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"Thermal analysis of TPX Superconducting Magnets"

THERMAL ANALYSIS OF TPX TF COILS

and

CODE VERIFICATION WITH ORNL TRIPLEX

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May 10, 1993

- Computer code *CICC*
- Design of TPX TF coils
    - Double pancake flow temperature margin
    - Single pancake flow temperature margin
- Code verification with ORNL NbTi triplex tests
    - Preliminary results
    - Problems calculating multiple stability

THE COMPUTER CODE *CICC*

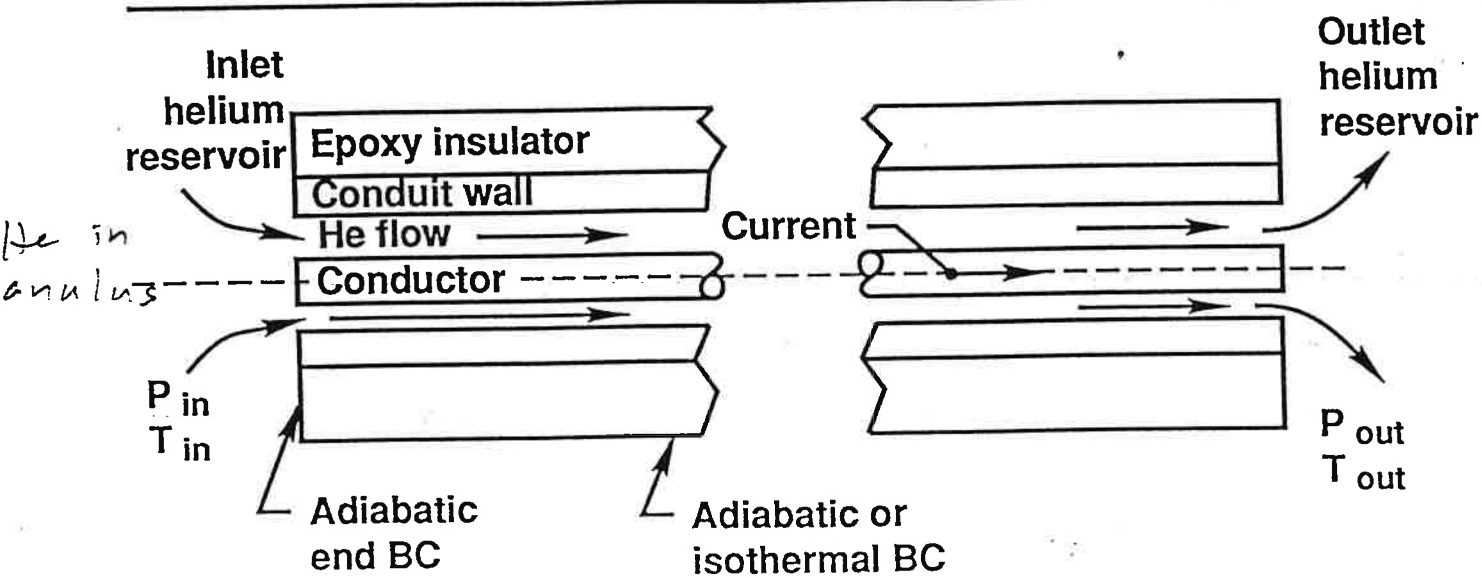
- *CICC* Models Thermo-Fluid Phenomena in Forced-Flow He-Cooled Superconducting Cable-In-Conduit.

1. The coil length is finite differenced.
   a. He 1-D pipe flow model
   b. 2-D axisymmetric solid conduction model
   c. Cryogenic NBS He properties

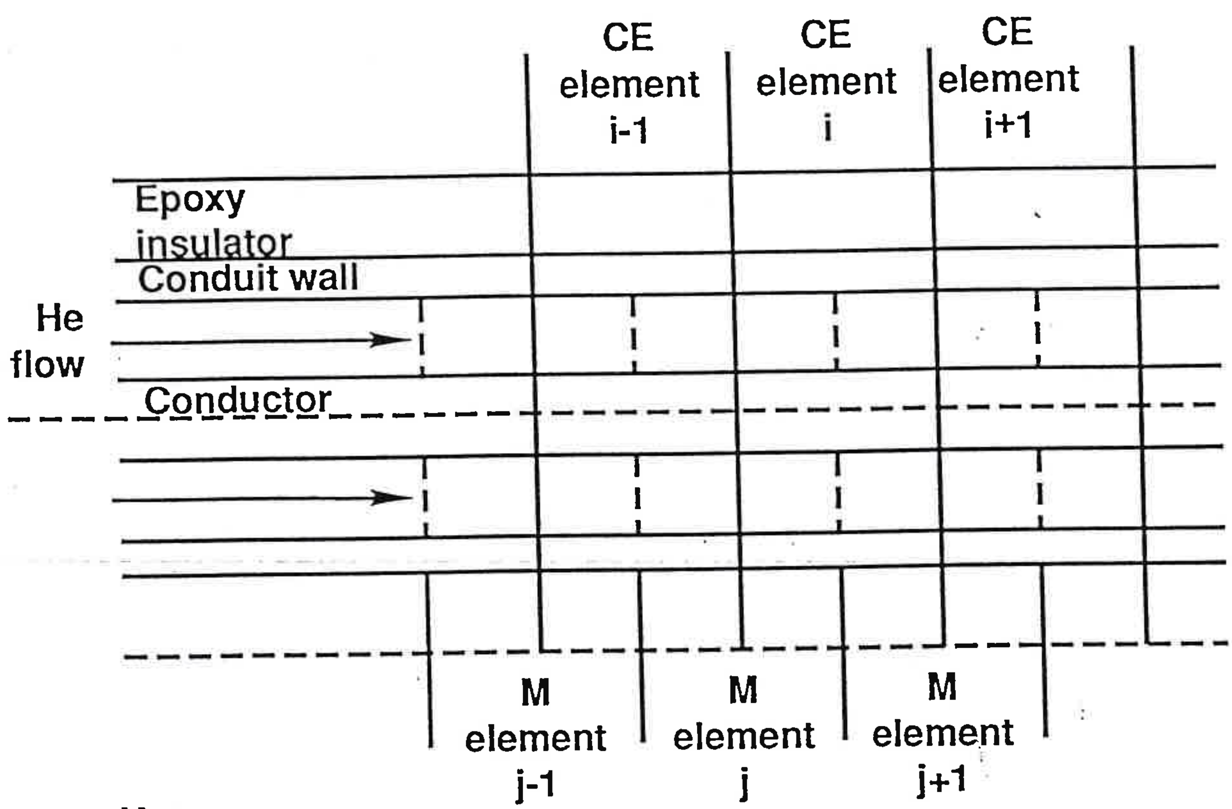
2. The solution in time uses the "method of lines" and an O.D.E. solver.

