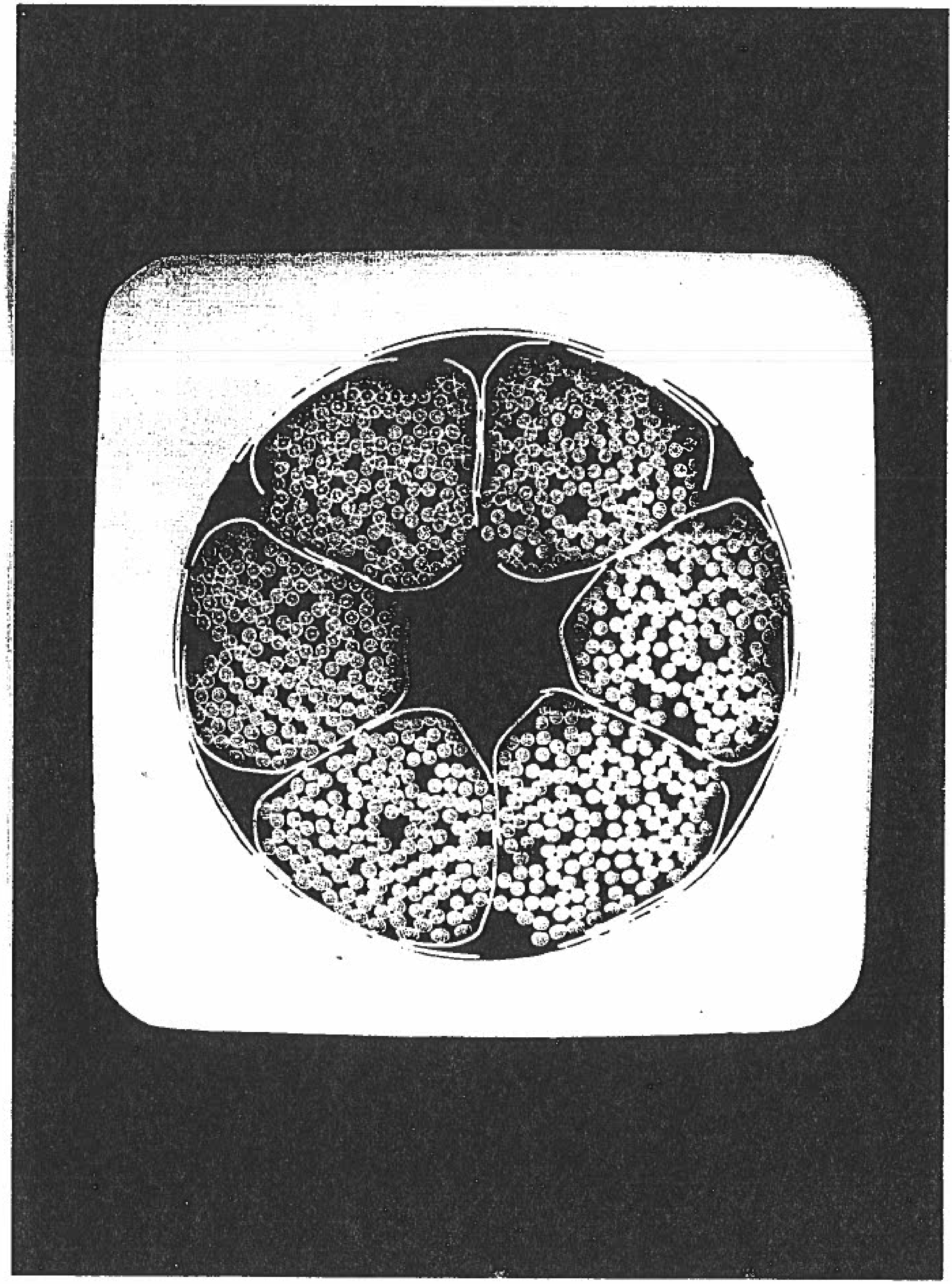
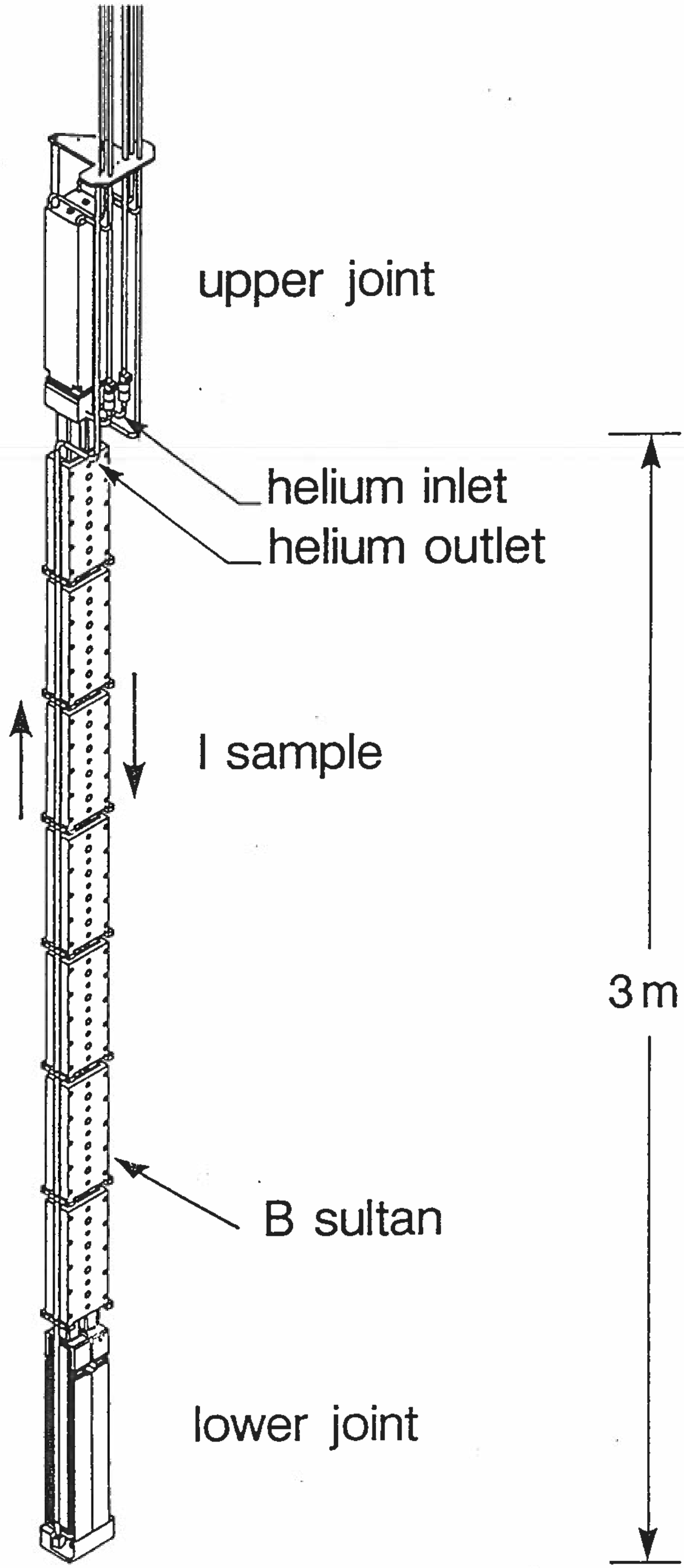


