

Temperature profile

Velocity profile

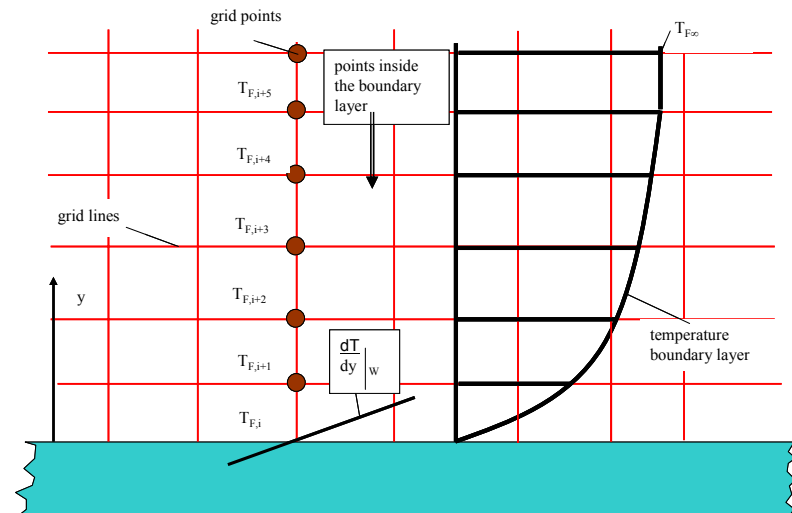
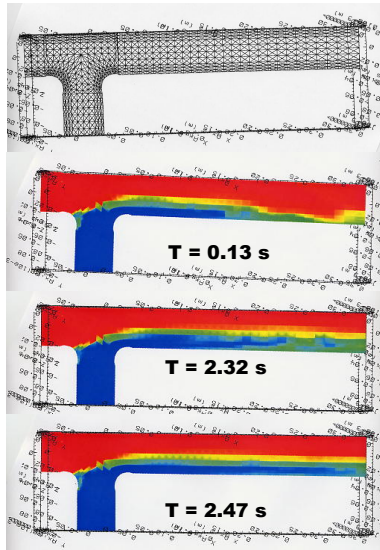
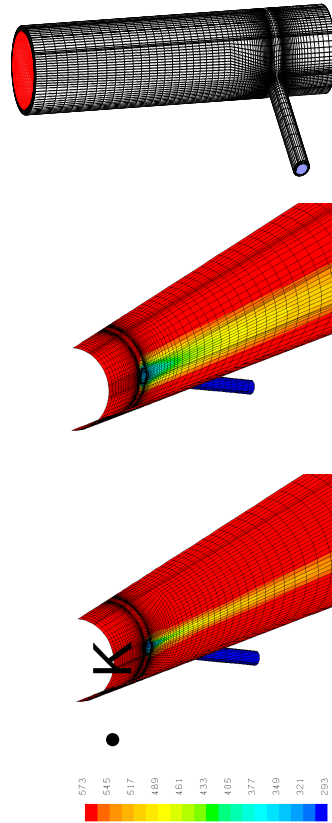


Figure 15: CFD calculation, fluid/wall-transition modelling parameter

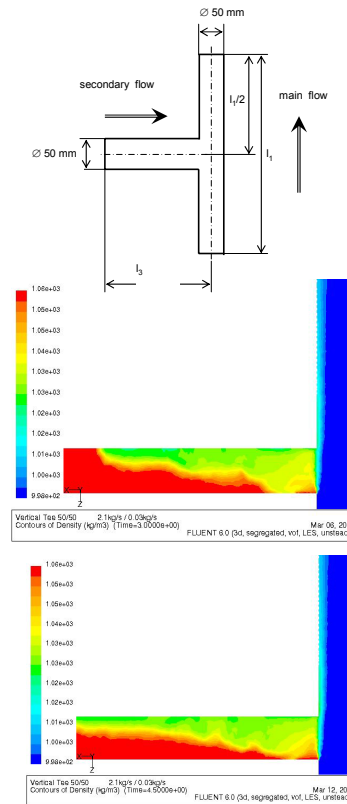
CEA
TRIO-U code



VTT
fluent



SPG
fluent



FANP-D
fluent

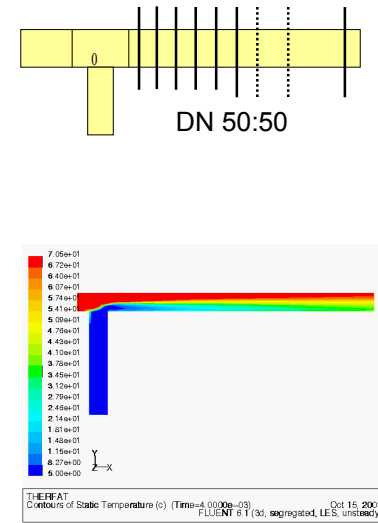


Figure 16: CFD calculations by different partners

Integrate modules and fatigue assessment

Process the plant files

The figure displays a series of interconnected software windows from a virtual simulation environment. The main window on the left, titled 'TRACE', shows an XML configuration for a 'transform' action. It lists input and output files, and a 'List Size' of 7. Below the XML, a table summarizes the test results:

Limit File	List File	List Size
d:\ignacio\therfat\test\limit.cfg	d:\ignacio\therfat\test\input.lst	7

Below this table, the results are categorized into 'ERROR_INVALID_SIGNAL' (red bars) and 'SUCCESS' (yellow bars). The 'ERROR_INVALID_SIGNAL' section lists test runs for 'OV040202.cd2' and 'OV040204.exp', both showing 'process', 'range', and 'virtual' components. The 'SUCCESS' section shows similar results for 'OV040203.cd2' and 'OV040203.exp'.