DASSL
Petzold

Forced flow cooled conductor schematic



Staggered grid in section of conductor



Notes:

1. CE element = continuity - energy element
2. M element = momentum element

20-A-0492-0033C

Conservation equations

Helium momentum equation

$$\frac{\partial(\rho u)}{\partial t} = \frac{\partial}{\partial x}(p + \rho u^2) - \left(\frac{f}{d_h}\right)\left(\frac{1}{2}\rho u|u|\right)$$

Helium continuity equation

$$\frac{\partial \rho}{\partial t} = -\frac{\partial(\rho u)}{\partial x}$$

Helium energy equation

$$\left(\frac{\partial}{\partial t}\right)\left[\rho\left(e + \frac{1}{2}u^2\right)\right] = -\frac{\partial}{(\partial x)}\left[(\rho u)\left(h + \frac{1}{2}u^2\right)\right] + \left(\frac{\partial}{\partial x}\right)\left(k\frac{\partial T}{\partial x}\right) + \frac{1}{A_c}\left[\frac{A_{tc}}{R_c}(T_c - T) + \frac{A_{tw}}{R_w}(T_w - T)\right]$$

Conductor energy equation

$$(\rho_c C_c)\left(\frac{\partial T_c}{\partial x}\right) = -\frac{\partial}{\partial x}\left(f_{Cu}k_{Cu}\frac{\partial T_c}{\partial x}\right) + \frac{1}{A_{cc}}\left[\frac{A_{tc}}{R_c}(T - T_c)\right] + (Q_{gen})$$

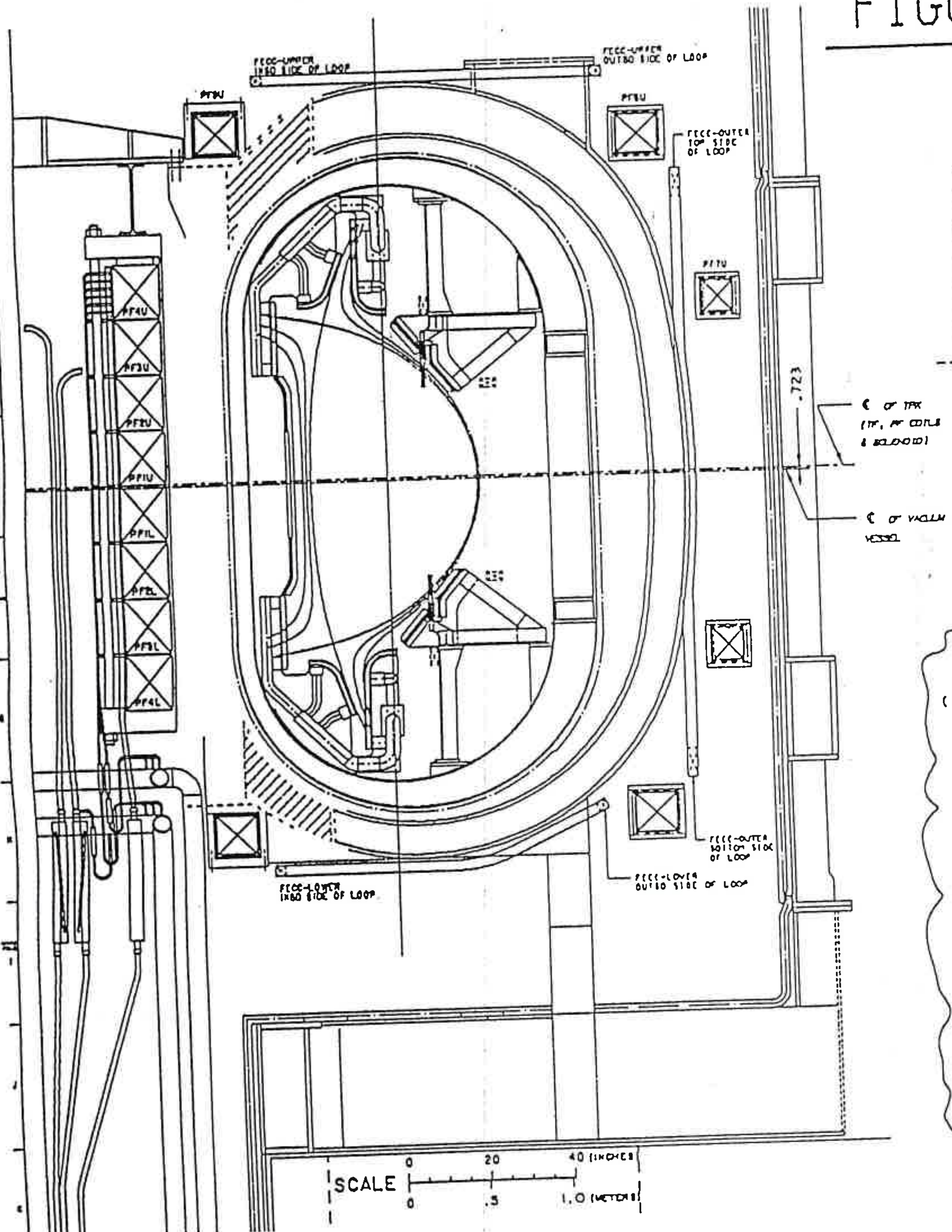
Conduit–wall energy equation

$$(\rho_w C_w)\left(\frac{\partial T_w}{\partial t}\right) = \frac{\partial}{\partial x}\left(k_w\frac{\partial T_w}{\partial x}\right) + \frac{1}{A_{cw}}\left\{\frac{A_{tw}}{R_w}(T - T_w) + \frac{(A_{te})_1}{(R_e)_1}[(T_e)_1 - T_w]\right\}$$

General epoxy layer energy equation

$$(\rho_e C_e)\left[\frac{\partial(T_e)_n}{\partial t}\right] = \frac{\partial}{\partial x}\left\{k_e\left(\frac{\partial(T_e)_n}{\partial x}\right)\right\} + \frac{1}{(A_{ce})_n}\left\{\frac{(A_{te})_n}{(R_e)_n}[(T_e)_{n-1} - (T_e)_n] + \frac{(A_{te})_{n+1}}{(R_e)_{n+1}}[(T_e)_{n+1} - (T_e)_n]\right\}$$

FIGURE 1



NOTES:

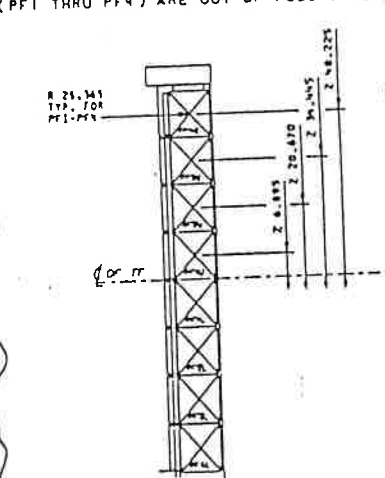
1. TF COIL AND DIVERTOR COOLANT LINES ROTATED INTO PLANE OF VIEW.
2. VACUUM VESSEL CENTERLINE OFFSET .723 INCHES FROM TF CENTERLINE.

