Institutt for energiteknikk
OECD HALDEN REACTOR PROJECT

HALDEN LOCA TEST SERIES
TRIAL RUNS-IFA-650.1

Erik Kolstad

Review meeting. Argonne. *July, 2003*

File:

LOCA TRIAL RUNS – IFA-650.1

Content

- Background / Objectives
- Test facility / Instrumentation
  - Test rig / rod
  - Outer loop
- Pre-test code calculations
- Trial runs / results
  800 °C – 2 runs
  1100 °C – 4 runs
- Summary

Loss of Coolant Studies

The move to high burnup and the introduction of new cladding materials have generated a need to re-examine the safety criteria for loss-of-coolant accidents and to verify their continued validity. The integral in-pile tests in the Halden reactor will address LOCA issues using ex-LWR high burnup fuel segments. The Halden experiment will focus on effects that are different from those obtained in out-of-reactor tests.

Some Halden Investigations in the Areas Thermal-Hydraulics, Critical Heat Transfer and LOCA

1963 - 68 Experiments on natural convection flow instabilities and dry-out limit

1965 - 72 Dry-out experiments in natural convection flow channels

1979 - 83 Safety-related tests. Blow-down, heatup & quench behaviour of
511 nuclear rods and electric simulators. Thermal response studies

1982 - 85 Safety-related tests. Blow-down, heatup & quench behaviour of
54x nuclear rods and electric simulators. Ballooning and rod-to-rod interaction studies

1996 - 98 Short-term dry-out test series

File:

Halden LOCA Experiment (IFA-650)

(USNRC/EPRI/EDF/FRAMATOM-ANP/GNF /IRSN)

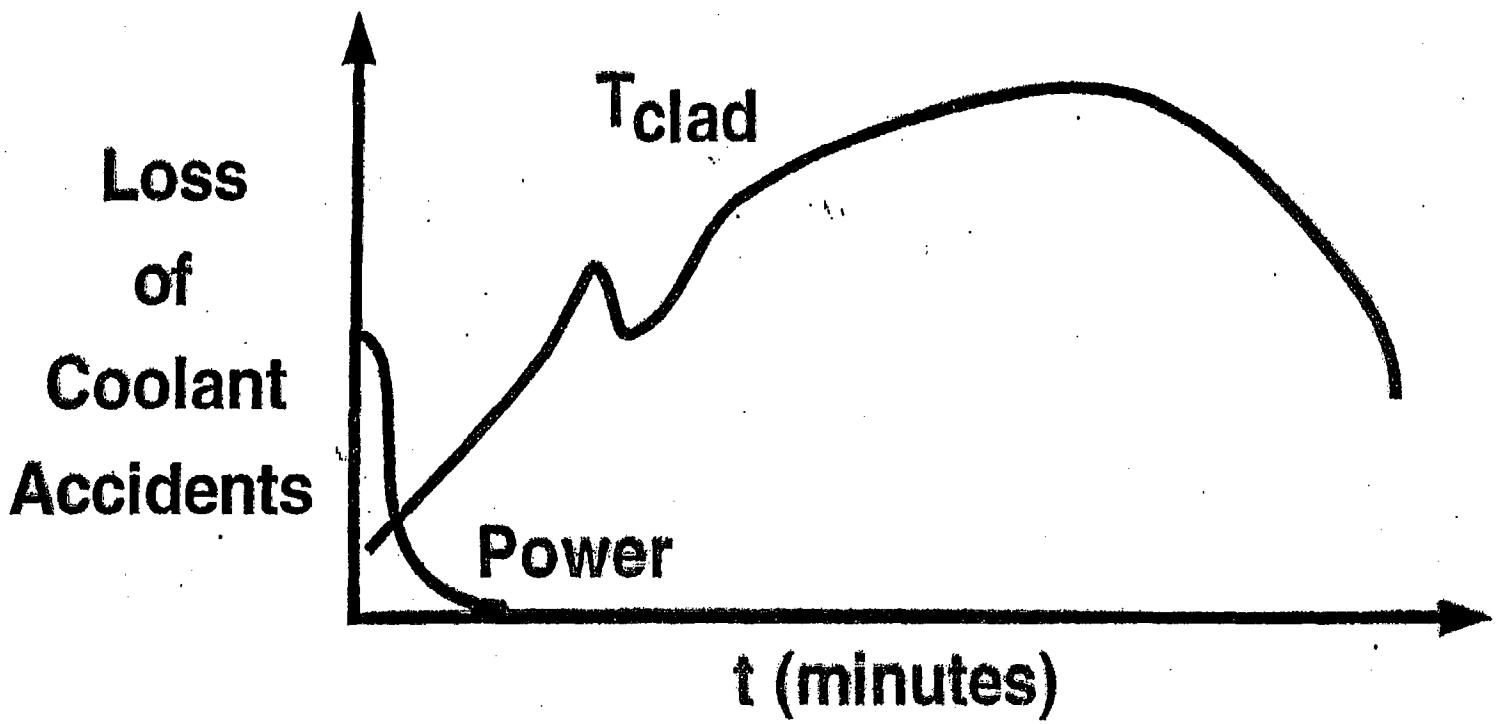
Primary objectives

1) Measure the extent of fuel (fragment) relocation into the ballooned region and evaluate its possible effect on cladding temperature and oxidation

2) Investigate the extent (if any) of - "secondary transient hydriding" - on the inner side of the cladding above and below the burst region

LOCA (1)

- *Loss Of Coolant Accident*
- *3 Phases:*
  - *Blowdown (fuel/core uncovered), decompression*
  - *Refill (ECCS systems start)*
  - *Reflood (water level above core top)*
- *Timing: uncovery, quenching, long-term cooling*
- *Fuel temp. rises --> cladding oxidation and hydriding: embrittlement (melting) of cladding --> fragmentation*
- → *Safety criteria:*
  - *Max. fuel temp. (PCT) not to exceed 2200 F (1204 C)*
  - *Oxidation of cladding not to exceed 17% of total clad thickness*
- *Rod swelling/ballooning may endanger core geometry / coolability*
- → *Safety requirement: calculated geometry changes still warrant core cooling*


Loss
of
Coolant
Accidents
T_{clad}
Power
t (minutes)

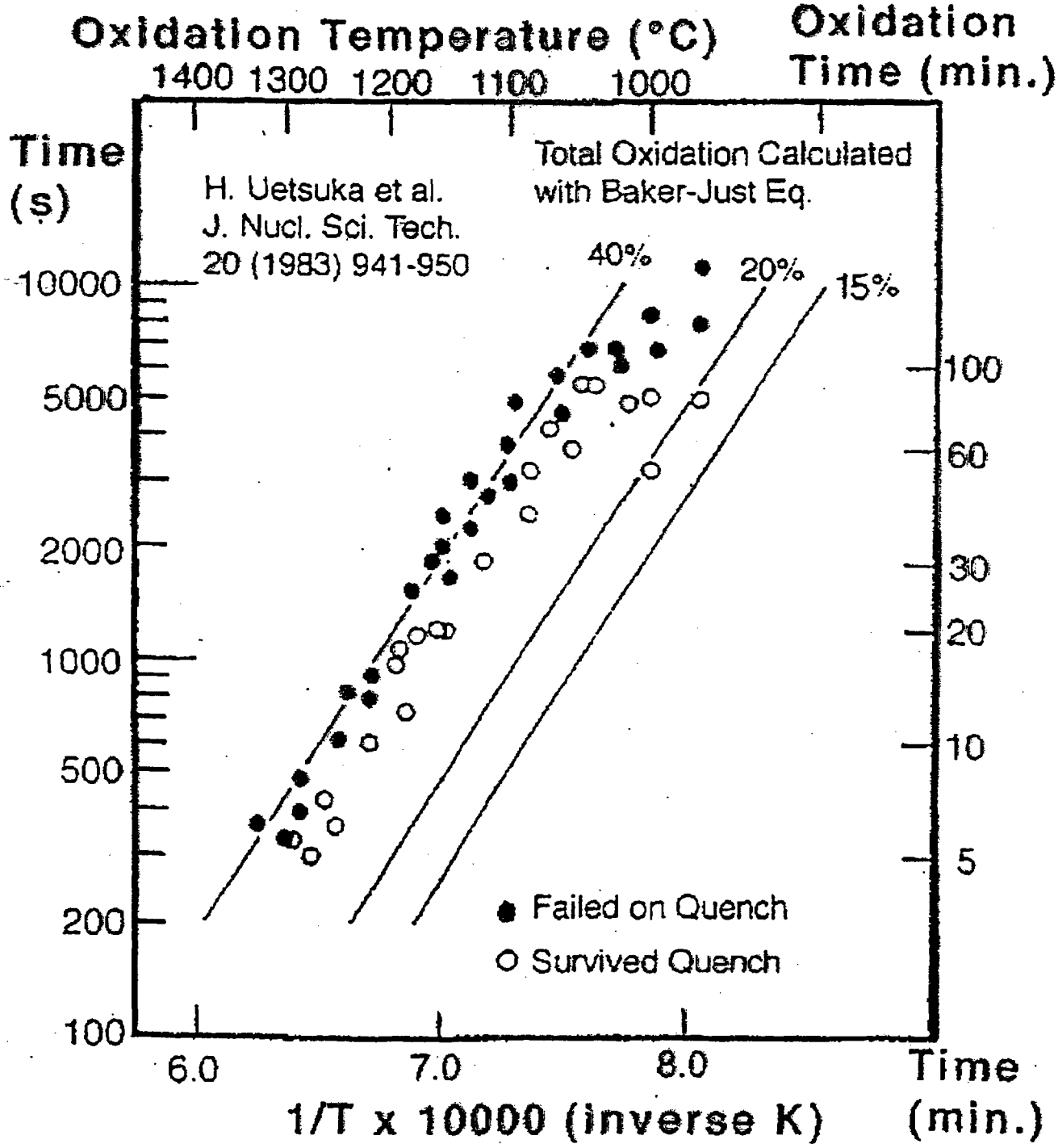
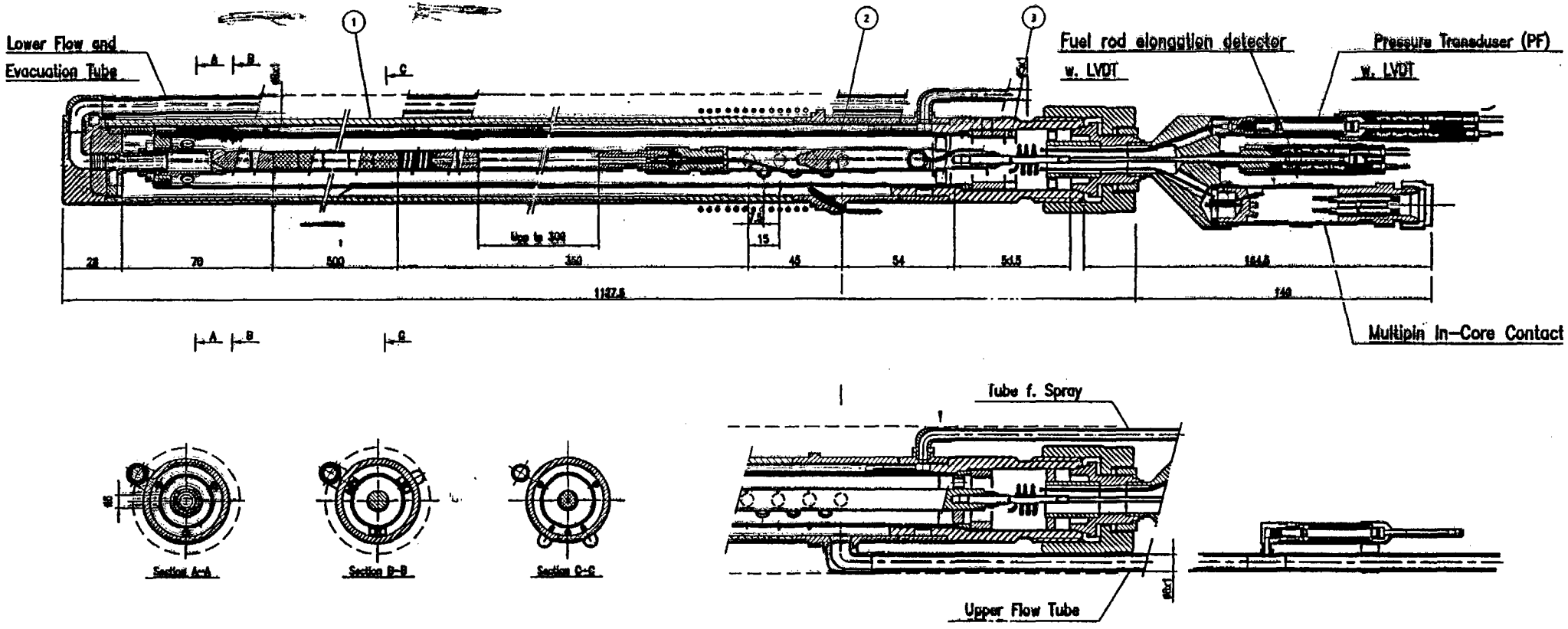
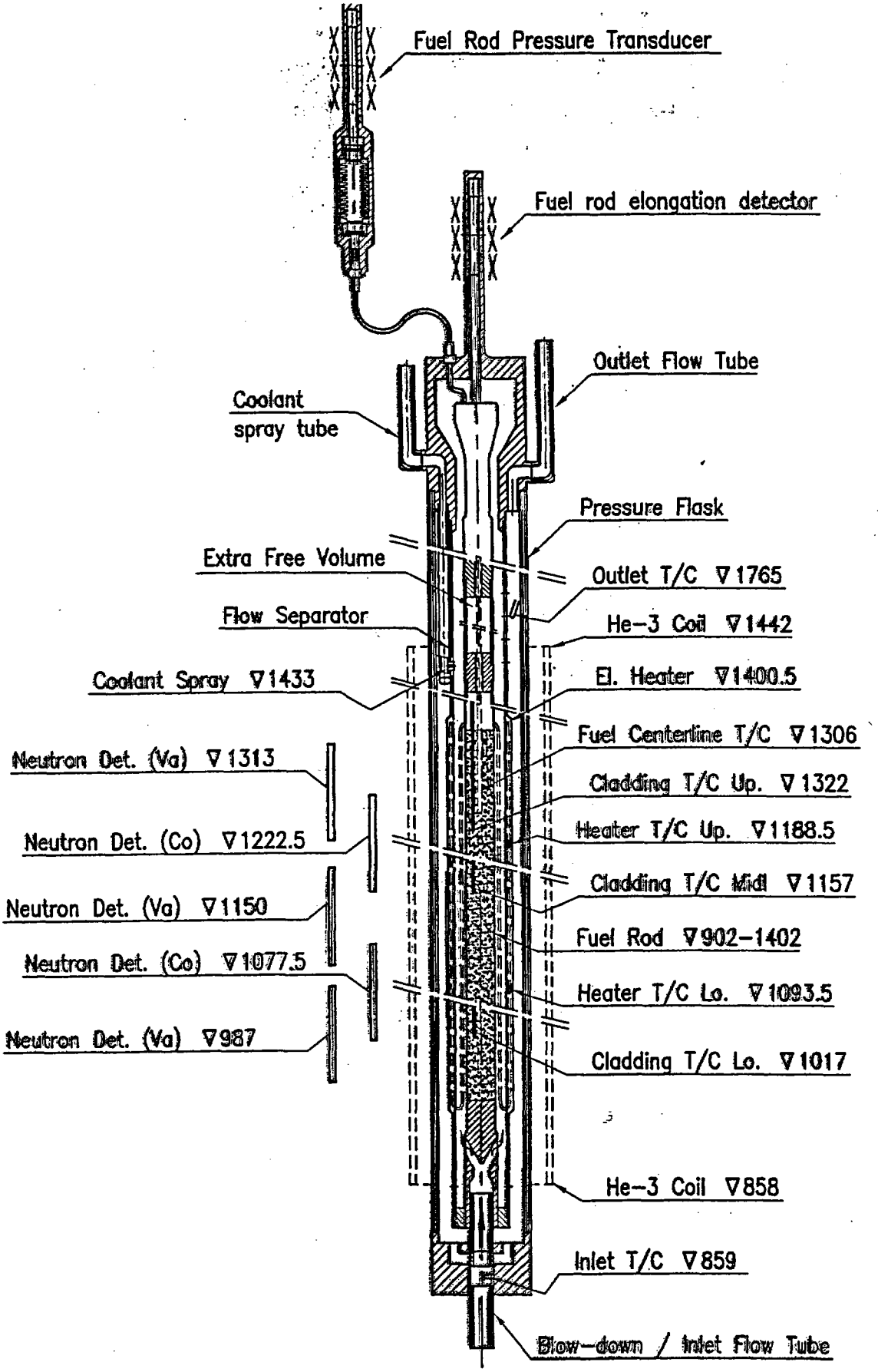