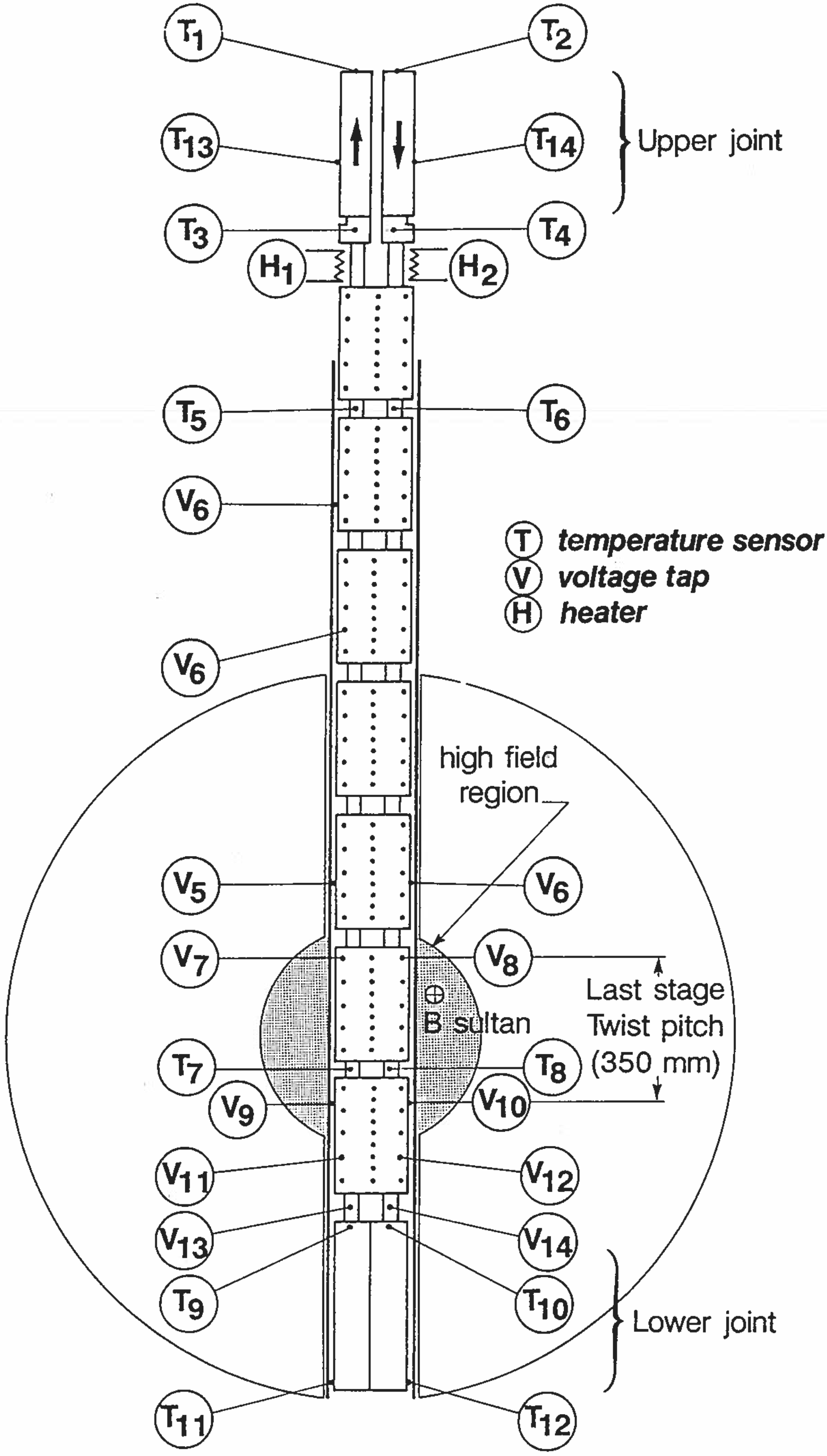
40 kA CEA A15 conductor for Fusion

9/24/93 CEA ACTIVITY ON