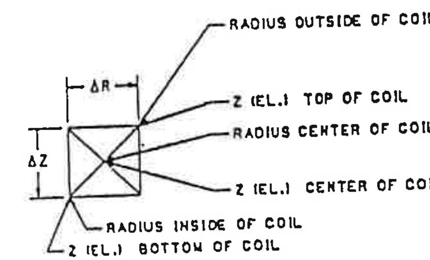
PF COIL GEOMETRY FROM ℄ OF TF COIL (REF BULMER EQUILIBRIUM #92074)								
COIL	R_{CC}	Z_{CC}	R_{IC}	R_{OC}	Z_{BC}	Z_{TC}	ΔR	ΔZ
PF1U	28.346	6.890	23.642	33.051	.315	13.465	9.409	13.150
PF2U	28.346	20.669	23.642	33.051	14.094	27.244	9.409	13.150
PF3U	28.346	34.449	23.642	33.051	27.874	41.024	9.409	13.150
PF4U	28.346	48.228	23.642	33.051	41.653	54.803	9.409	13.150
PF5U	48.425	86.614	43.701	53.150	81.929	91.299	9.449	9.370
PF6U	148.819	83.858	144.134	153.504	79.153	88.563	9.370	9.409
PF7U	167.086	42.953	163.779	170.393	39.173	46.732	6.614	7.559

LOWER HALF OF PF COILS SYMMETRICAL TO TOP HALF

FECC COIL GEOMETRY FROM ℄ OF TF COIL								
COIL	R_{CC}	Z_{CC}	R_{IC}	R_{OC}	Z_{BC}	Z_{TC}	ΔR	ΔZ
FECC-UI	58.630	99.653	57.380	59.880	98.403	100.903	2.50	2.50
FECC-UO	139.659	99.653	138.409	140.909	98.403	100.903	2.50	2.50
FECC-OT	157.779	71.628	156.529	159.029	68.128	75.128	2.50	7.00
FECC-OB	157.779	-71.628	156.529	159.029	-75.128	-68.128	2.50	7.00
FECC-LI	58.630	-95.759	57.380	59.880	-97.009	-94.509	2.50	2.50
FECC-LO	136.145	-81.772					2.50	2.50

AS SHOWN IN DWG., SOLENOID COILS (PF1 THRU PF4) ARE OUT OF POSITION.





REFERENCE DWGS:
PPL.LH.TPX.PF-STRUCTURE-2

2-12-93
LLL.PPPL.BROWN.2-12-93.PFLOCS
TPX.RLG.PFLOCS.5-6-7.UPDATED

COMPUTER GENERATED DRAWING NO MANUAL CHANGES PERMITTED

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
TOKAMAK PHYSICS EXPERIMENT
PRELIMINARY DESIGN
2.25M BASELINE
4.00 TESLA CONFIGURATION
PF COIL GEOMETRY

PRELIMINARY ISSUES

TPX TEMPERATURE MARGIN

Flat top=	1000 s
Number of TF coils=	16
Turns/pancake=	7
Pancakes=	12
Helium flow rate=	400 g/s (total)
Inlet temperature=	5.0 K
Outlet pressure=	4 atm
Peak field=	7.63 T
Current=	33.5 kA
Current sharing=	7.7 K

DOUBLE AND SINGLE PANCAKE COMPARISON

	Max. Bore Temp.	Temp. Margin
Dbl. Pancake	6.5 ~~5.9~~ K	1.2 ~~1.8~~ K
Sgl. Pancake	5.9 ~~6.6~~ K	1.8 ~~0.9~~ K

Dbl. Pancake Energy Margin= 375 mJ/cc

Fig. 1, Transient Conductor Winding Pack
Heating in Outer Leg at the Bore
Double Pancake Flow Configuration
5 kW Nuclear Heating

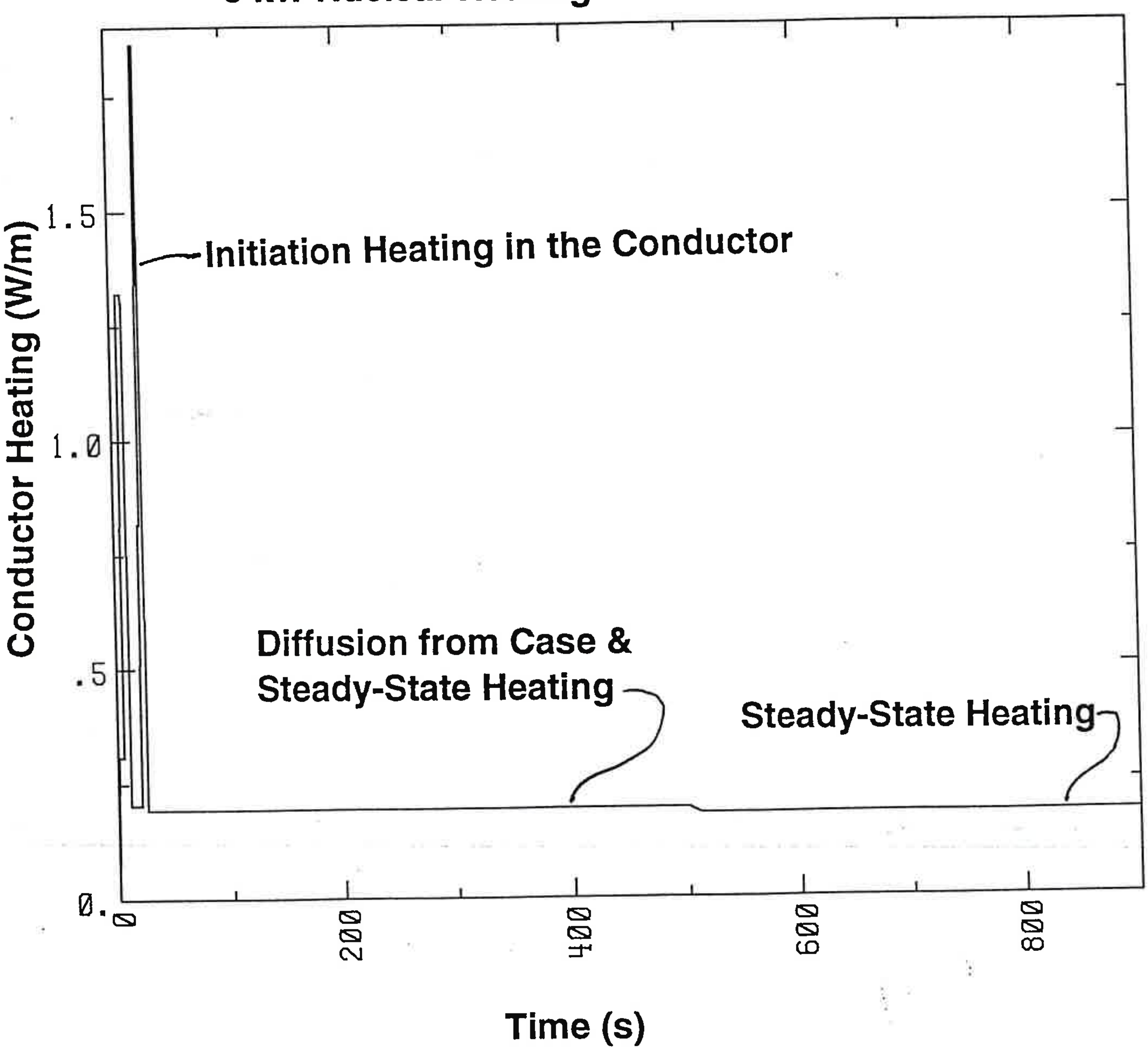


Fig. 3, Maximum Transient Temperature at Bore
Double Pancake Flow Configuration
5kW Nuclear Heating