Figure X, Failure versus non-failure boundary for unconstrained

Conditions and Schedule

- Fresh rods for practicing
  - Low pressure for studying of required LHGR, flow and power control, spray, control of PCT, test termination etc.
  - Rod with overpressure to assess ballooning capabilities
  - More cladding TCs
  - Fuel TC
- Two high burnup PWR rods
  - Ca. 150 bar pressure at operating conditions
  - Possibly two temperature levels (800 / 1100)
- Two high burnup BWR rods
- One medium burnup BWR rod


Lower Flow and
Evacuation Tube
Fuel rod elongation detector
w. LVDT
Pressure Transduser (PF)
w. LVDT
Multipin In-Core Contact
Section A-A
Section B-B
Section C-C
Tube f. Spray
Upper Flow Tube



Schematic of LOCA Test Rig

with Instrument levels

LOCA Trial Runs - IFA-650.1

Power calibrations (17 MW & 18 MW)

$Q_A = KG \cdot ND$ $\quad ND = (ND1+ND2+ND3)/3$

$KG = Q_A/ND$ $\quad$ (kW/nA)

$LHGR = Q_A/LF$ $\quad LF$ = Fuel length = 50 cm

(Gamma heat ~5 - 6%)

KG (no He^3) = 0.90 KG (40 bar He^3)

Most runs without He^3

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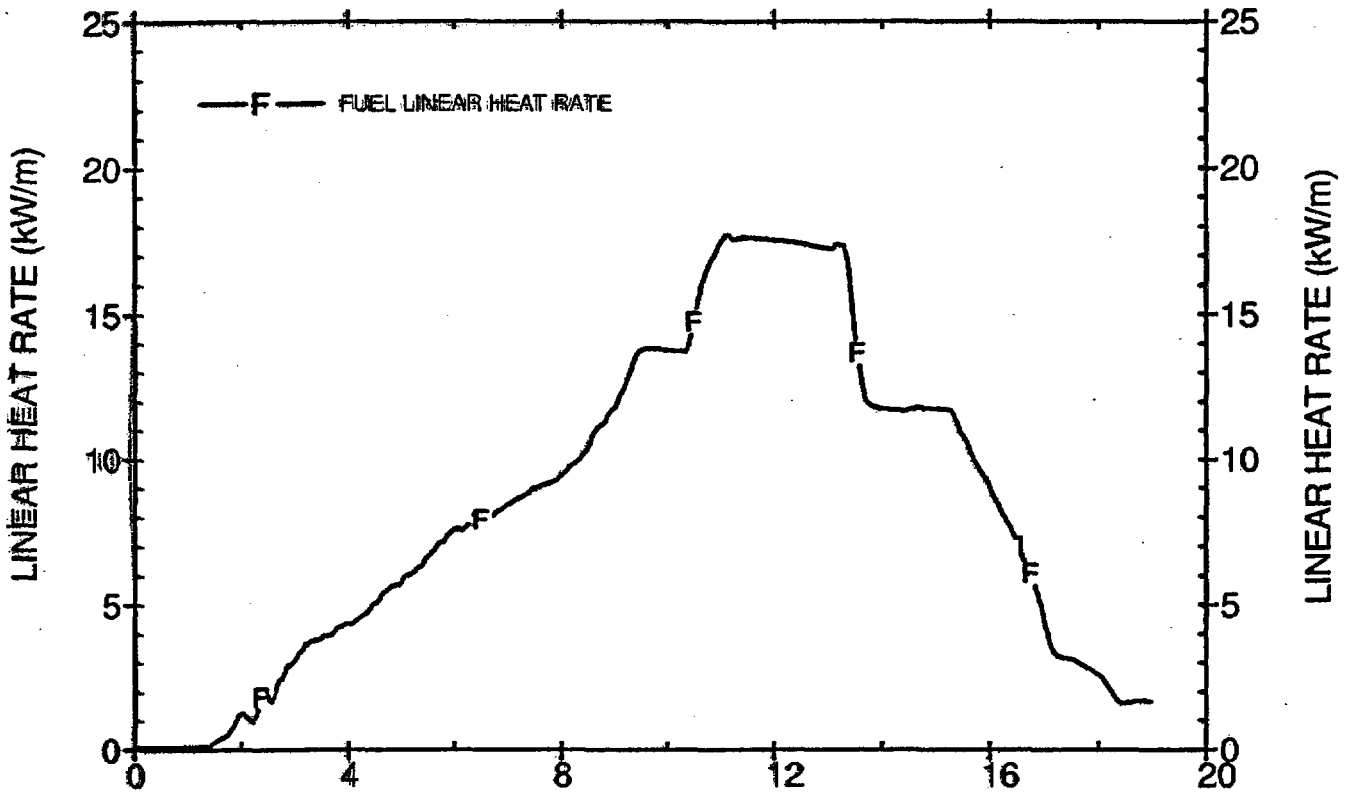
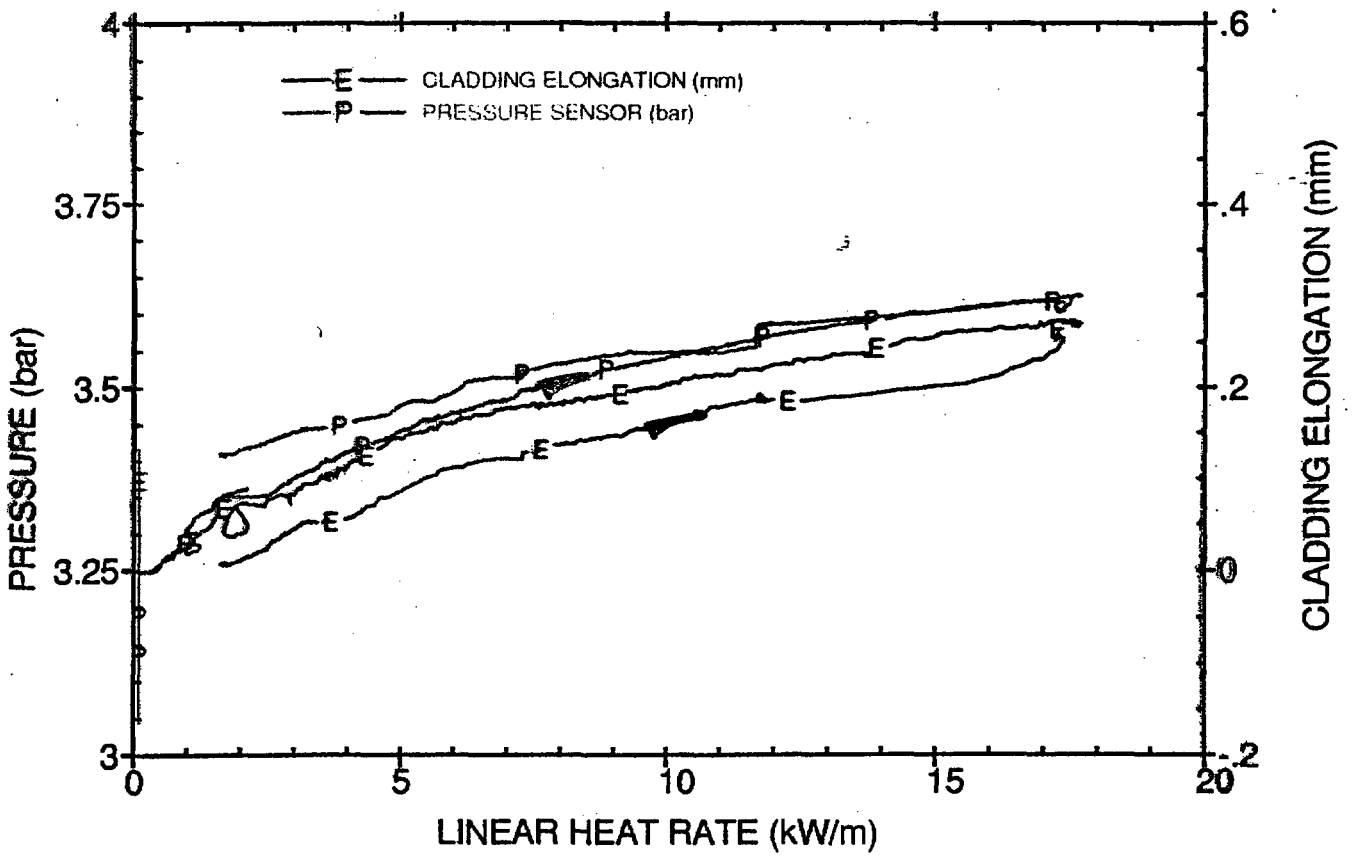
LOCA Trial Runs, IFA-650.1