CIC DEVELOPMENT FOR FUSION

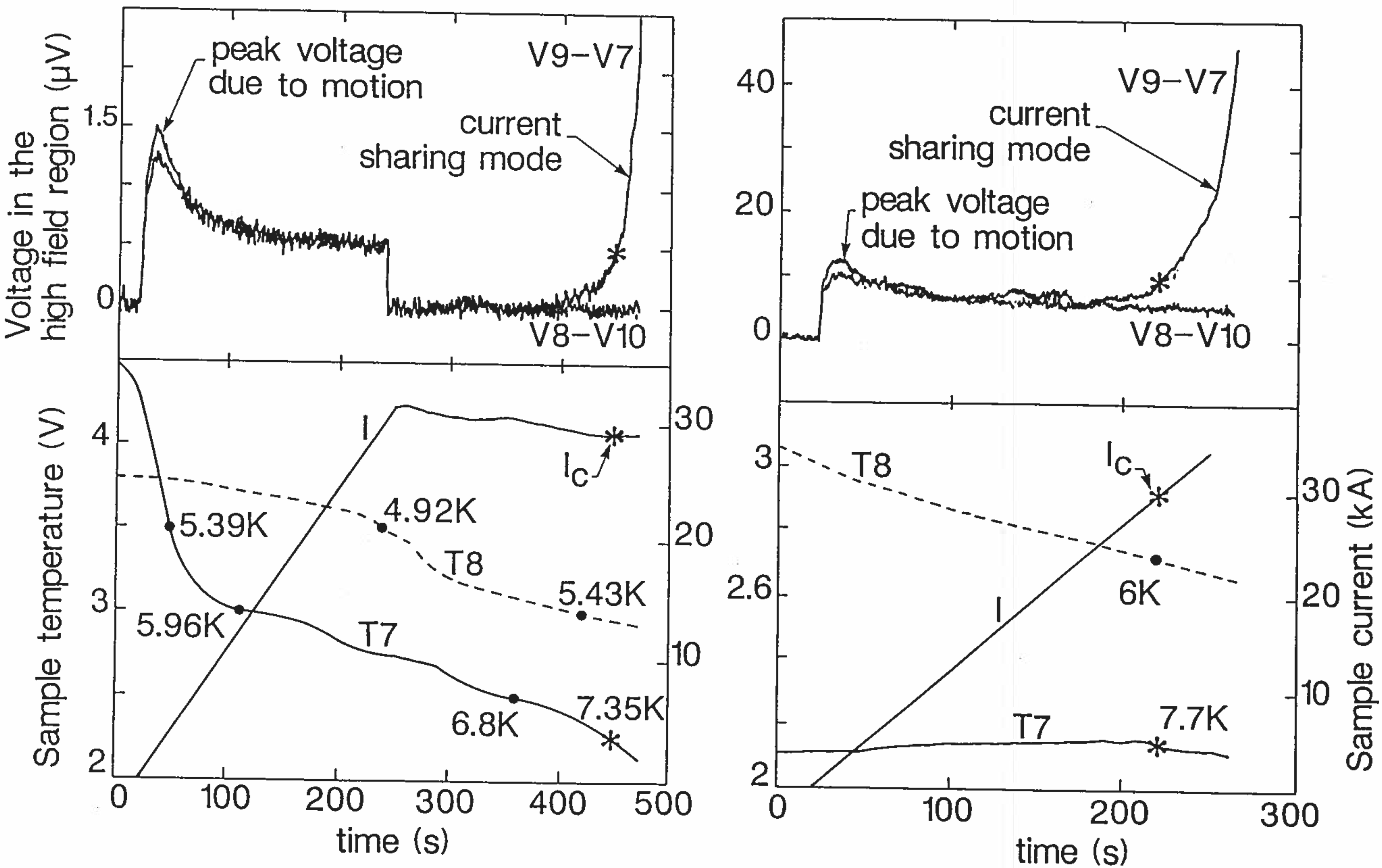
(presented by J.L DUCHATEAU)