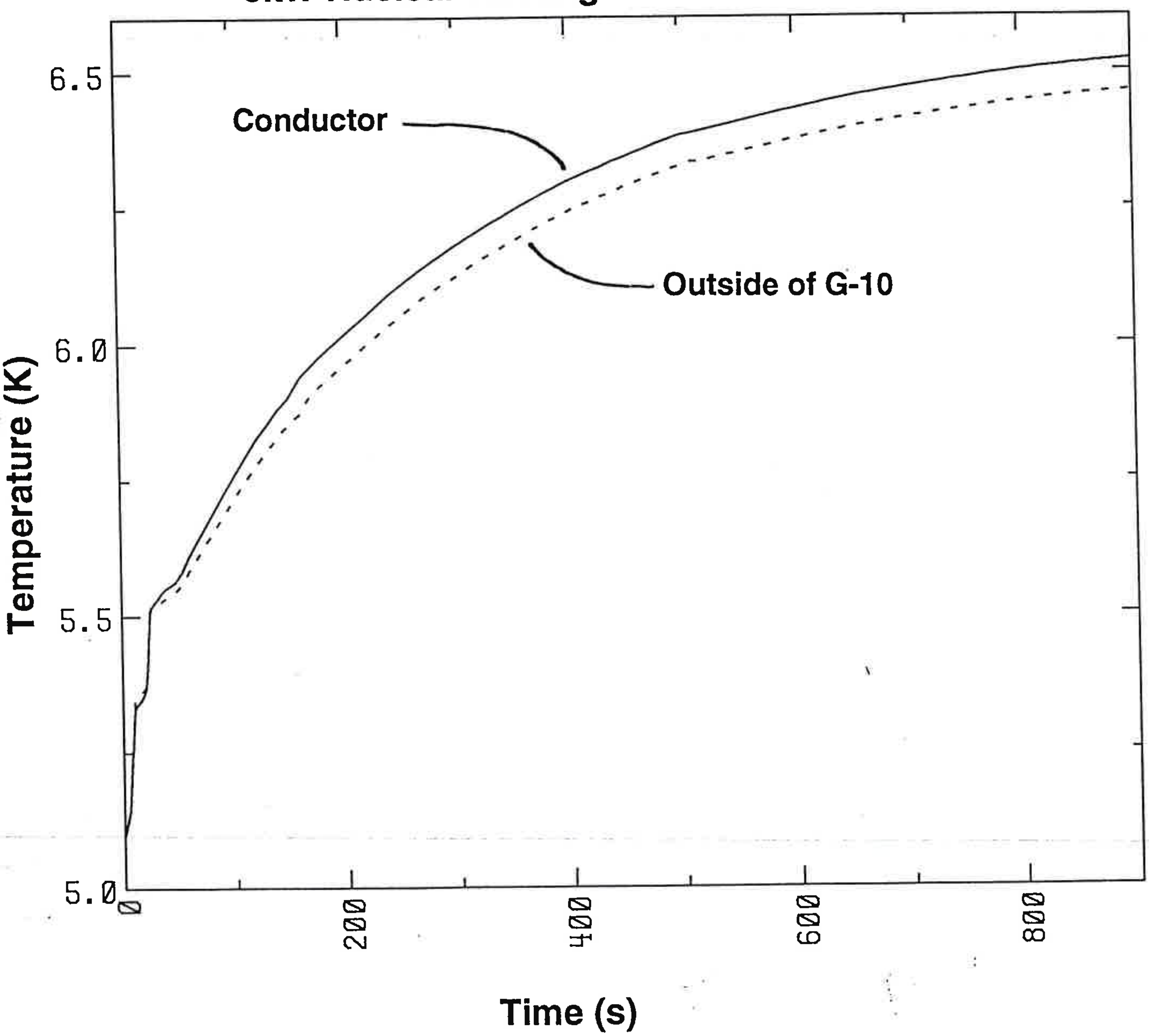


Fig. 12, Maximum Transient Temperature at Bore
Single Pancake Flow Configuration
5kW Nuclear Heating

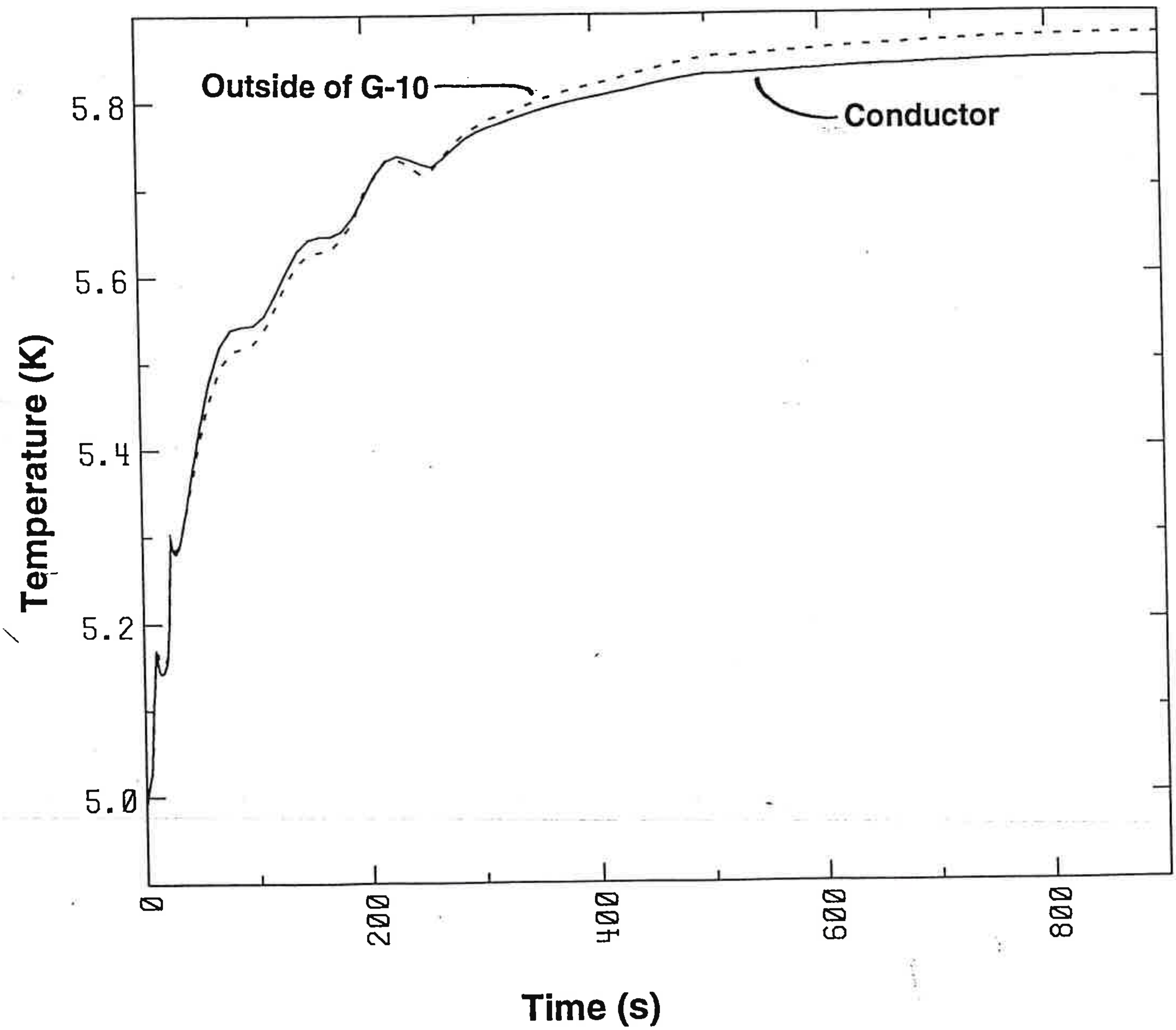


Fig. 2, Steady-State Conductor Winding Pack
Heating Profile
Double Pancake Flow Configuration
5kW Nuclear Heating