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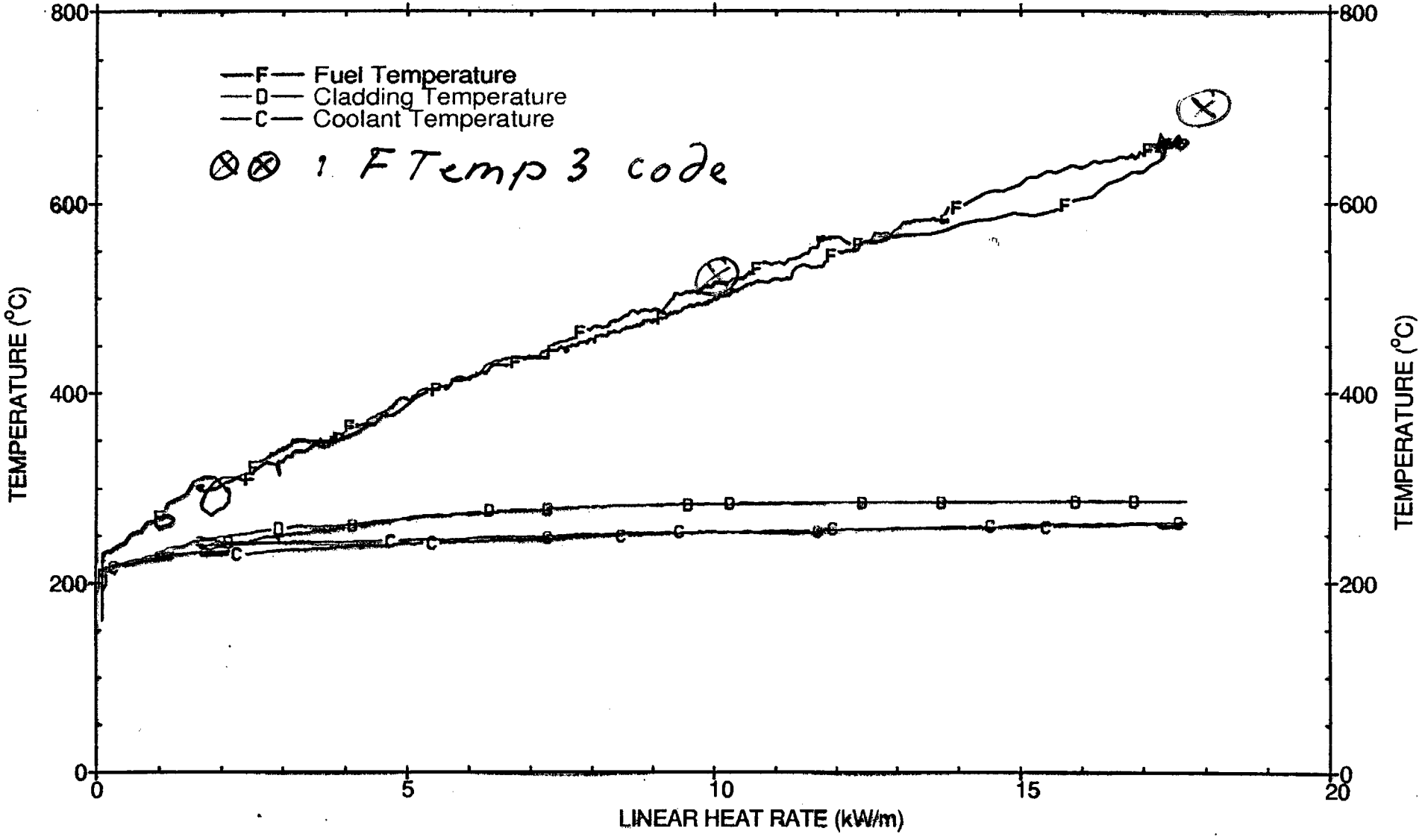
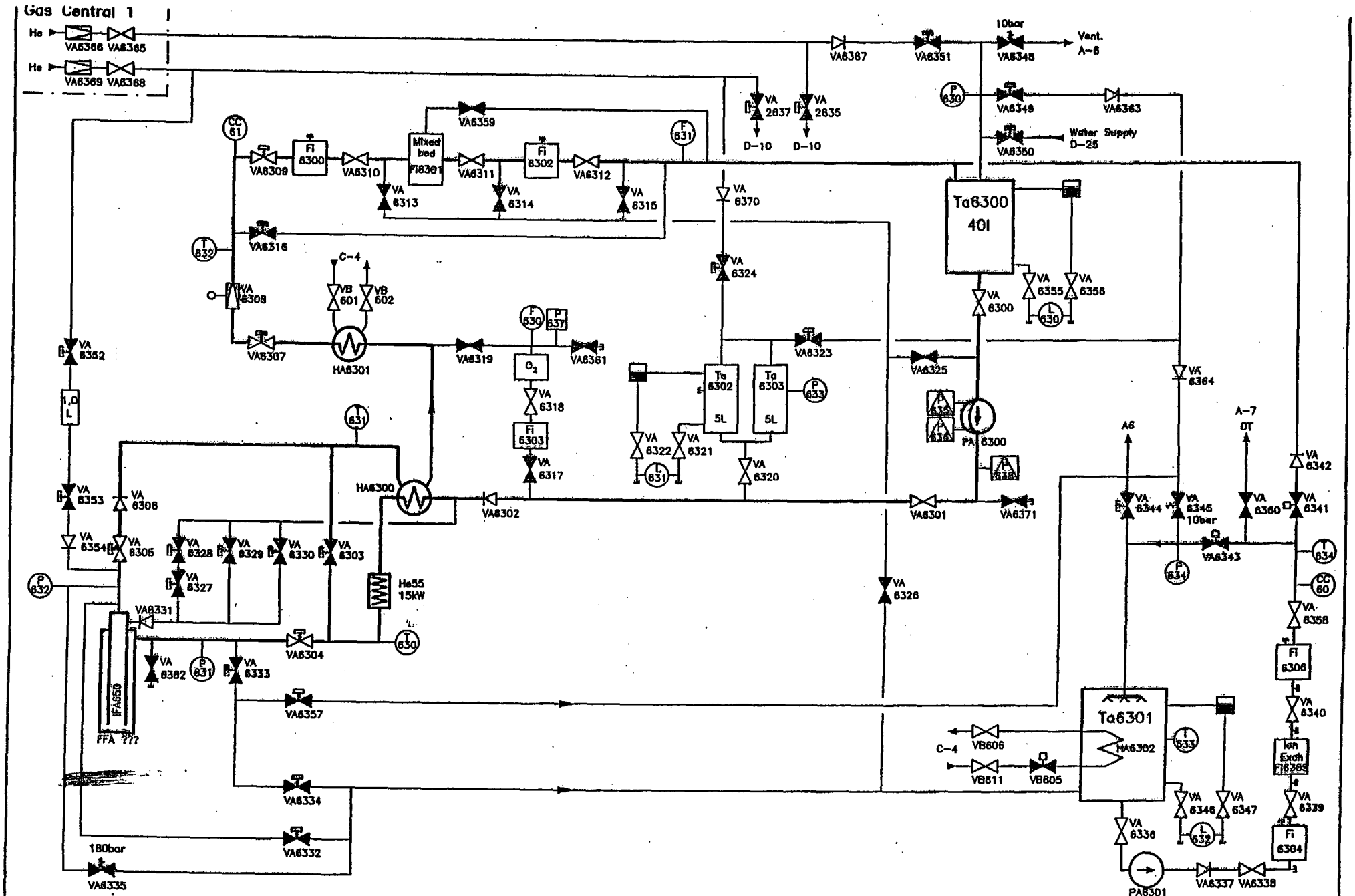
LOCA Trial Runs, IFA-650.1,





Drew.No.	Date : 010110	Approved	Changed 021203 RSk	INSTITUTT FOR ENERGITEKNIKK OECD HALDEN REACTOR PROJECT HALDEN NORWAY	Name: Loop13, Heavy Water High Press.	SS No.: D-20
Repl.for.	Drawn : RSk	Checked Exp.Dep.	Changed 030131 RSk			
	Checked :		Changed			

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LOCA Trial Runs - IFA-650.1

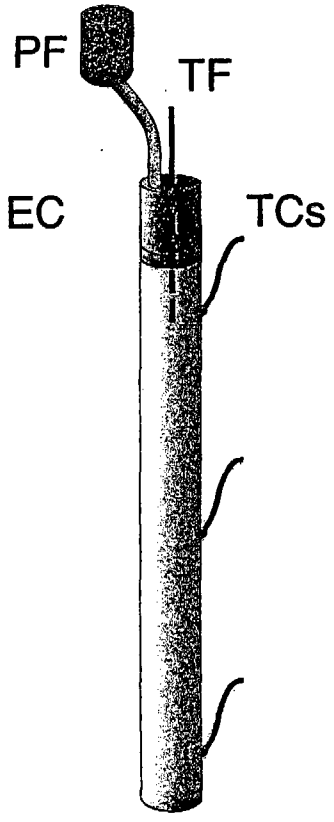
Test rig instrumentation

- 3 neutron detector (Va)
- 2 Co-flux detectors
- 2 inlet TCs
- 2 outlet TCs
- 1 He^3 coil
- Heated flow separator (w/TCs)
- Flow meter (outer circuit)

Design Features, cont.