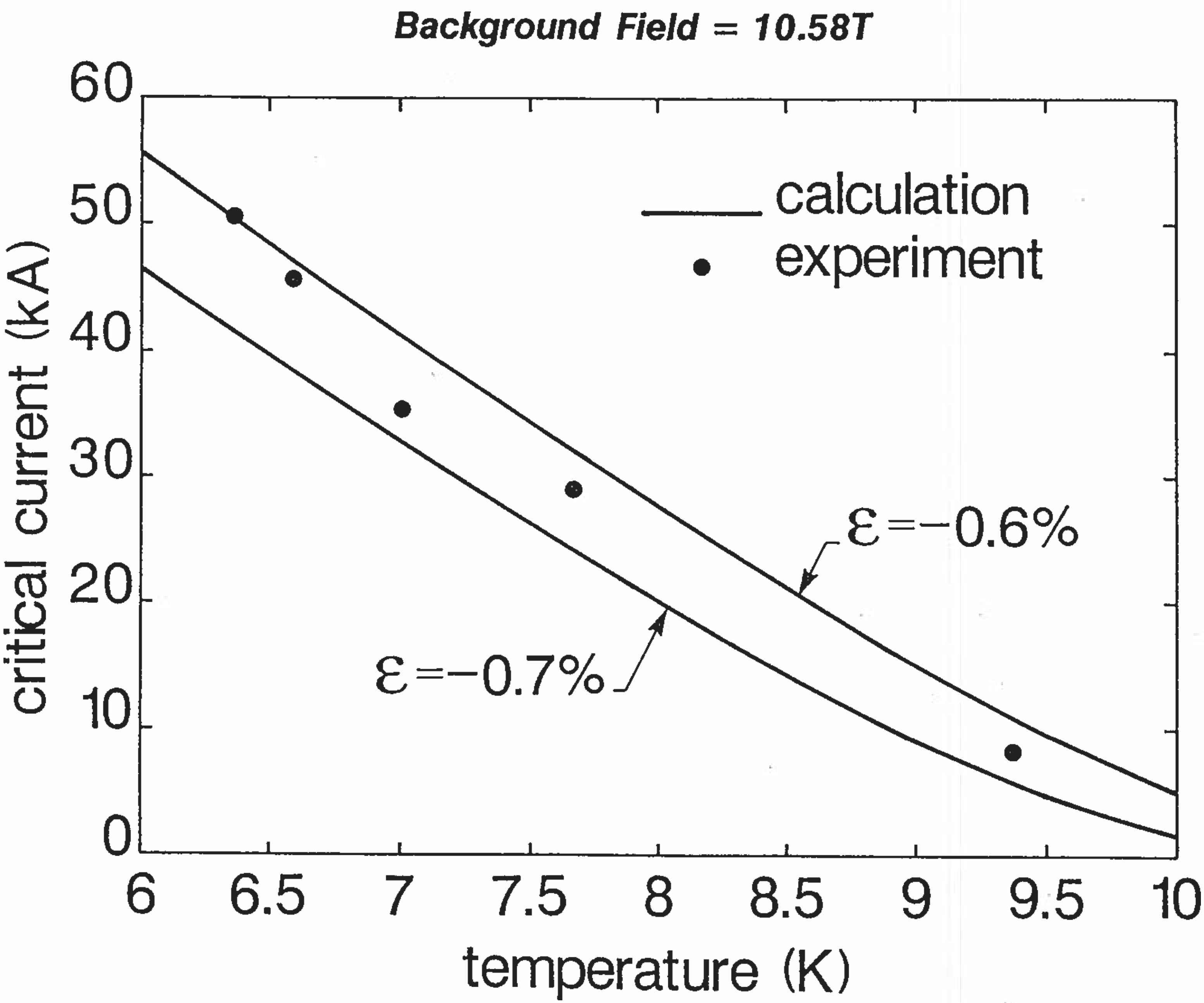
- * Conductor development - Fabrication and tests
- * Investigations on Stability and Energy margin
- * Investigations on Thermohydraulics
- * Losses: Measurements of losses on full size cable and subsize elements - Modelization.
- * Conductor degradation due to DTc between A 316 and Nb_3Sn - Tentatives to improve
- * Conductor design and optimisation
- * Conductor connections