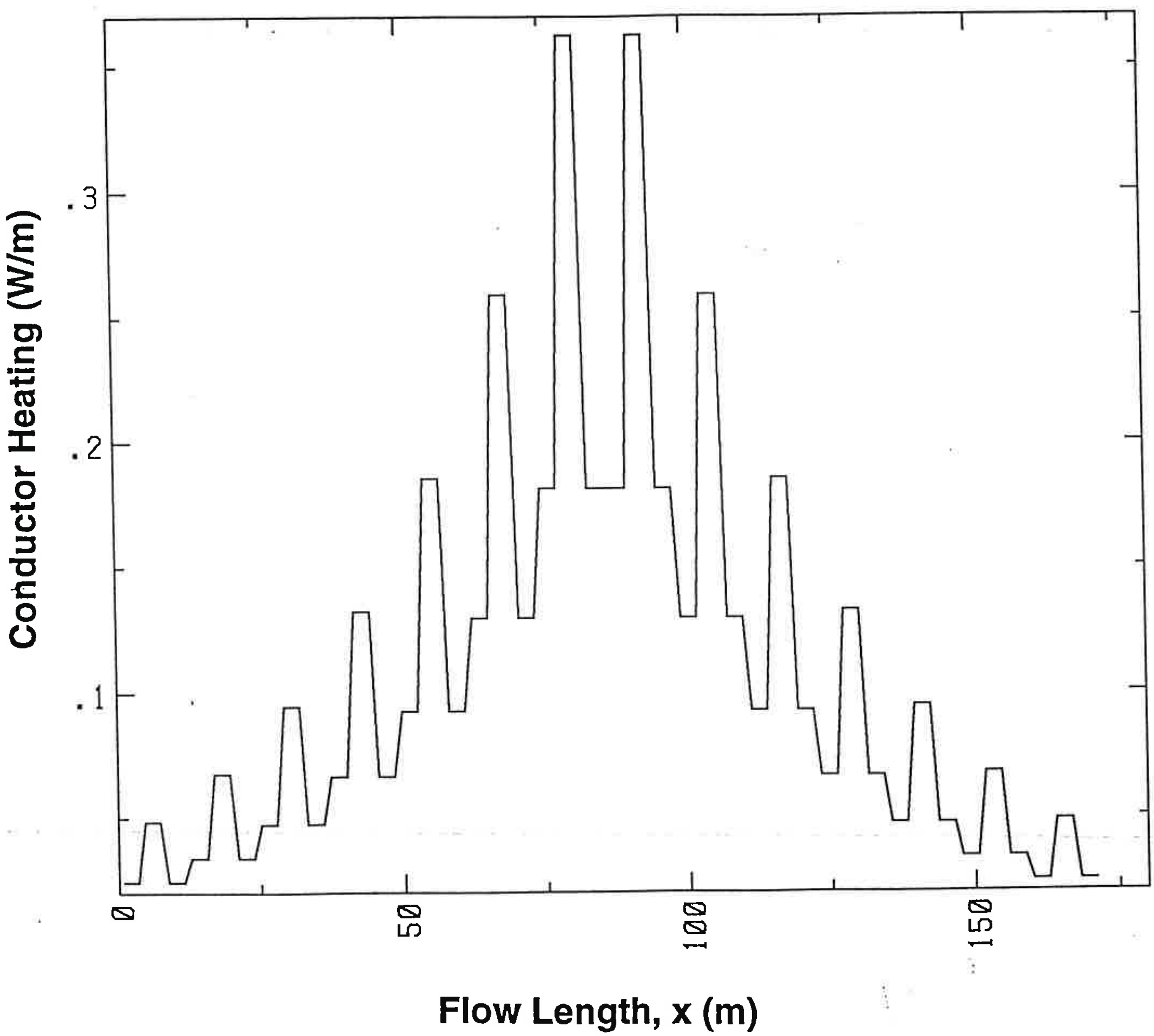


Fig. 6, Temperature Profile after 900 s
Double Pancake Flow Configuration
5kW Nuclear Heating