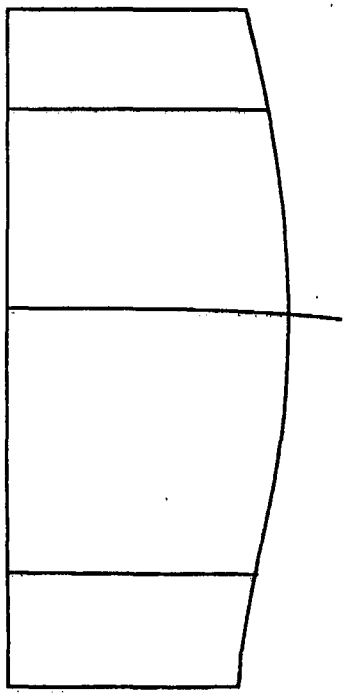
- Instrumentation
  - cladding surface thermocouples
  - cladding extensometer
  - pressure sensor
  - fuel thermocouple (fresh fuel only)
  - fast response neutron detector
- Rod pressure will be close to the normal operating coolant pressure
- The free volume should be large, representative of the remaining volume in a full-scale fuel rod (≤ 15 cm^3)
- No axial constraint will be provided, but the design may include a grid piece to assess the effect on cooling

LOCA-TEST IFA-650.1



Rod instrumentation

Axial power distribution



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LOCA Trial Runs - IFA-650.1

Test rod/instrumentation

Rod (Zr-4)

Length:	500 mm
O.D/I.D:	9.50/8.36 mm
Gap size:	70µmm
Enrichment:	4 w/o U-235
Fill pressure:	2 bar He
Free volume:	15 cc

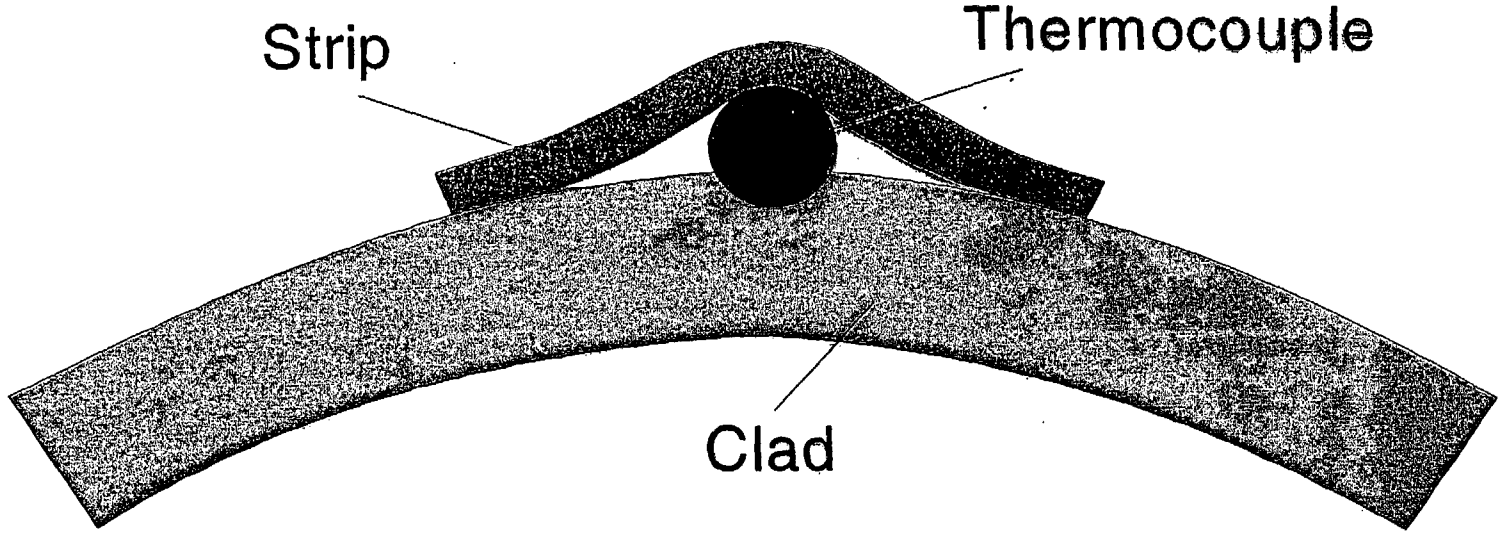
Dished pellets

Instrumentation

3 Clad TCs
1 Clad extensometer
1 Fuel thermocouple
1 Rod pressure sensor
2 Heater thermocouples

LOCA TESTER-IFA-650.1 OG IFA-650.2

Attachment of clad O.D. thermocouples



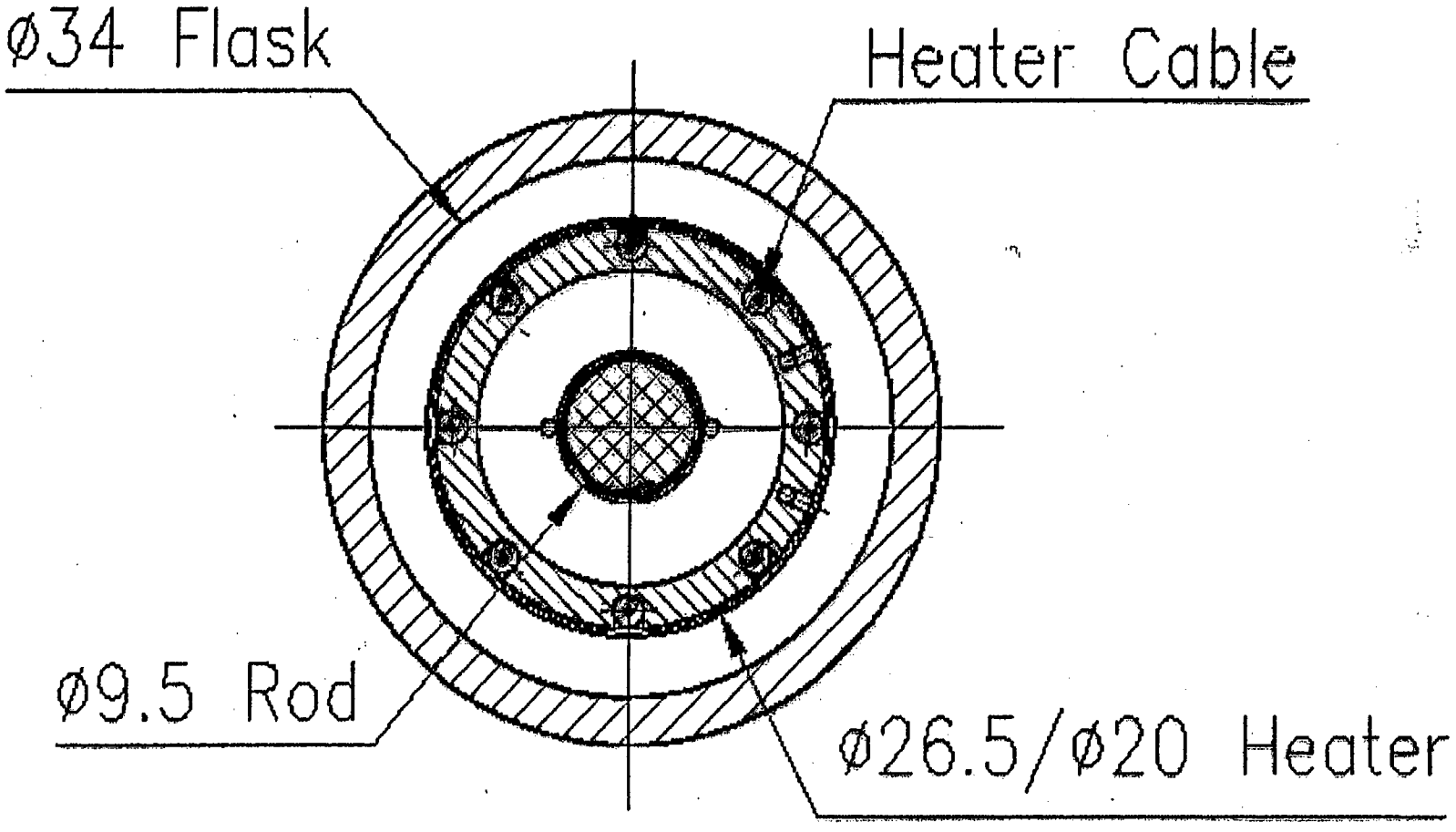
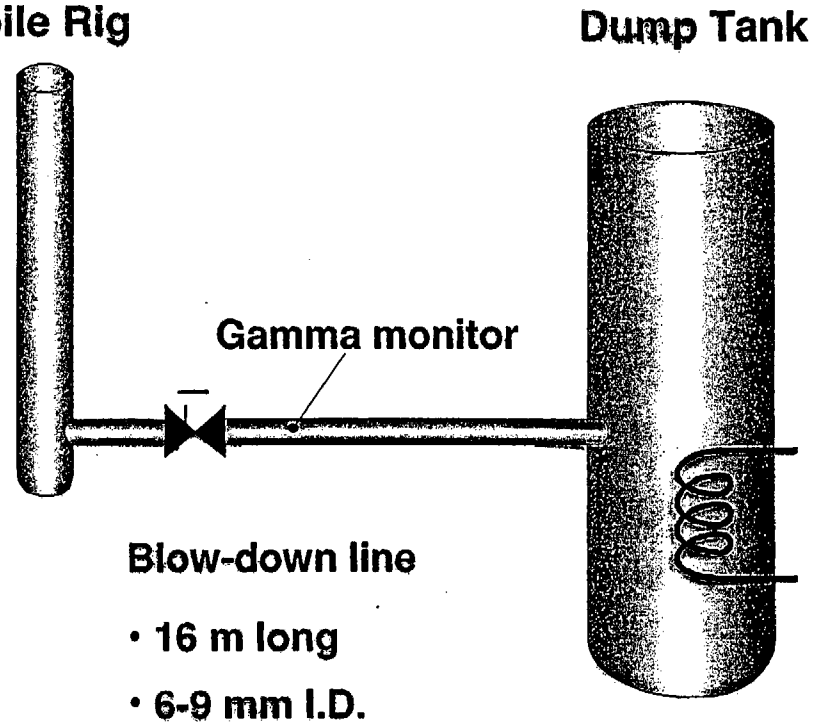


Figure 3. Cross sectional geometry of the fuel pin, flow separator and pressure tube.

LOCA TRIAL RUNS – IFA-650.1



1 liter
70 bar
Natural
circulation D_2O
(15-30 w/cm)

Blow-down line

- 16 m long
- 6-9 mm I.D.
- Gamma monitor
- Blow-down rate control

- Shielded tank
- Cooled
- Slight over-pressure (2-3 bar)
- Level gauge

LOCA Trial Runs - IFA-650.1

Pre-test code calculations

- TRAC - BF1 code (PSI)
- FRAPTRAN - GENFLOW (VTT)
- SCTEMP and ALGOR (Halden)

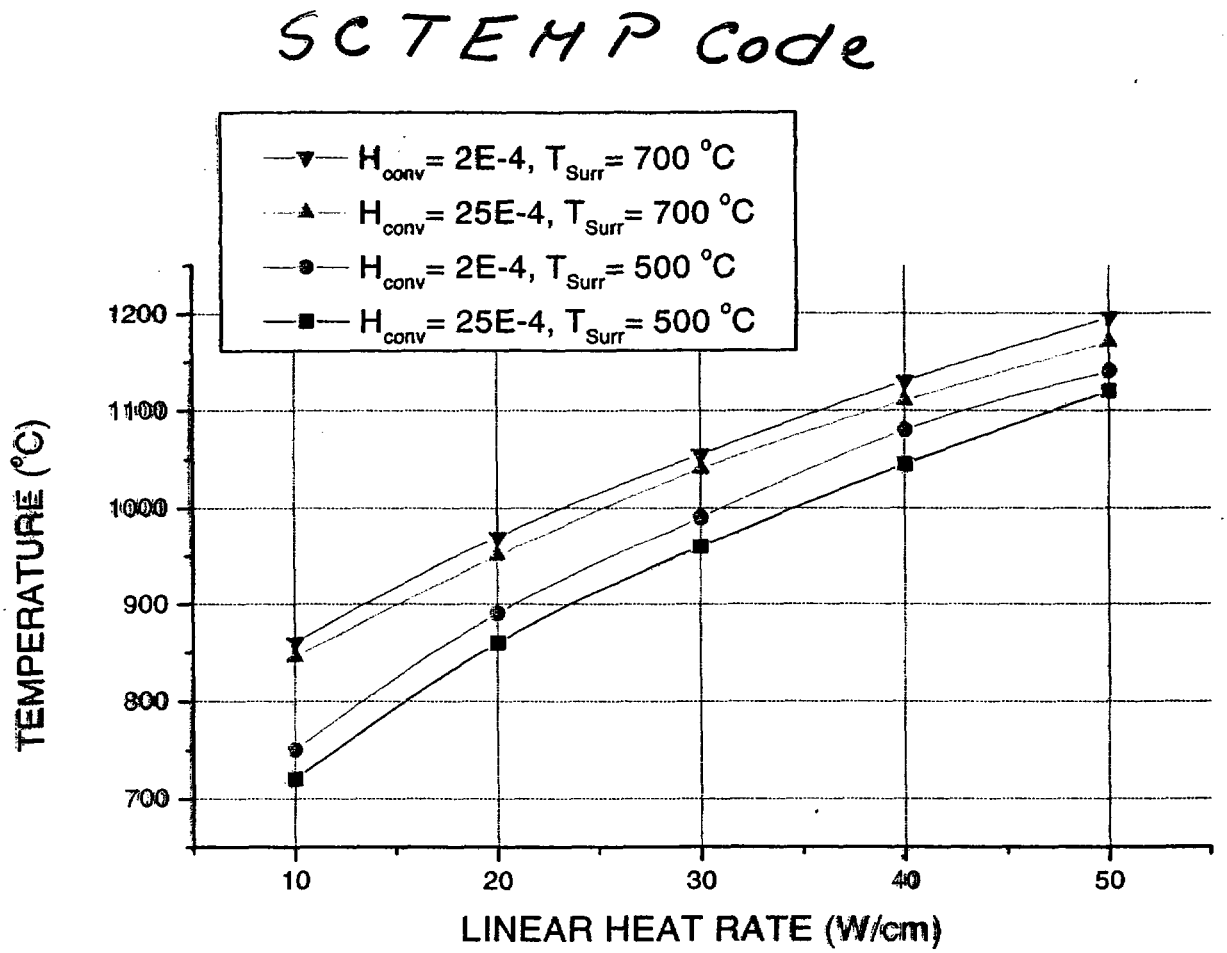


Figure 4. Maximum surface cladding temperature as a function of LHR using for different convective heat transfer coefficients and surroundings temperatures