upper joint
helium inlet
helium outlet
I sample
3 m
B sultan
lower joint

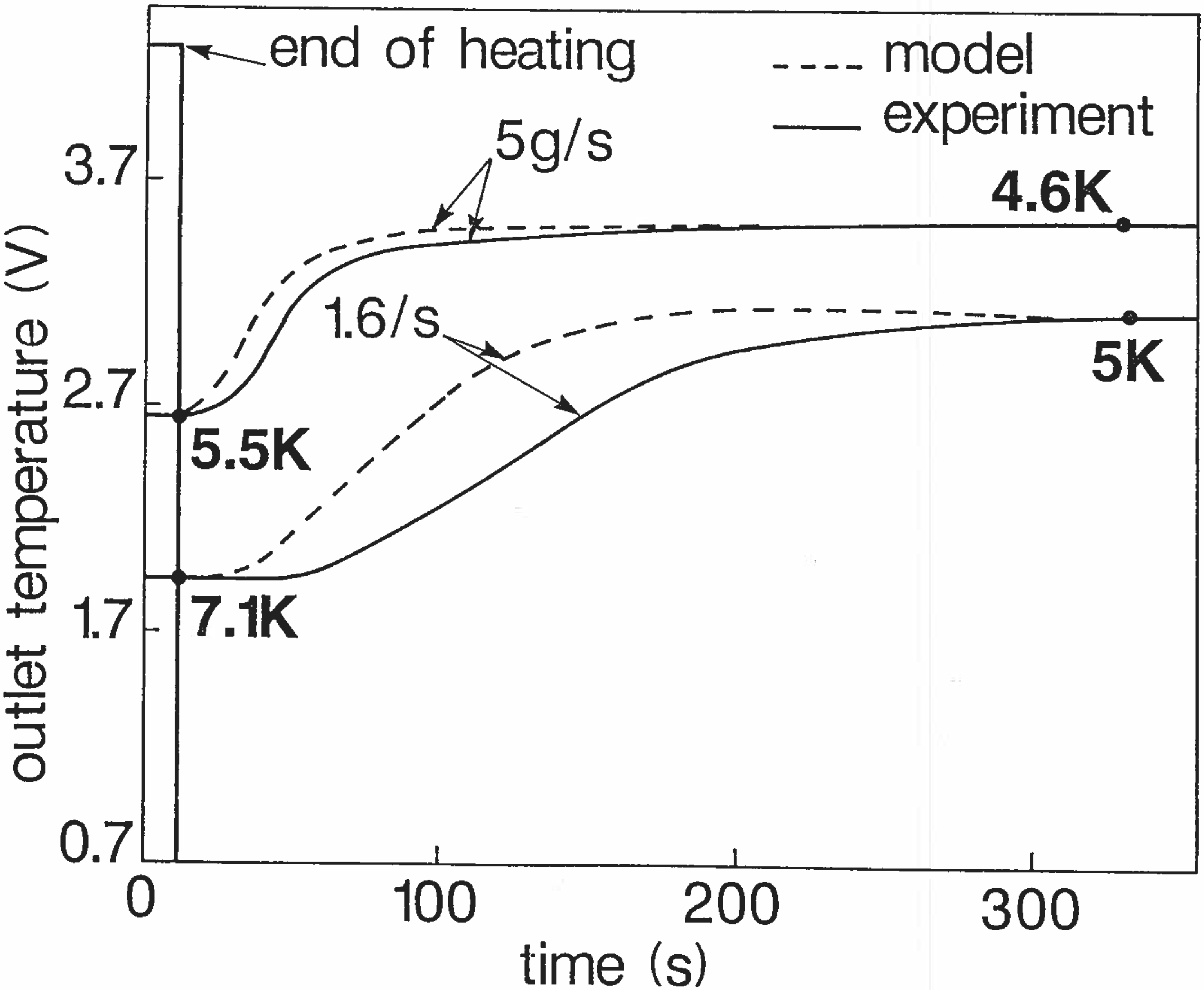


T1
T2
T13
T14
Upper joint
T3
T4
H1
H2
T5
T6
V6
T temperature sensor
V voltage tap
H heater
V6
high field
region
V5
V6
V7
V8
Last stage
Twist pitch
(350 mm)
B sultan
T7
T8
V9
V10
V11
V12
V13
V14
T9
T10
Lower joint
T11
T12


Voltage in the high field region (μV)
peak voltage due to motion
V9–V7
current sharing mode
V8–V10
Sample temperature (V)
I
I_c
5.39K
4.92K
T8
5.43K
5.96K
T7
6.8K
7.35K
time (s)
peak voltage due to motion
V9–V7
current sharing mode
V8–V10
T8
I_c
6K
I
T7
7.7K
time (s)
Sample current (kA)


Background Field = 10.58T
calculation
experiment
ε=−0.6%
ε=−0.7%
critical current (kA)
temperature (K)
0
10
20
30
40
50
60
6
6.5
7
7.5
8
8.5
9
9.5
10

Recooling and train effect on sensor T10
for two different mass flow rates



Supercritical Helium cooling of a cable in conduit conductor with an inner tube

① unique flow

Warm helium is simply replaced by cold helium travelling at the velocity v :

$$v = \frac{m}{\rho_{He} S_{He}} \Longrightarrow t_r = L/v$$

m	mass flow rate
ρ_{He}	Helium density
S_{He}	Helium flow area
t_r	recooling time

② two flows

annulus
$$\frac{\partial T_1}{\partial t} + U_1 \frac{\partial T_1}{\partial x} + \beta_1 (T_1 - T_2) = Q$$

inner tube
$$\frac{\partial T_2}{\partial t} + U_2 \frac{\partial T_2}{\partial x} - \beta_2 (T_1 - T_2) = 0$$

$$\beta_1 = \frac{H P_{m1}}{\rho_1 C_{p1} S_{p1}} \qquad \beta_2 = \frac{H P_{m2}}{\rho_2 C_{p2} S_{p2}}$$

$$\frac{1}{H} = \frac{1}{h_1} + \frac{e}{K} + \frac{1}{h_2}$$

h_1 heat transfer from annulus fluid to tube

e, K thickness and thermal conductivity of tube

h_2 heat transfer from fluid in the tube to the [illegible]

$H \to \infty$ again $\sigma = \frac{m}{\rho \; S}$

H non infinite

A train (in time) must be added to the recooling time.

This train effect is reduced if H is increased.

Influence of the inner tube (ITER cable)

$e_1 = 1.5$ mm $H_1 = 100 W/m^2$ $\Delta t = 787$ s

$e_2 = 0{,}15$ mm $H_2 = 300 W/m^2$ $\Delta t = 454$ s

$$\Delta t \sim 1/\sqrt{H}$$

Suppressing the inner tube leads to faster recooling times.

HYDRAULICS EXPERIMENTS IN C.E GRENOBLE

* experiment on subsize ITER type conductors.