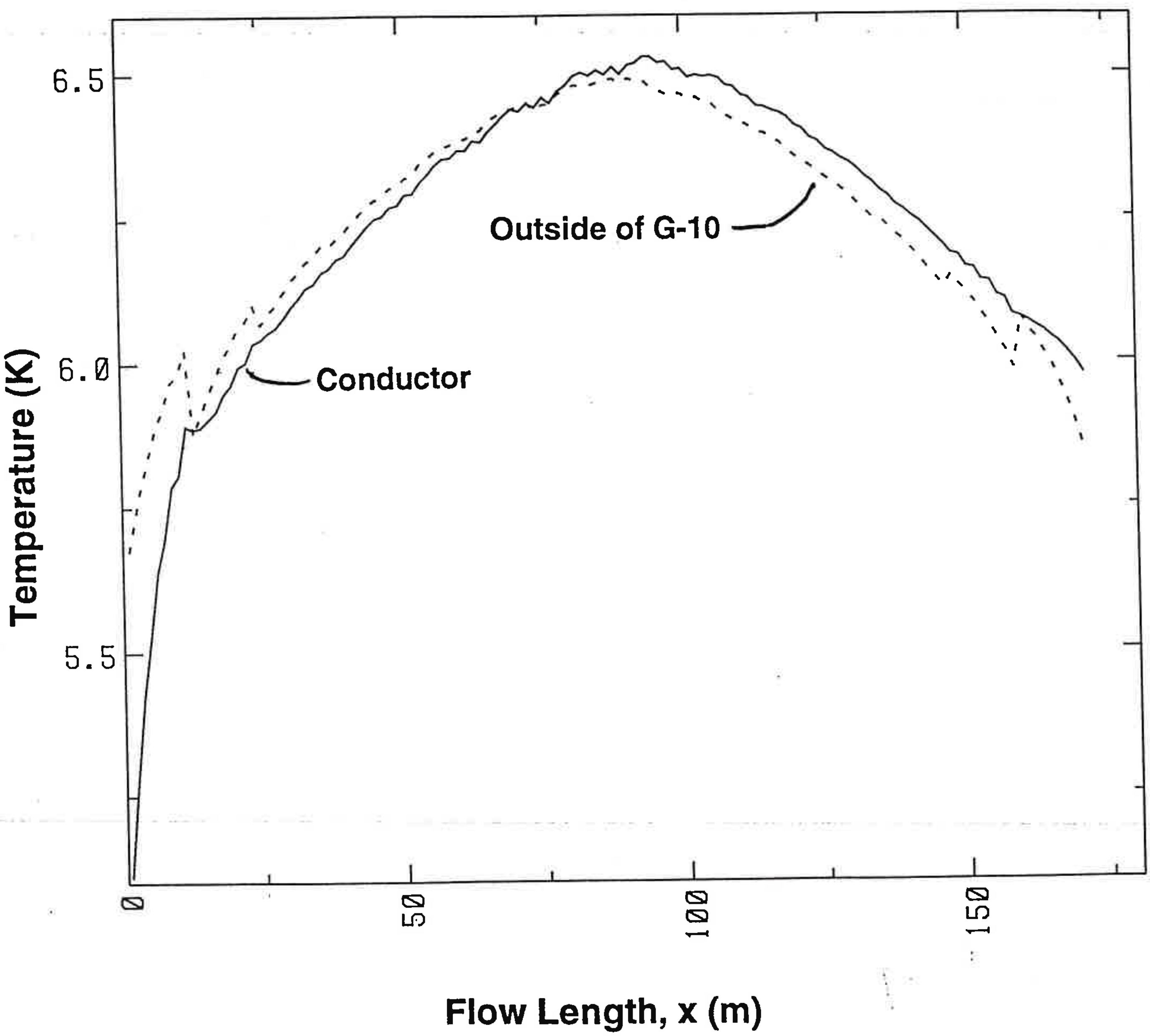
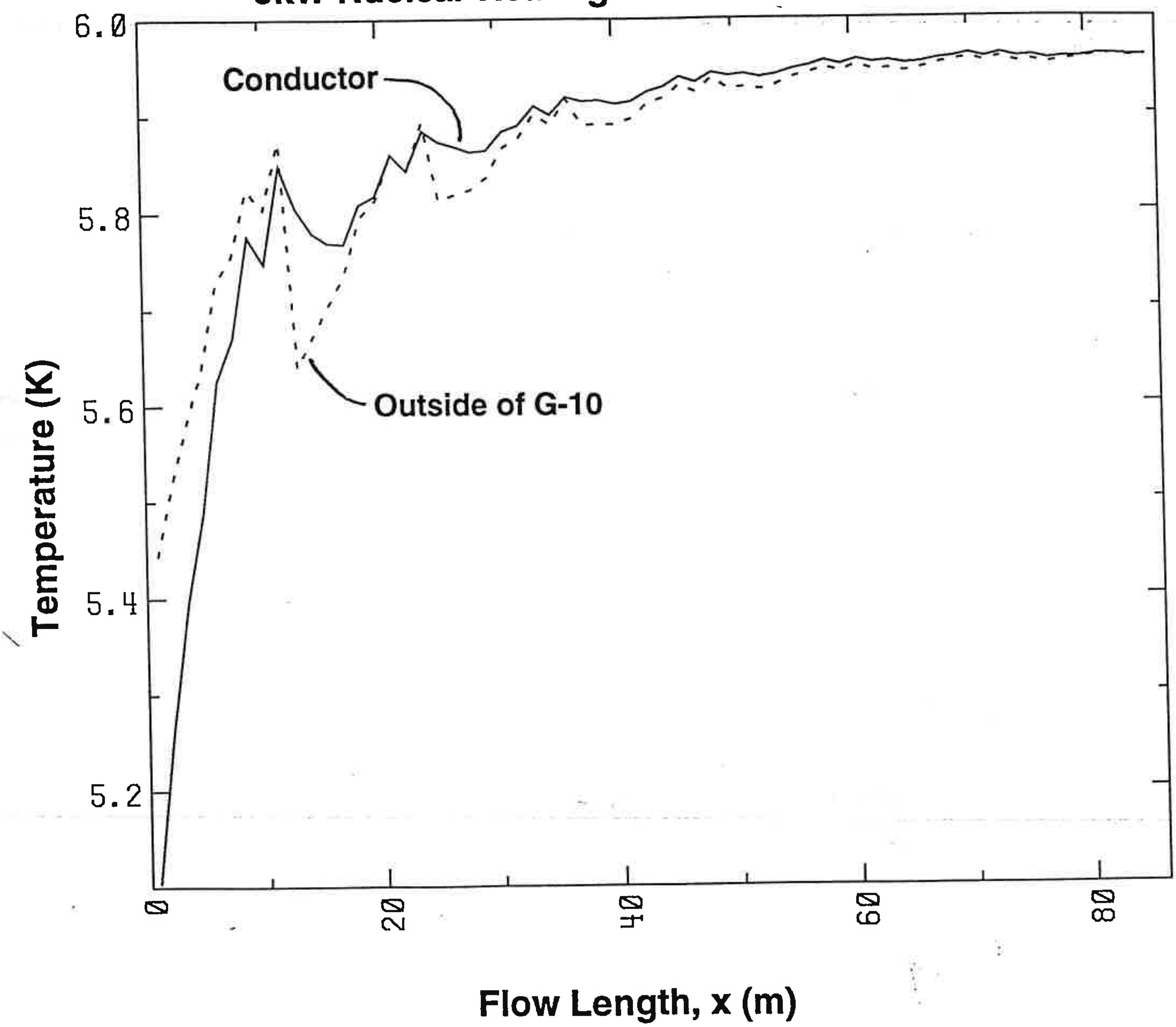
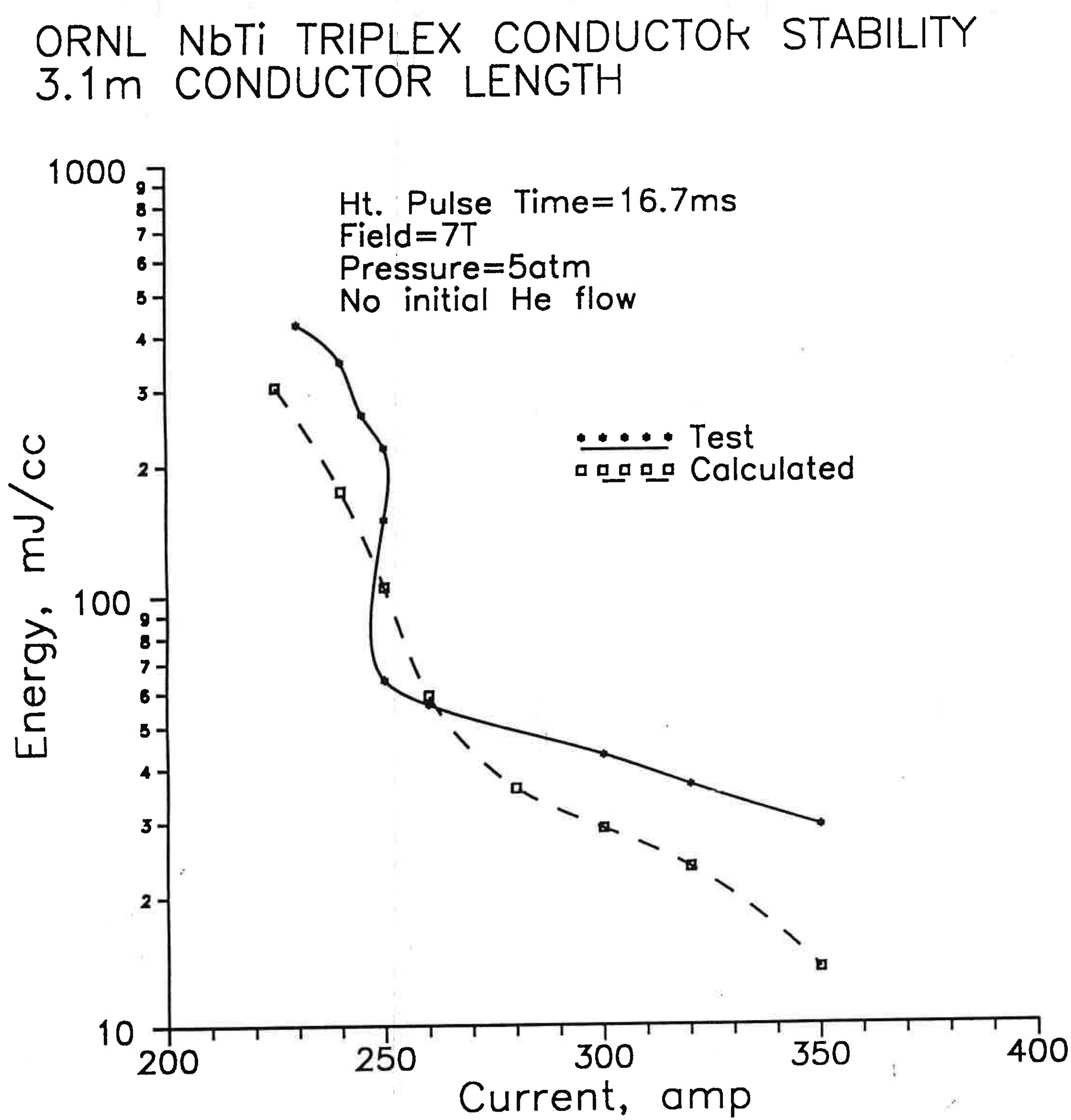