LOCA-Tests-IFA-650.1

Cladding temperature transient control by:

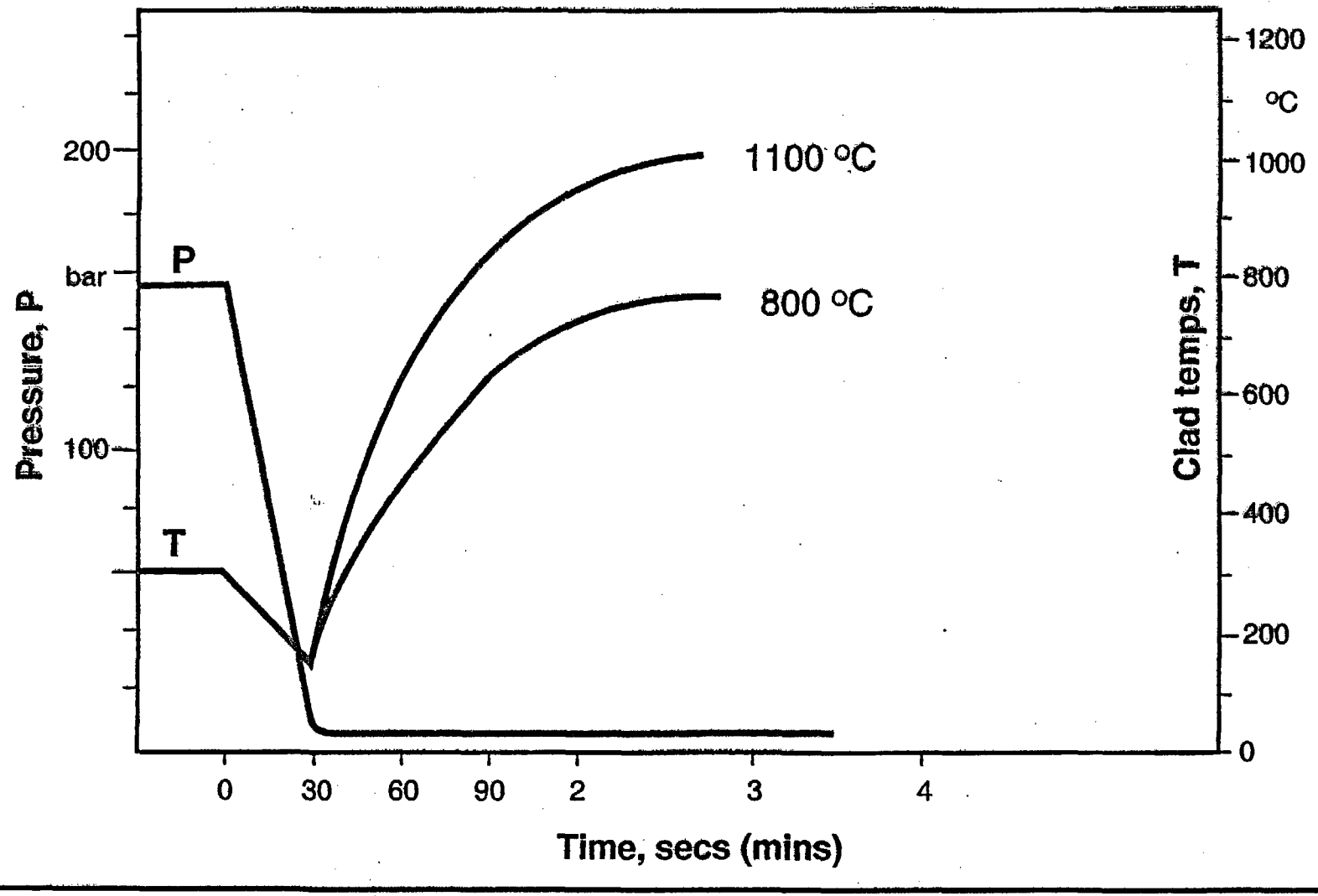
- Linear heat rate (LHR) (10 -40 W/cm)
- Spray system
- Heated flow separator (up to 20 W/cm)

LOCA-Tests-IFA-650.1

Test scheme for the first rod.

1 - Steady-state operation (10-50 W/cm) with loop 13 connected
2 - Disconnection of loop 13.Natural convection flow
3 - Blow-down (< 30 secs) (to dump tank)
4 - Heat-up (< 2 mins)
5 - Peak clad temperatures (PCT) 800-1100 degr.C
6 - Quench by spray. Disconnect dump tank
7 - Re-establishment of state 2 (and 1)
8 - Repeat and re-run

LOCA-TEST IFA-650.1



LOCA TRIAL RUNS – IFA-650.1

- Blow-down tests at zero power
- Power calibrations (~18 MW)
- Trial runs (5-6 MW)

<u>800 °C (2 runs)</u>

- 14 W/cm (rod) + 6 W/cm (heater) (~ 830 °C)
- 14 W/cm + 6 W/cm (~ 830 °C)

<u>1100 °C (4 runs)</u>

- 20 W/cm + 12 W/cm (heater) (~ 900 °C)
- 25 W/cm + 6 W/cm (~ 930 °C)
- 25 W/cm + 18 W/cm (~ 1030 °C)
- 30 W/cm + 20 W/cm (~ 1120 °C)

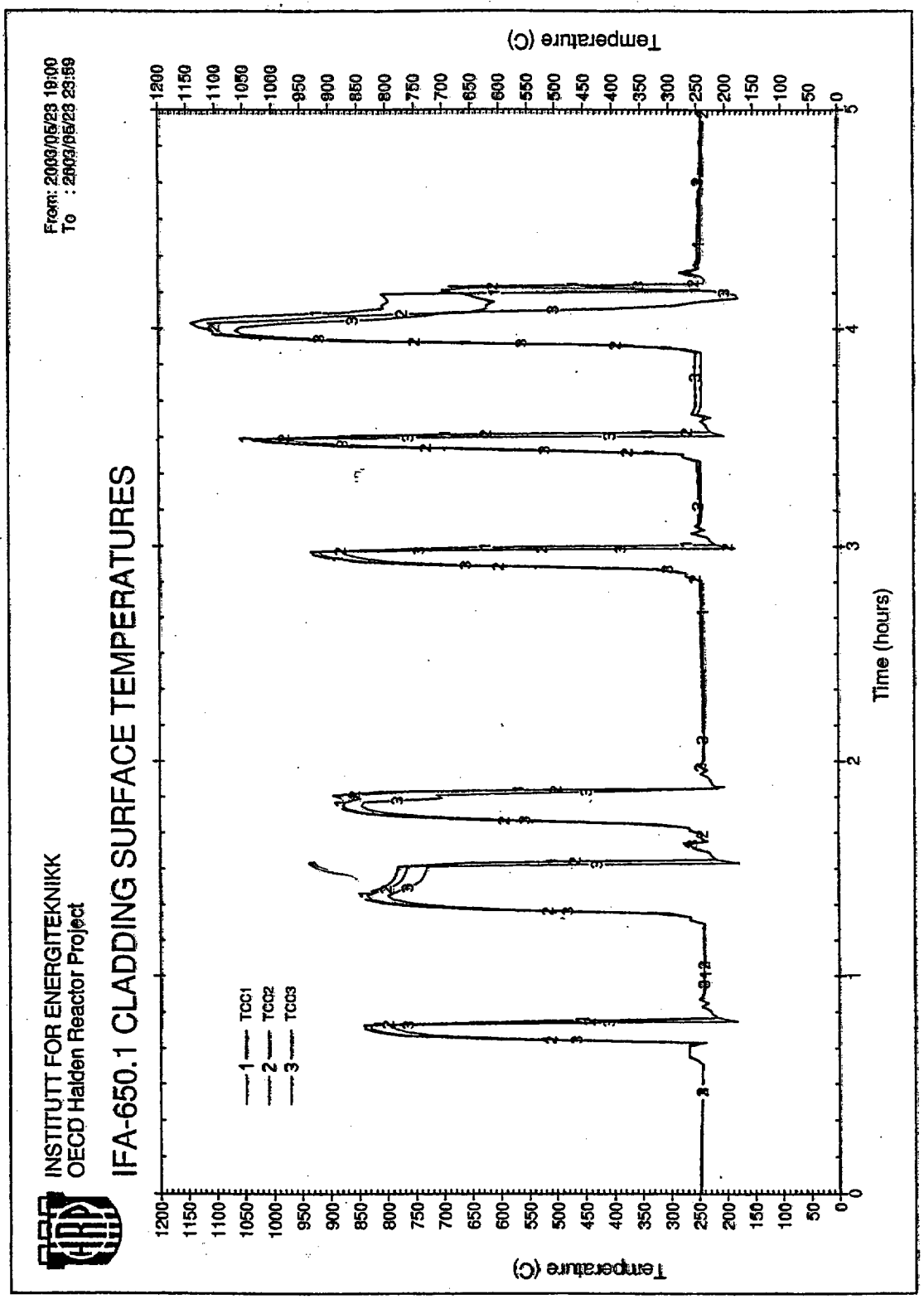


Figure 5 Cladding temperature in IFA-650.1.