* Supercritical and Superfluid helium possible.

* Hydraulic resistance measurement
  - Influence of the inner tube

* Train effect studies

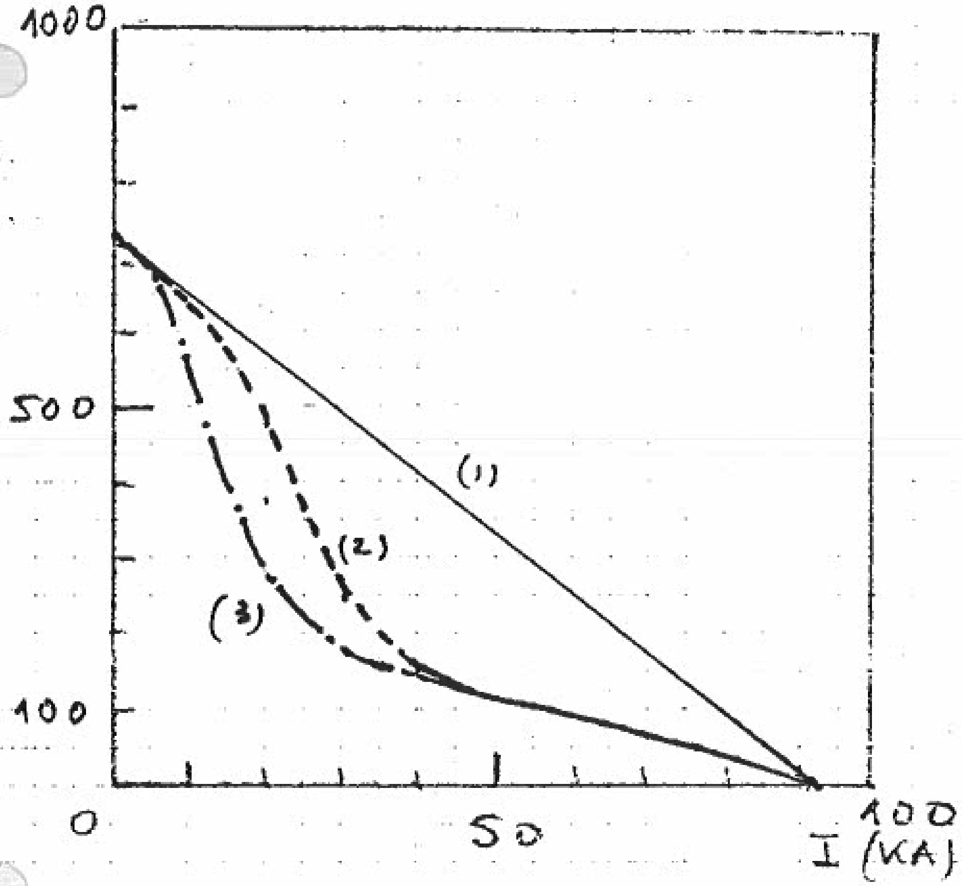
STABILITY EXPERIMENTS IN C.E CADARACHE

* Deposition of large heat quantities over long lengths of conductor.

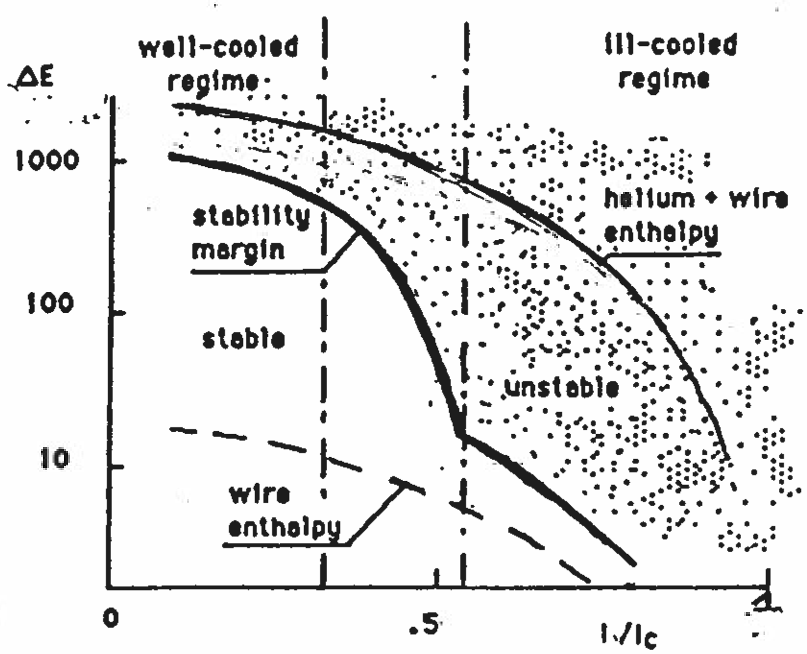
* Generation of heat by discharging the current of a superconducting pure coil into a resistor (< 50 ms) – (Inductive heating through A.C losses)