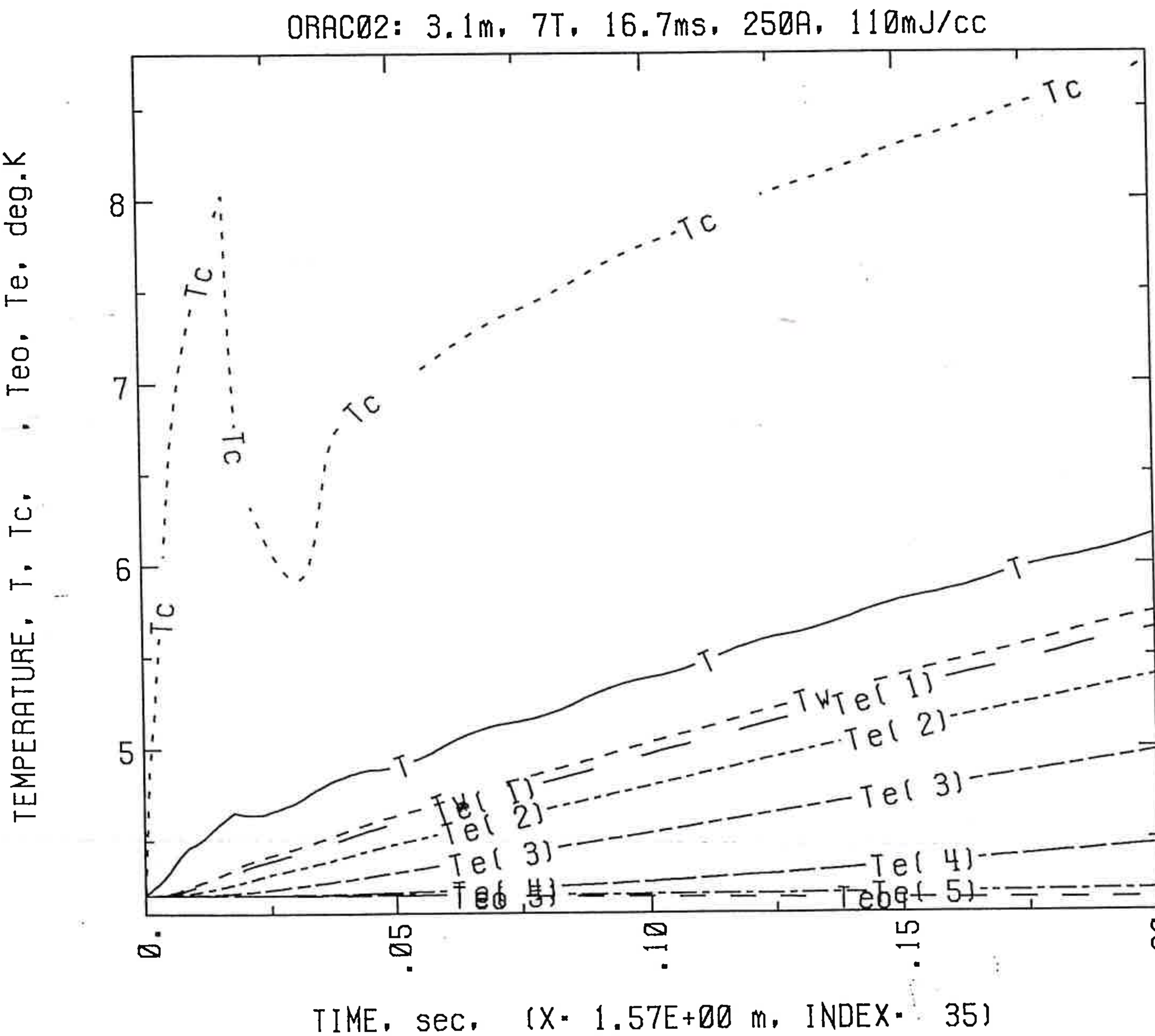
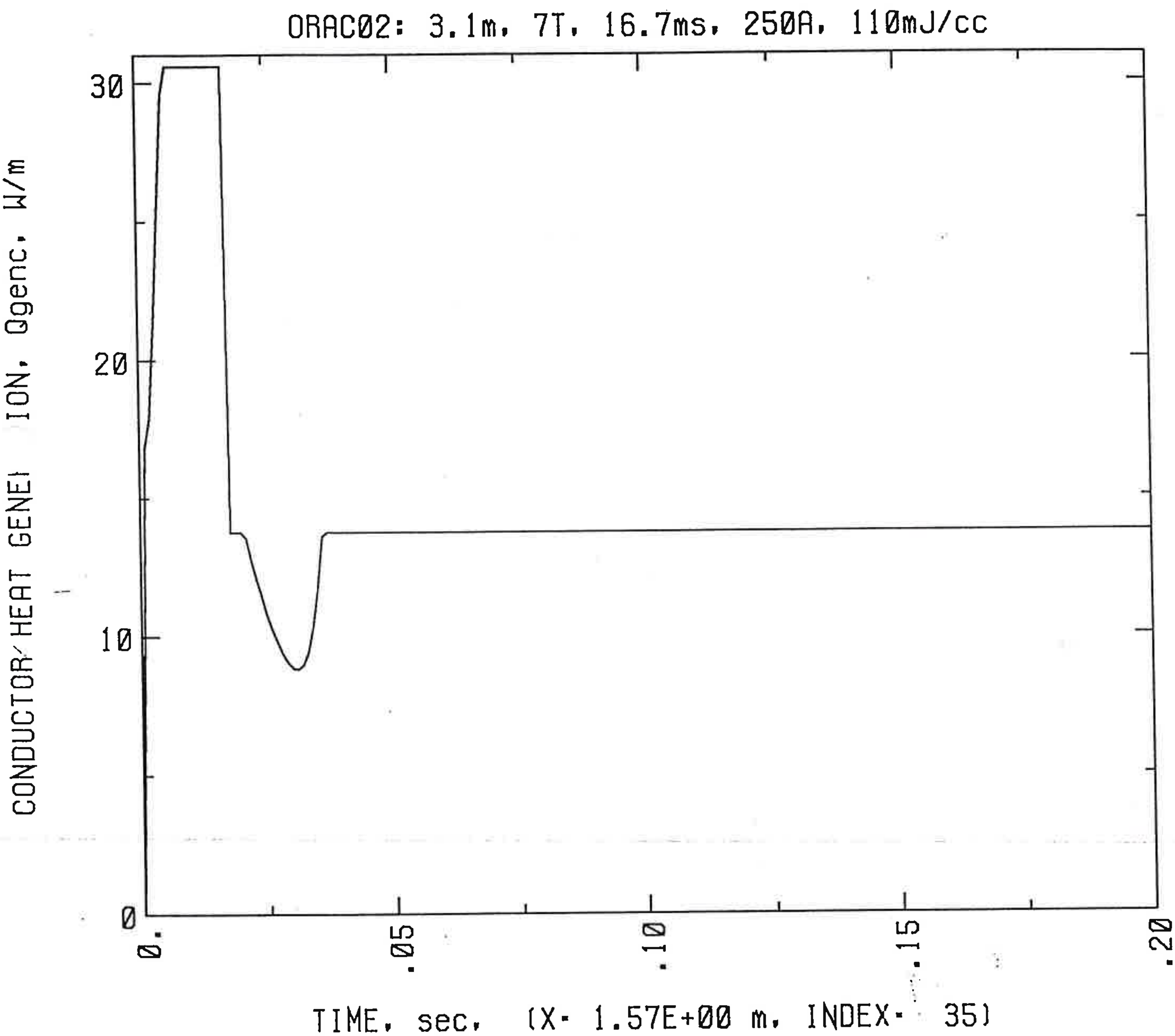