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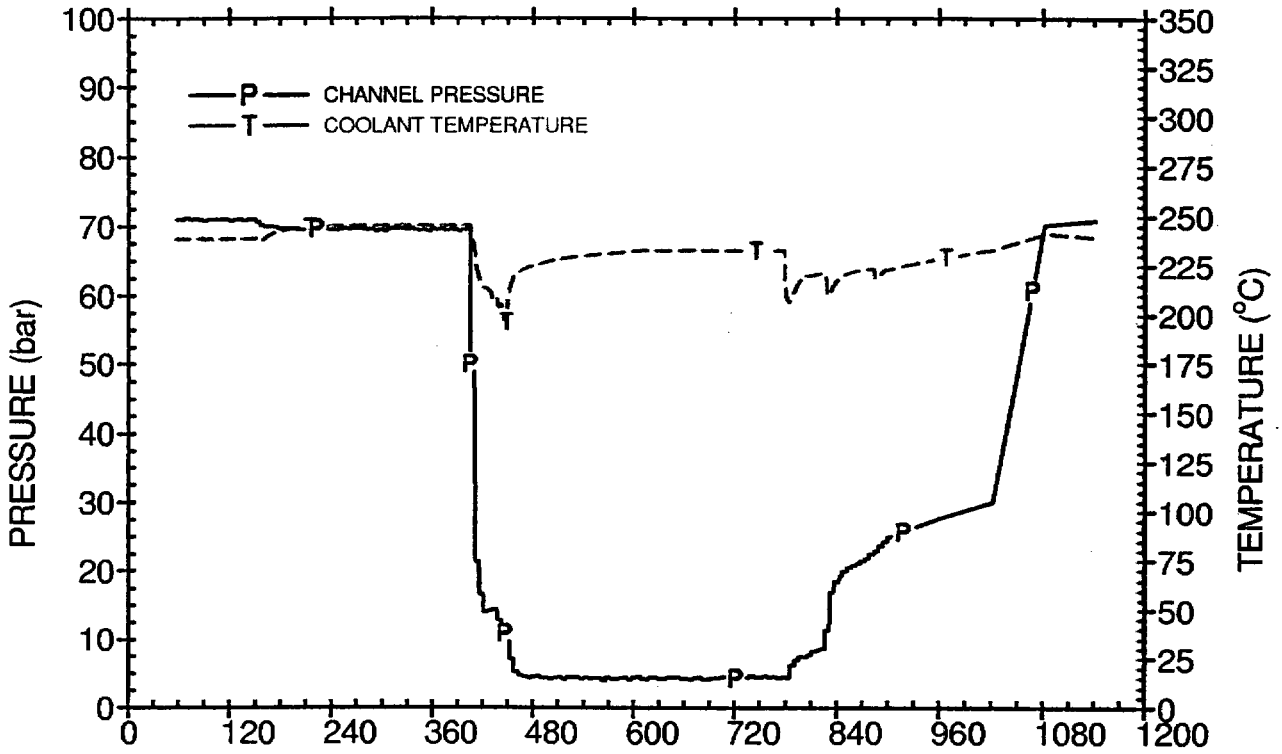
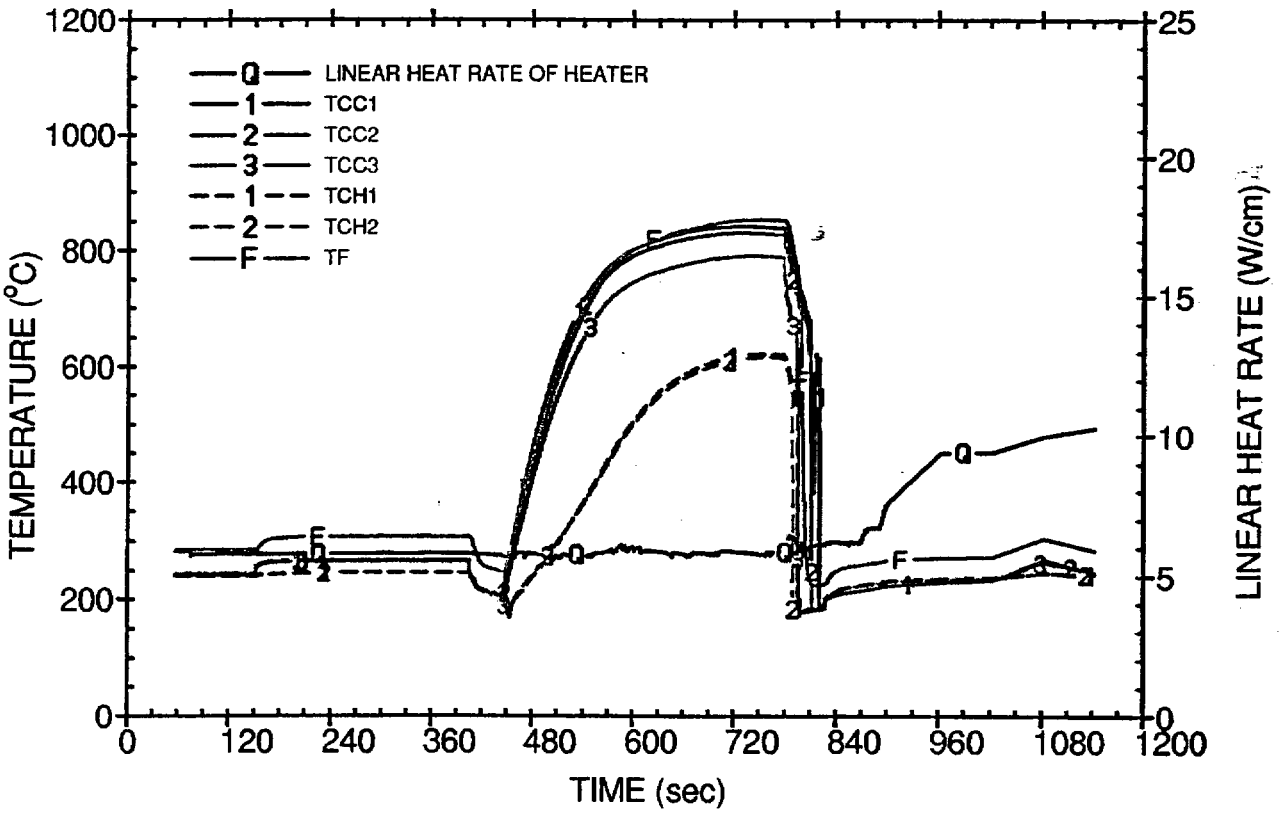
LOCA Trial Runs, IFA-650.1

1st Run, Q_{rod} = 14 W/cm, Q_{heater} = 6 W/cm, TF_{max} = 850°C





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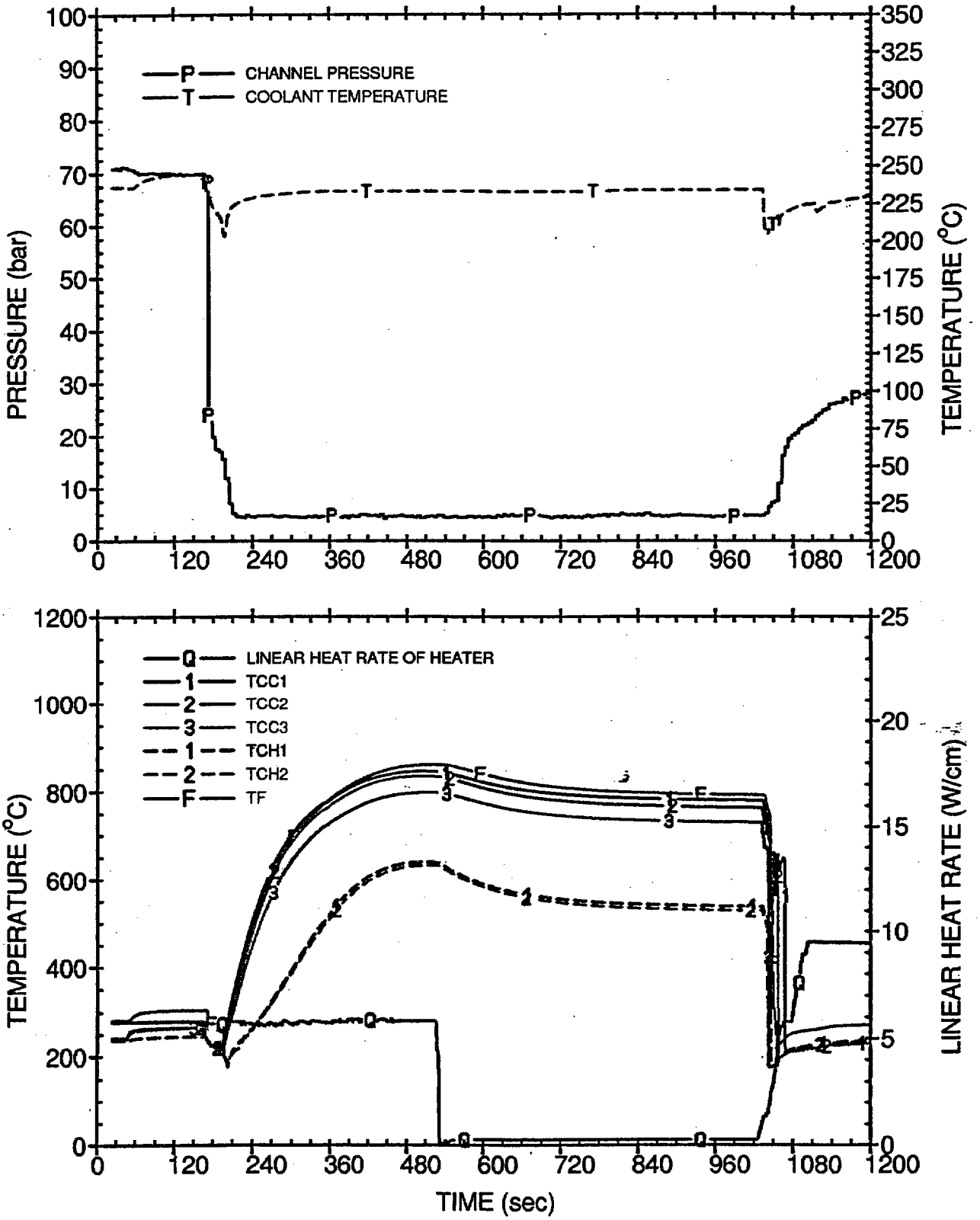
LOCA Trial Runs, IFA-650.1

2nd Run, Q_{rod} = 14 W/cm, Q_{heater} = 6 W/cm, TF_{max} = 910°C



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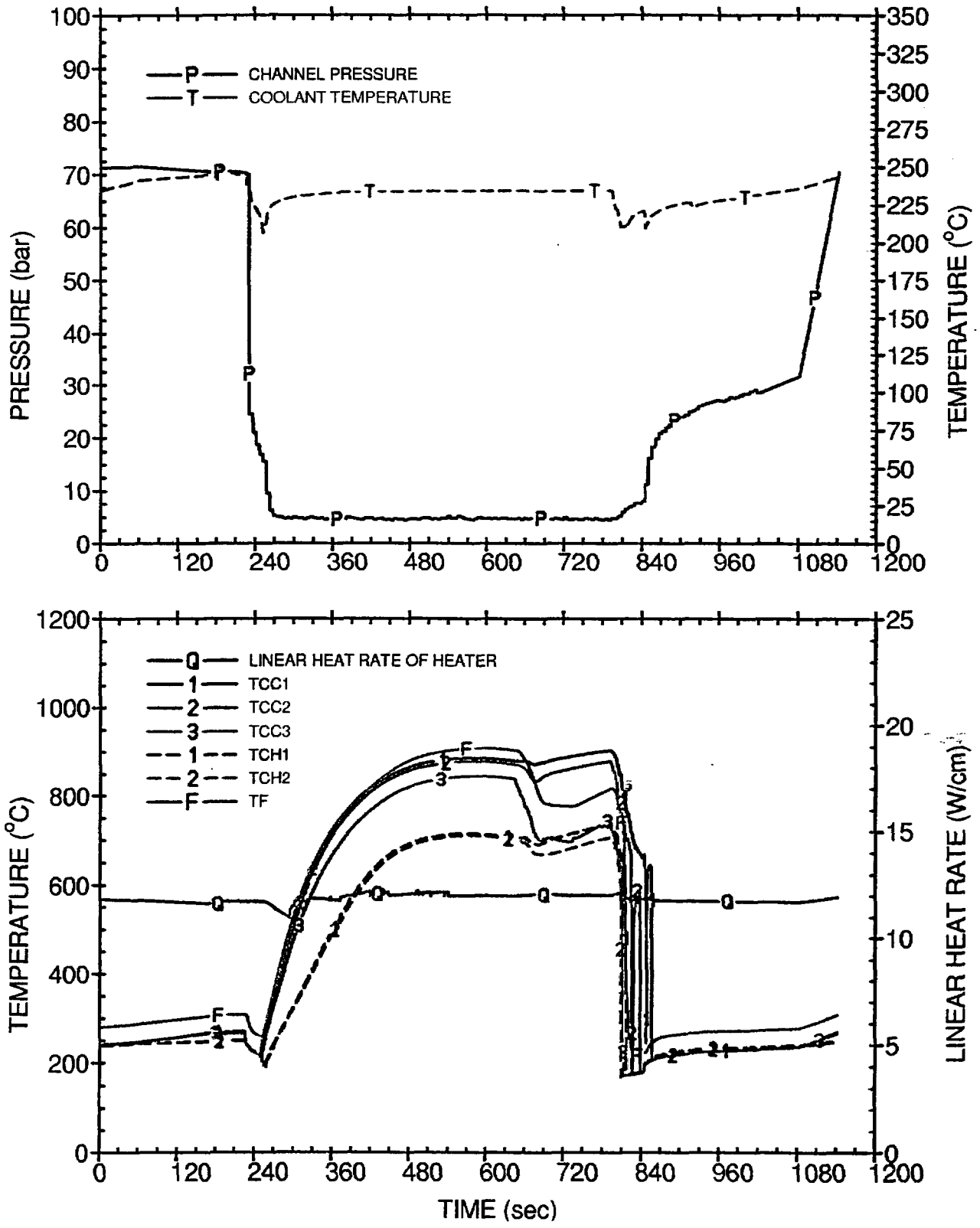
LOCA Trial Runs, IFA-650.1