* Background field : 9 T – I_{max} = 2,5 kA

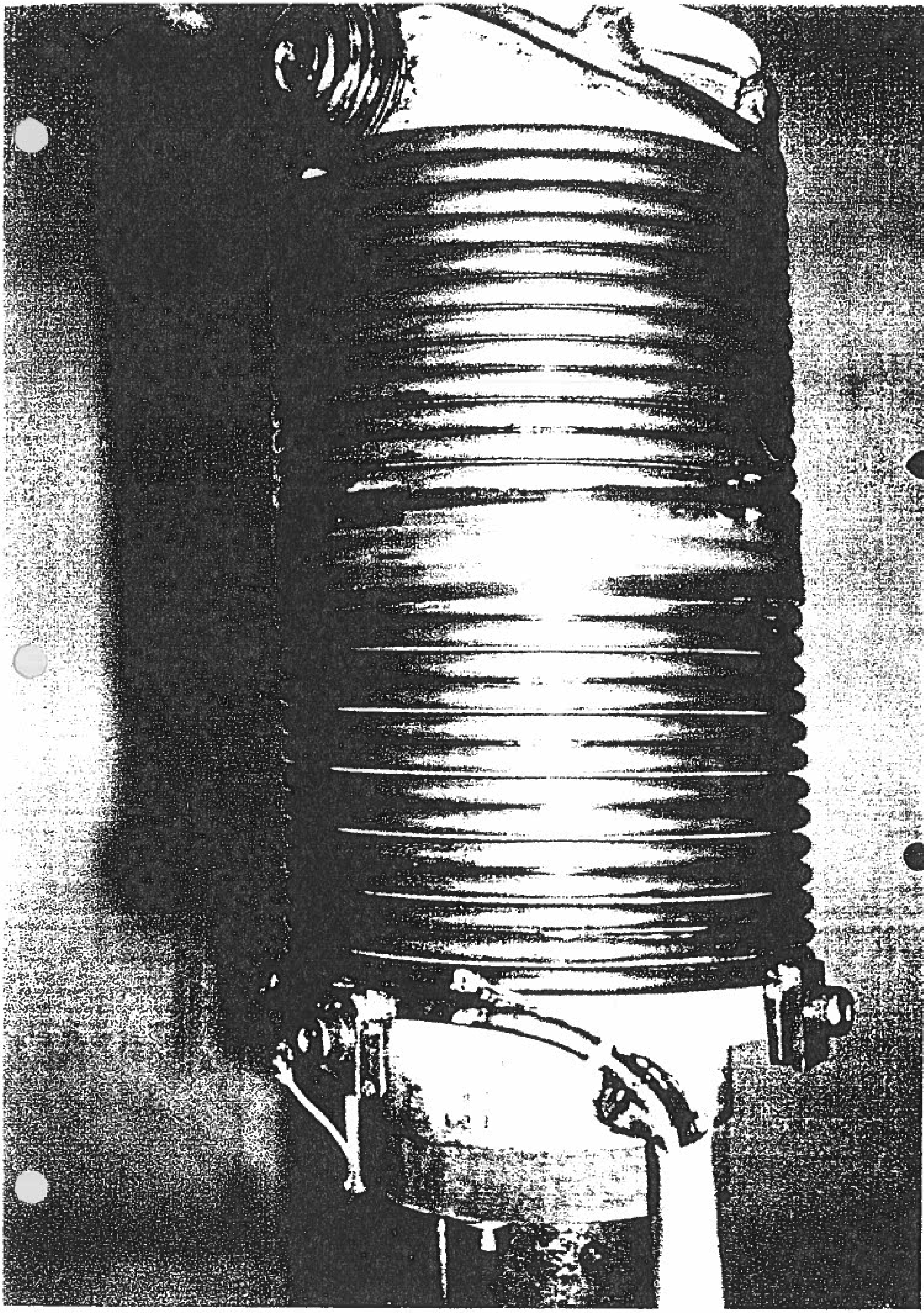
* Conductors tested in hypercritical helium or superfluid helium



1000
500
100
0
50
100
I (KA)
(1)
(2)
(3)



well-cooled regime
ill-cooled regime
ΔE
1000
100
10
stability margin
stable
unstable
helium + wire enthalpy
wire enthalpy
0
.5
I./Ic



Comments on coupling current losses in Cable in Conduit Conductors under transverse loads

Specification for ITER design : $n\tau = 50$ ms

This seems feasible, however the time constant of the conductor under operation can be significantly reduced :

* Deformation of the conductor due to external and internal Lorentz forces

* Influence of fatigue or cabling process on chrome plating -

Advantage of a resistive wrapping around the last but one stage (petal)