Fig. 15, Temperature Profile after 900 s
Single Pancake Flow Configuration
5kW Nuclear Heating

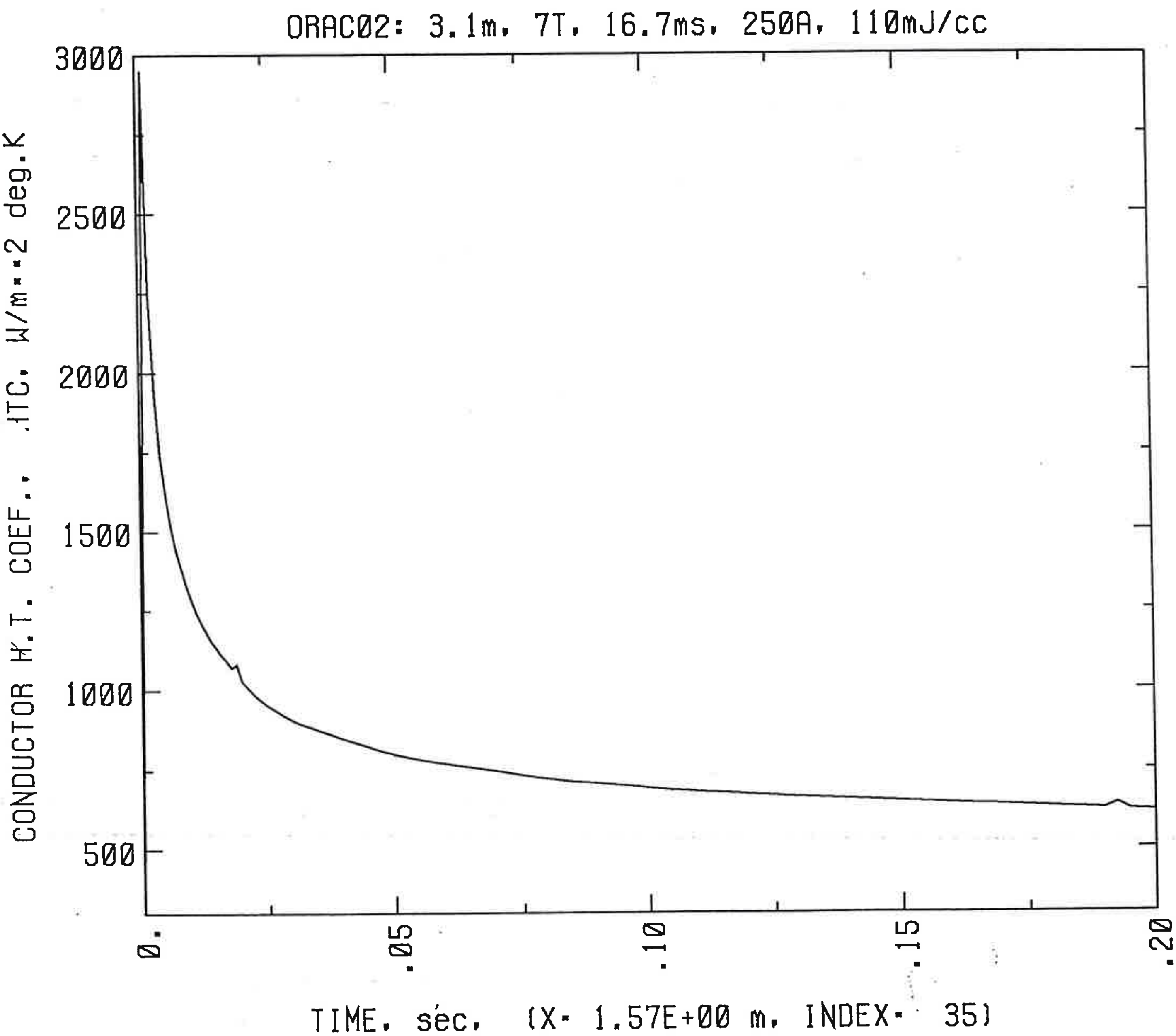



ORNL NbTi TRIPLEX CONDUCTOR STABILITY
3.1m CONDUCTOR LENGTH
Ht. Pulse Time=16.7ms
Field=7T
Pressure=5atm
No initial He flow
Test
Calculated
Energy, mJ/cc
Current, amp
10
100
1000
200
250
300
350
400


ORAC02: 3.1m, 7T, 16.7ms, 250A, 110mJ/cc
TEMPERATURE, T, Tc, , Teo, Te, deg.K
8
7
6
5
Tc
T
Tw
Te(1)
Te(2)
Te(3)
Te(4)
Te(5)
Teo
0.
.05
.10
.15
.20
TIME, sec, (X= 1.57E+00 m, INDEX= 35)



ORAC02: 3.1m, 7T, 16.7ms, 250A, 110mJ/cc
CONDUCTOR HEAT GENE ION, Qgenc, W/m
30
20
10
0
0.
.05
.10
.15
.20
TIME, sec, (X= 1.57E+00 m, INDEX= 35)



ORACØ2: 3.1m, 7T, 16.7ms, 250A, 110mJ/cc
3000
2500
2000
1500
1000
500
CONDUCTOR H.T. COEF., HTC, W/m**2 deg.K
Ø.
.05
.10
.15
.20
TIME, sec, (X= 1.57E+00 m, INDEX= 35)

QUESTIONS

- Code is apparently not able to calculate multiple stability with the symmetric flow geometry.

  Multiple stability can be obtained if heating is near one end of conductor.

- Calculated stability is lower than measured.

  Code results are being compared to FENIX experimental results in current sharing region.