3rd Run, Q_{rod} = 20 W/cm, Q_{heater} = 12 W/cm, TF_{max} = 910°C



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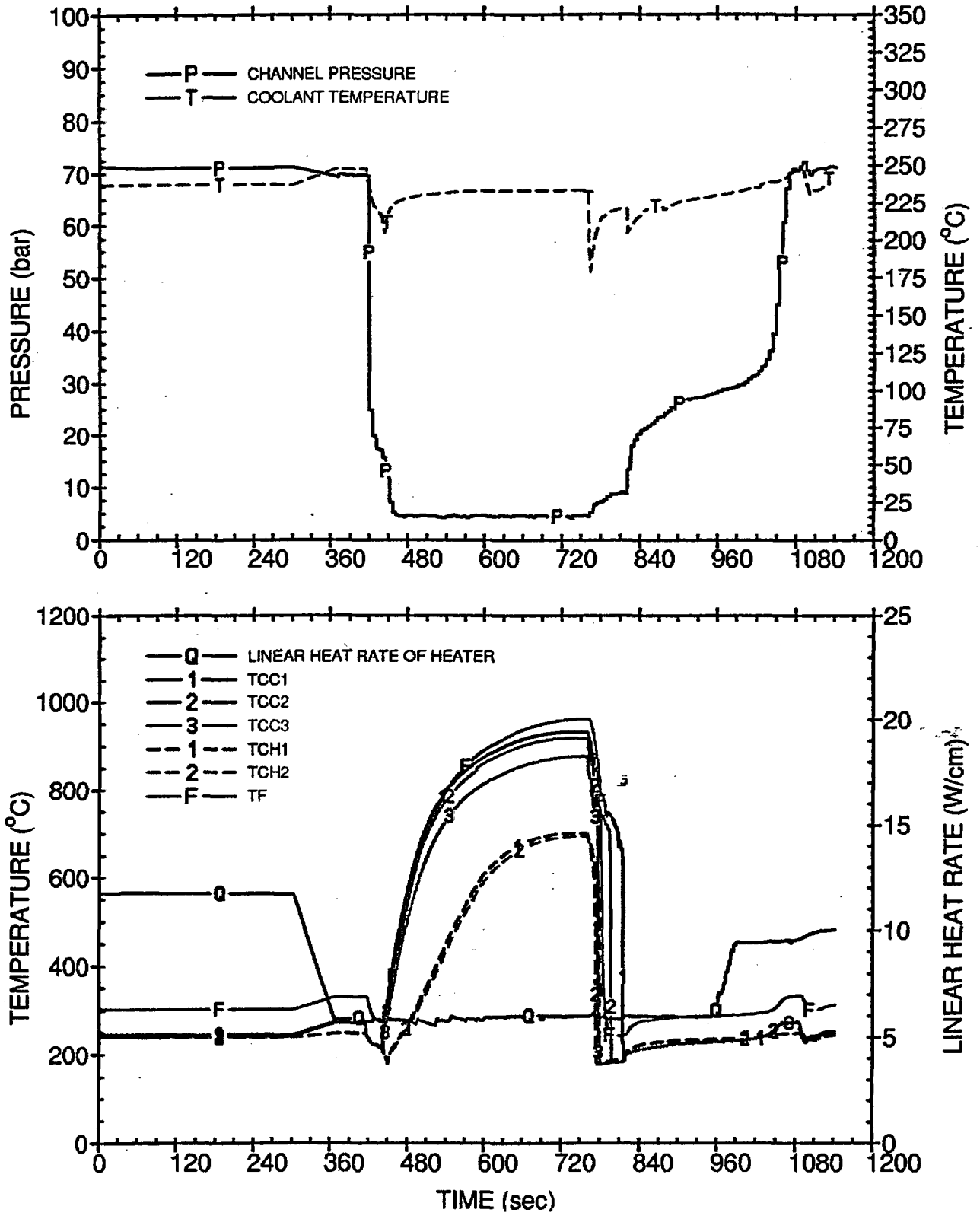
LOCA Trial Runs, IFA-650.1

4th Run, Q_{rod} = 25 W/cm, Q_{heater} = 6 W/cm, TF_{max} = 960°C



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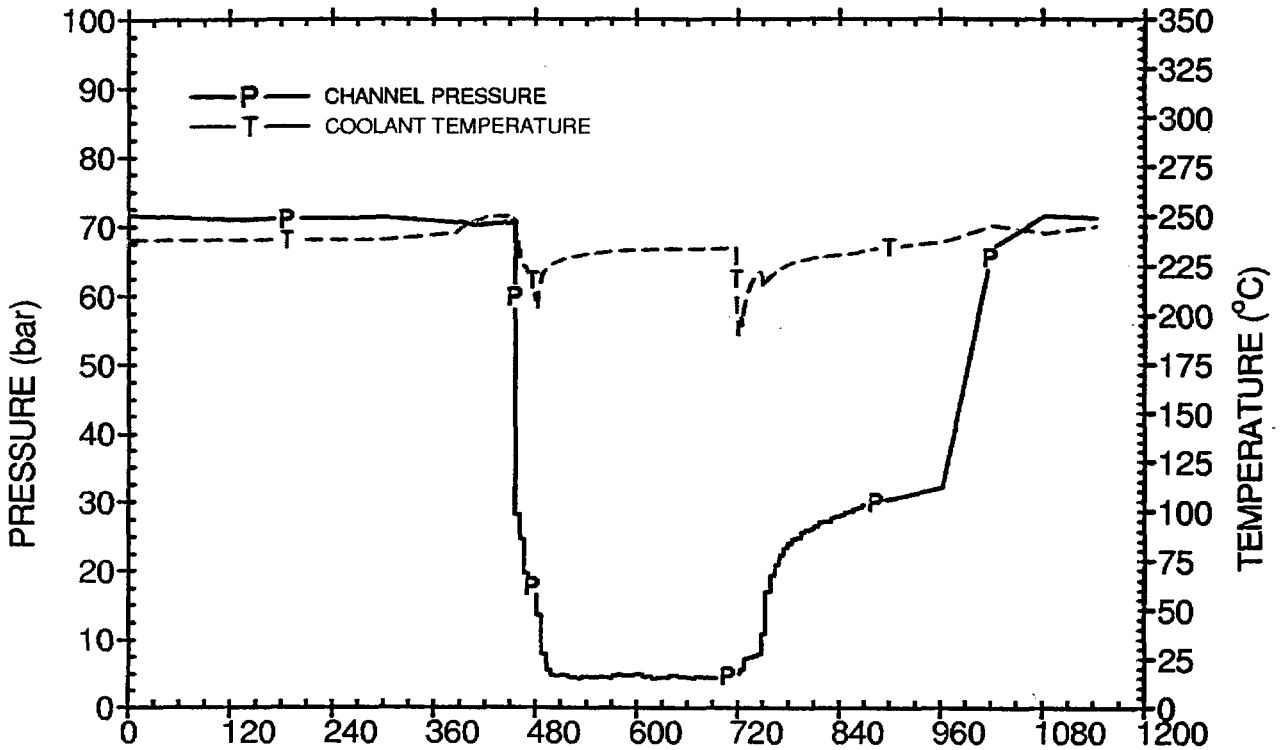
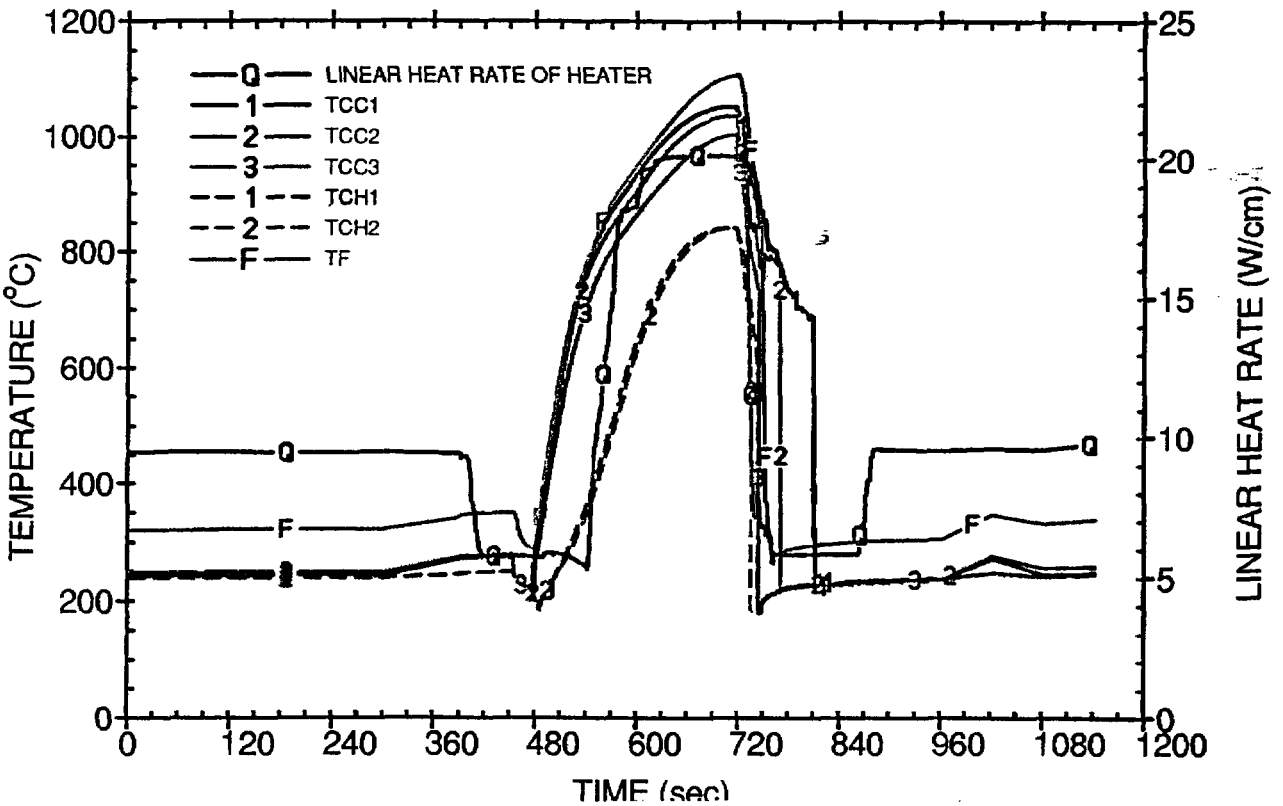
LOCA Trial Runs, IFA-650.1