$$n r = n r_{petal} + n r_{cable}$$

$$n r = \alpha \frac{l_{p1}^2}{\rho_{t1}} + \beta \frac{l_{p2}^2}{\rho_{t2}}$$

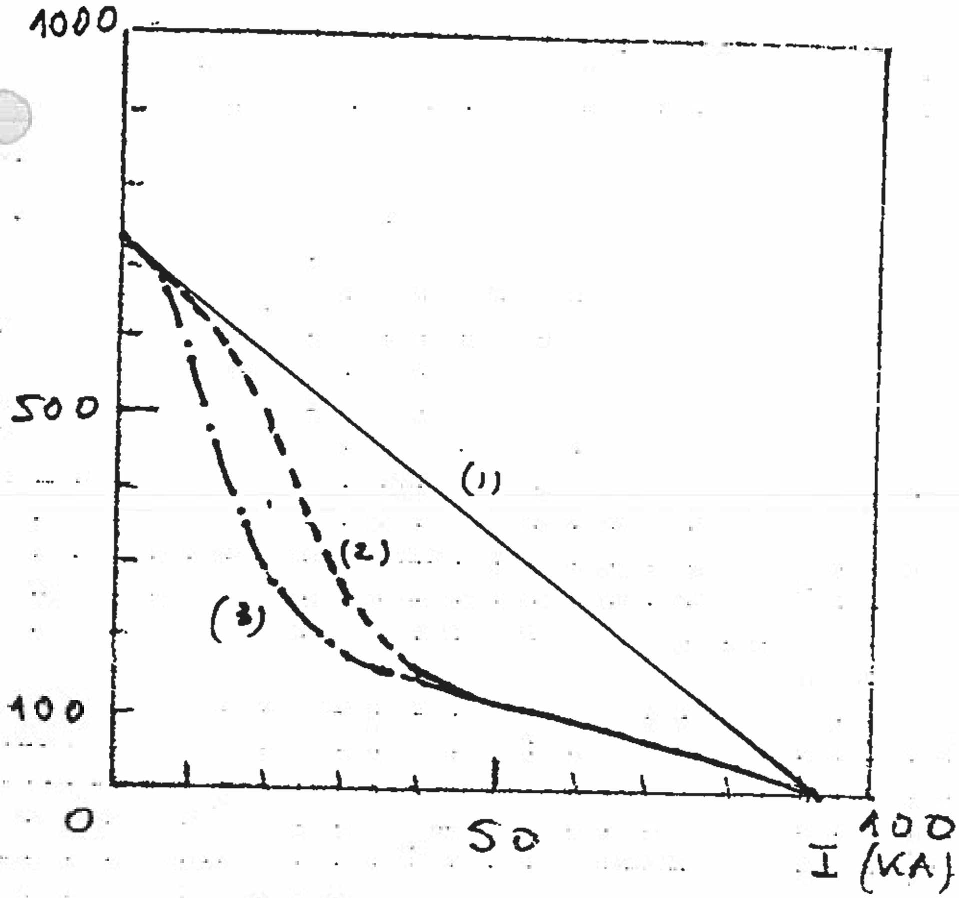
1 for petal $\quad l_{p1} \sim 150$ mm

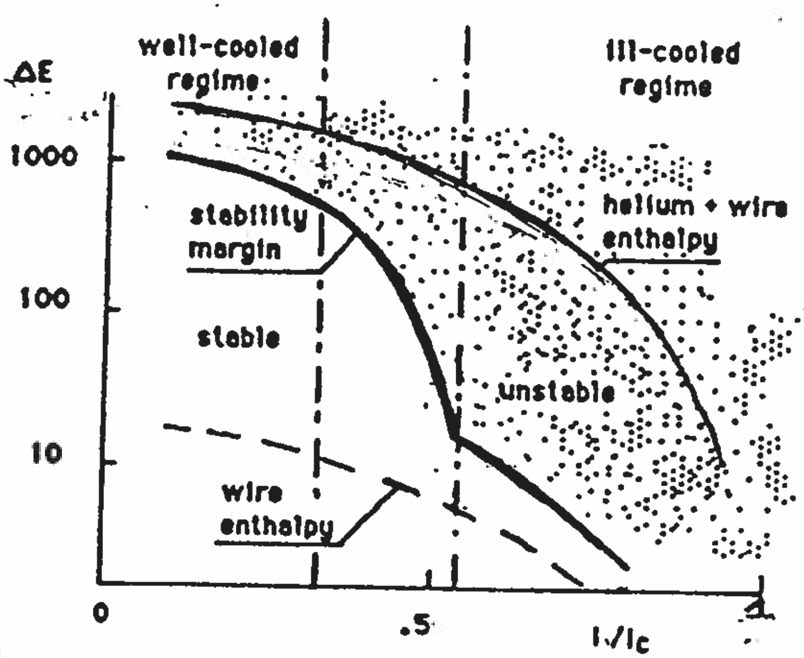
2 for final cable $\quad l_{p2} \sim 400$ mm.

How acting on these two terms?

1 → thin bronze layer around the filament bundles (15-20 μm)

2 → Resistive metal wrapping around the petal -


1000
500
100
0
50
100
I (KA)
(1)
(2)
(3)


ΔE
1000
100
10
0
.5
I/Ic
well-cooled regime
ill-cooled regime
stability margin
stable
unstable
helium + wire enthalpy
wire enthalpy

DUCHATEAU and al. - Nb_3Sn superconductor for fusion application, facing NET-ITER specifications, evaluation of the industrial capability
ASC. 1992 -

B. Ciazynski and al. - A.C losses and current distribution in 40 kA NbTi and Nb_3Sn conductors for NET/ITER
ASC. 1992

A. Torossian and al. - Drastic improvement of Ic of Nb_3Sn C.i.c conductor by prestraining at room temperature
SOFI Boston ~~Sept~~ 1993 - (to be published)

Ciazynski, B. TURCK - Stability criteria and critical energy in superconducting cable in conduit conductors.
(Paper submitted for publication in Cryogenics)

B. Turck and al. - Design methods and actual performances of conductors for the superconducting coils of Tokamaks
SOFI Boston 1993 (to be published)

D. Bessette and al. - Qualification of a 40kA Nb_3Sn Superconducting Conductor for NET/ITER Coils.
MT13 Victoria 1993 -