5th Run, Q_{rod} = 25 W/cm, Q_{heater} = 20 W/cm, TF_{max} = 1100°C





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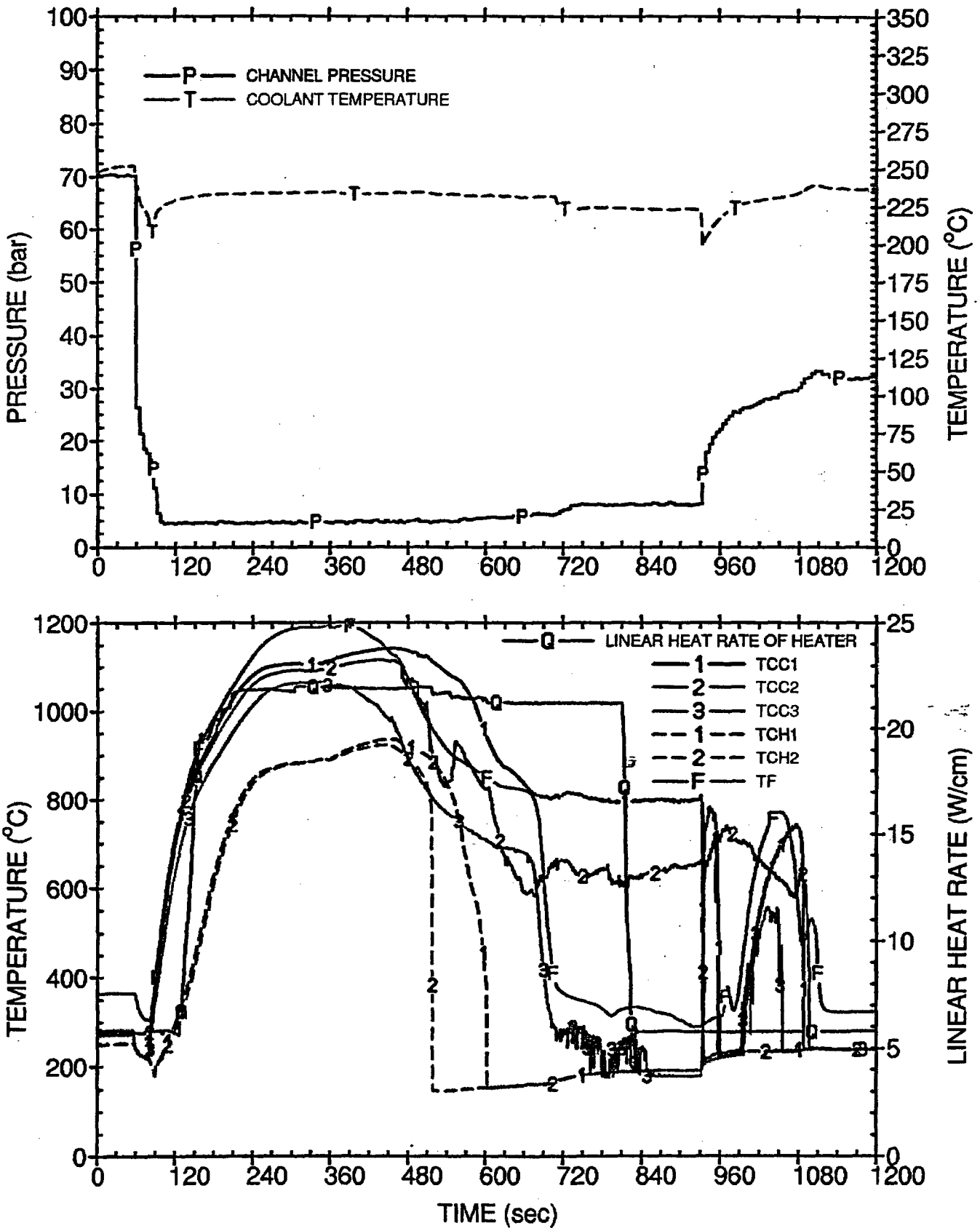
LOCA Trial Runs, IFA-650.1

6th Run, Q_{rod} = 30 W/cm, Q_{heater} = 22 W/cm, TF_{max} = 1200°C



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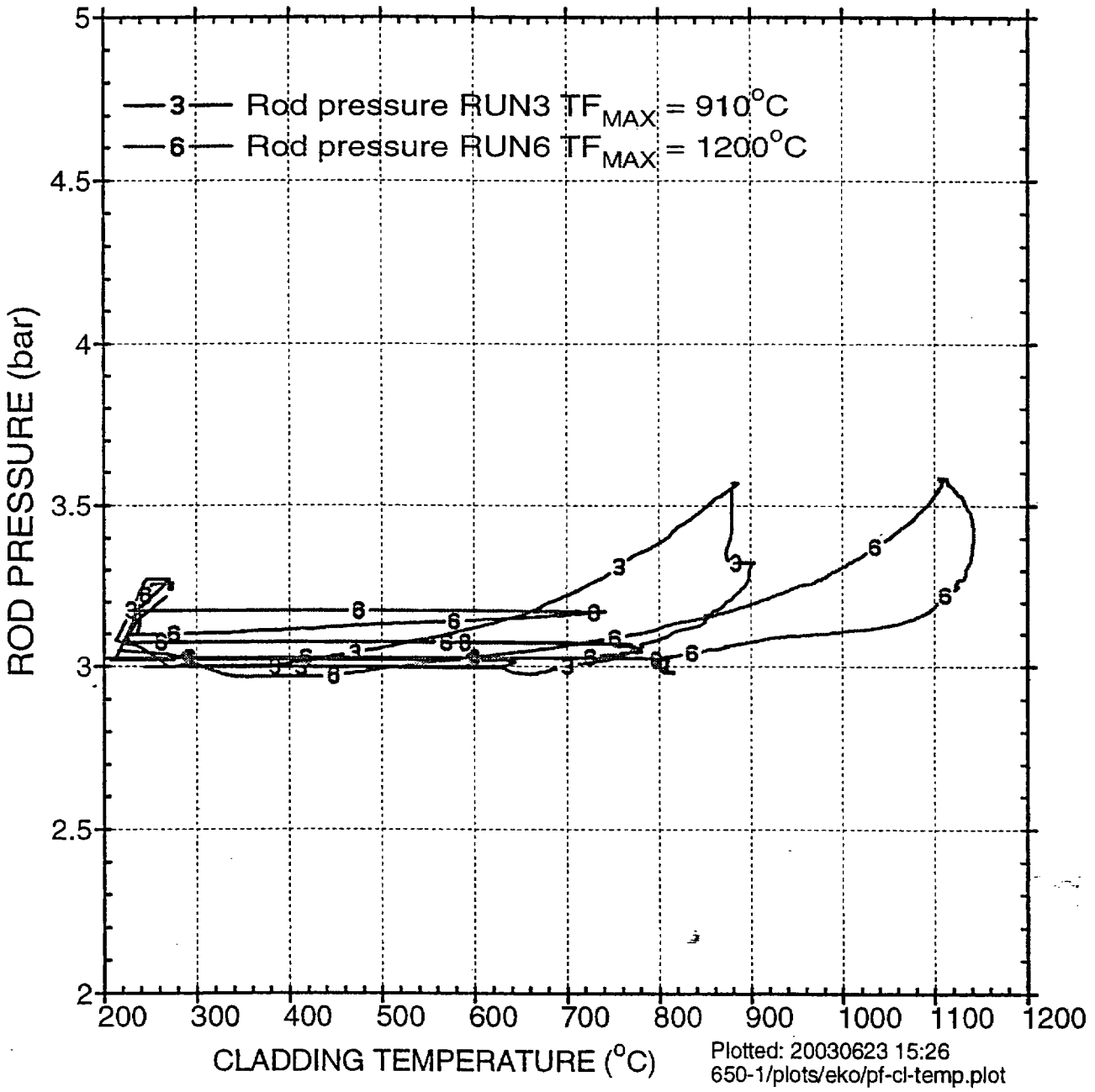
LOCA Trial Runs, IFA-650.1



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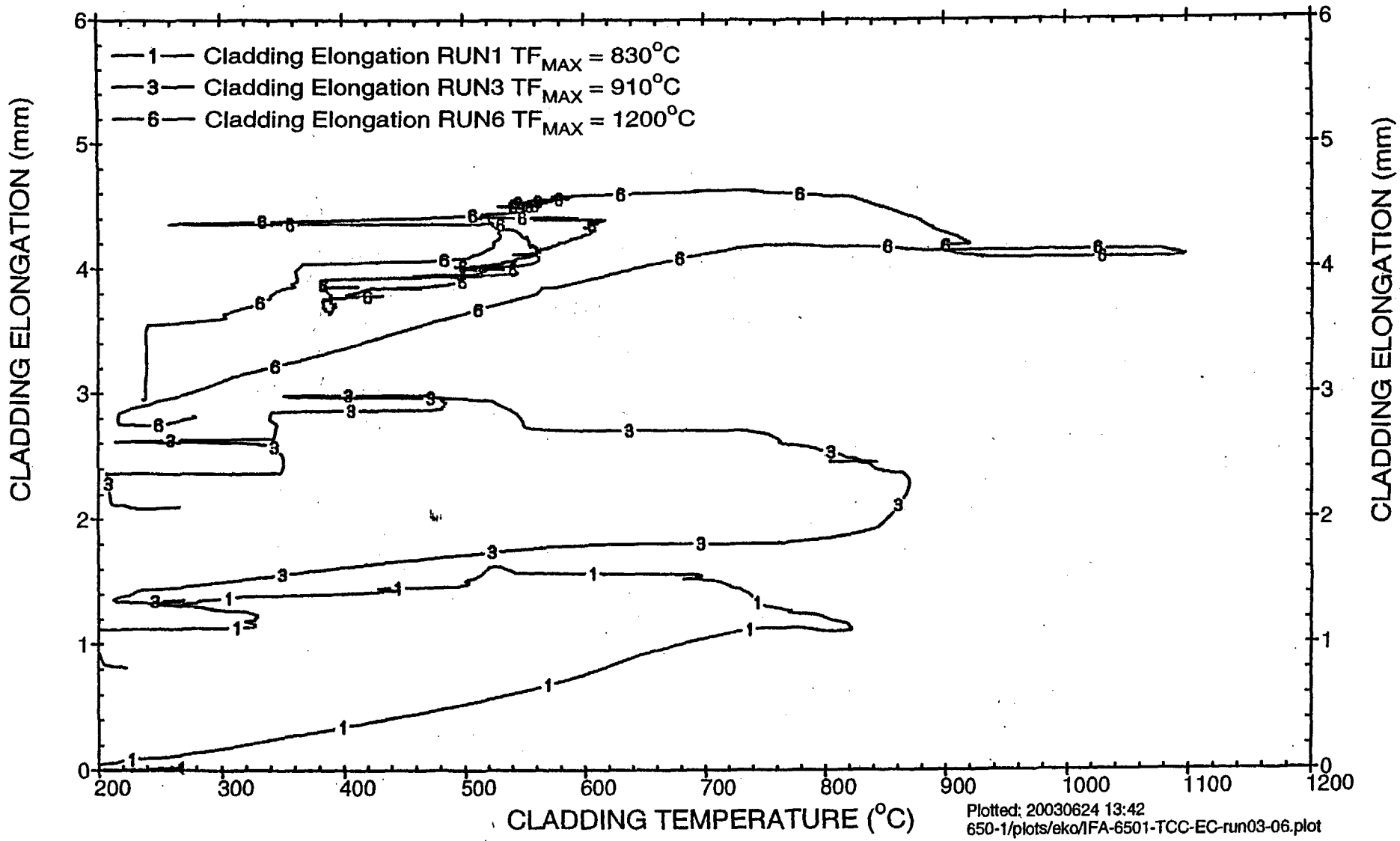
LOCA Trial Runs, IFA-650.1,



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LOCA Trial Runs - IFA-650.1

Summary:

- Trial runs on May 23rd (from 70 bar)
  - 2 runs to PCT = 800°C
  - 4 runs to PCT = 1100°C
- Loop and rig worked well
- Rod instrumentation worked well
- PCT reached by adjusting
  - LHGR (15 - 30 W/cm)
  - Heater (6 - 20 W/cm)
- Blowdown times ~30 secs
- Quench by spray system
- Check of axial power profile
- Next test in ~~September~~ October (pressurised PWR rod)

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Test Objects

- Pairs of rods (50 - 80 MWd/kg, 40 – 50 cm length) from commercial LWRs to be tested in PWR and BWR conditions, suitable to address possible effect of axial fuel fragment relocation
  - when does it occur (blow-down/heat-up, quenching)?
  - does bonding prevent the movement of fragments?
- Include medium burnup fuel (~40 MWd/kg, less or no bonding) to bridge the gap between low and high burnup
- VVER fuel envisaged for testing at a later stage

LOCA FUEL BEHAVIOUR TESTS IFA-650 (PWR)

	Loading/Materials	2001	2002	2003	2004	2005
PWR	IFA - 650.1 (PWR) (Fresh rod)			▪		
	IFA-650.2 (PWR)			▪	PIE	
	IFA-650.3 (PWR)				▪	PIE
BWR	IFA-650.4 (BWR) (Fresh rod)				▪	
	IFA-650.5 (BWR)					▪ PIE
	IFA-650.6 (BWR)					▪
	IFA-650.7 (BWR)					

Instrumentation: Cladding TCs, 1 PF & 1EC
He3 coil, Flow control, spray system