Other windows show XML code for 'range' and 'process' actions, and a 'VIRTUAL' window displaying a table of test signal ranges:

Virtual Signals	Start Date	End Date	Start Time	End Time
limit	2004-02-02	2004-02-02	00:00:00	23:59:59

Below this, a section titled 'Input Signals Not Found' lists signals that need to be calculated: 'CL_TEMPMIN' (needs CLA_Temp) and 'CL_TEMPMAX' (needs CLA_Temp). A 'Not Required Virtual Signals' section lists: 'LoopCFlow', 'SGA_PRS', 'SGB_PRS', 'SGC_PRS', 'RXPOWER', 'pressurizer_pressure', 'start', and 'end'.

Additional windows show XML code for 'init_signal' and 'init' actions, and a 'PROCESS' window displaying a table of test signal ranges:

Virtual Signals	Start Date	End Date	Start Time	End Time
limit	2004-02-02	2004-02-02	00:00:00	23:59:59

The 'PROCESS' window also shows sections for 'Invalid Signals' (SGAPress2, CLA_Temp), 'Not Initialized Signals' (CLA_Temp), and 'Init Signals' (PORV_Viv_1, PORV_Viv_2, AuxSprayVlv, PORV1, PORV2).

Man-machine interface

Test signal ranges

Calculate virtual signals

Figure 17: Virtual sensors, software application

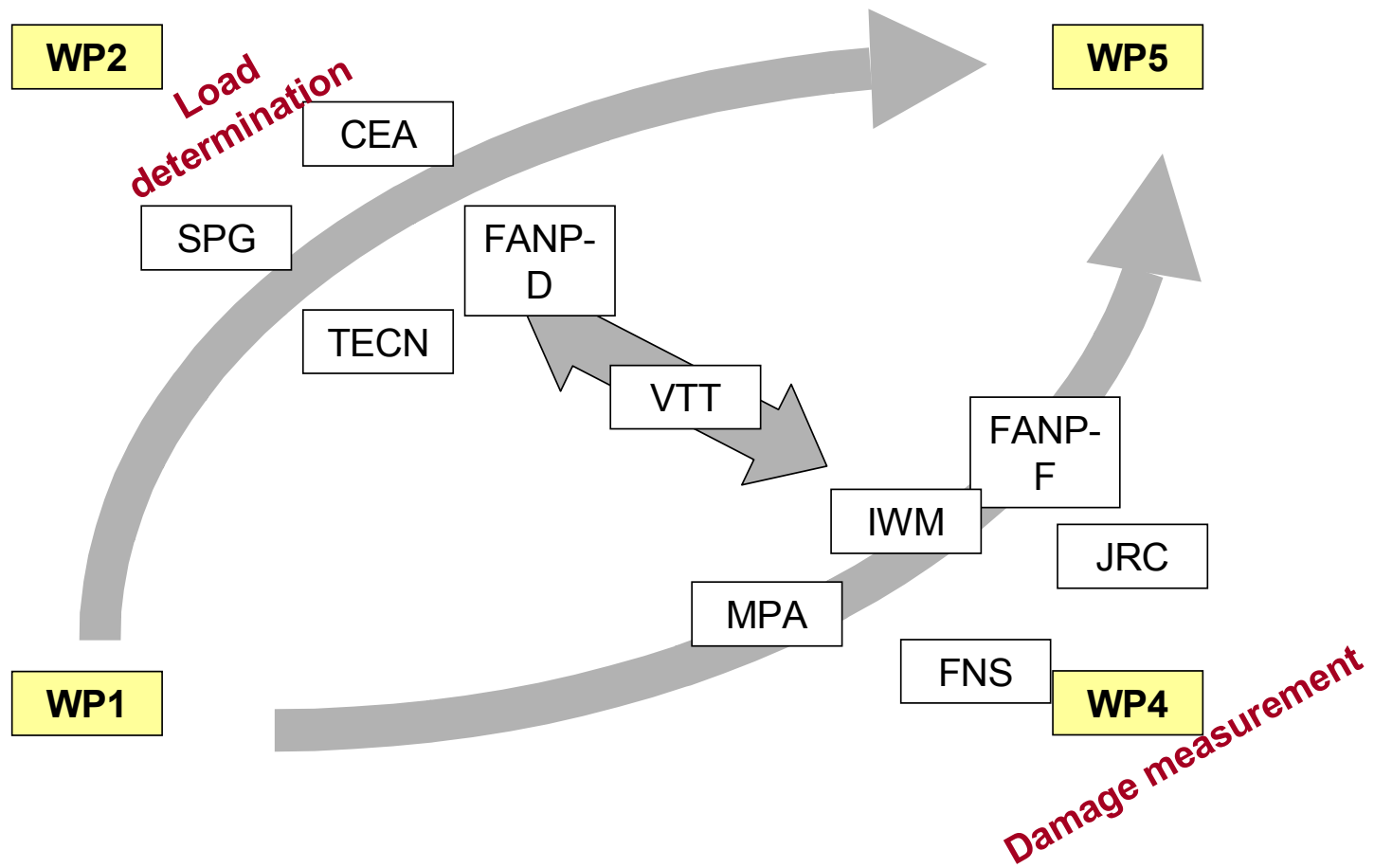


Figure 18: WP 3 partner roles

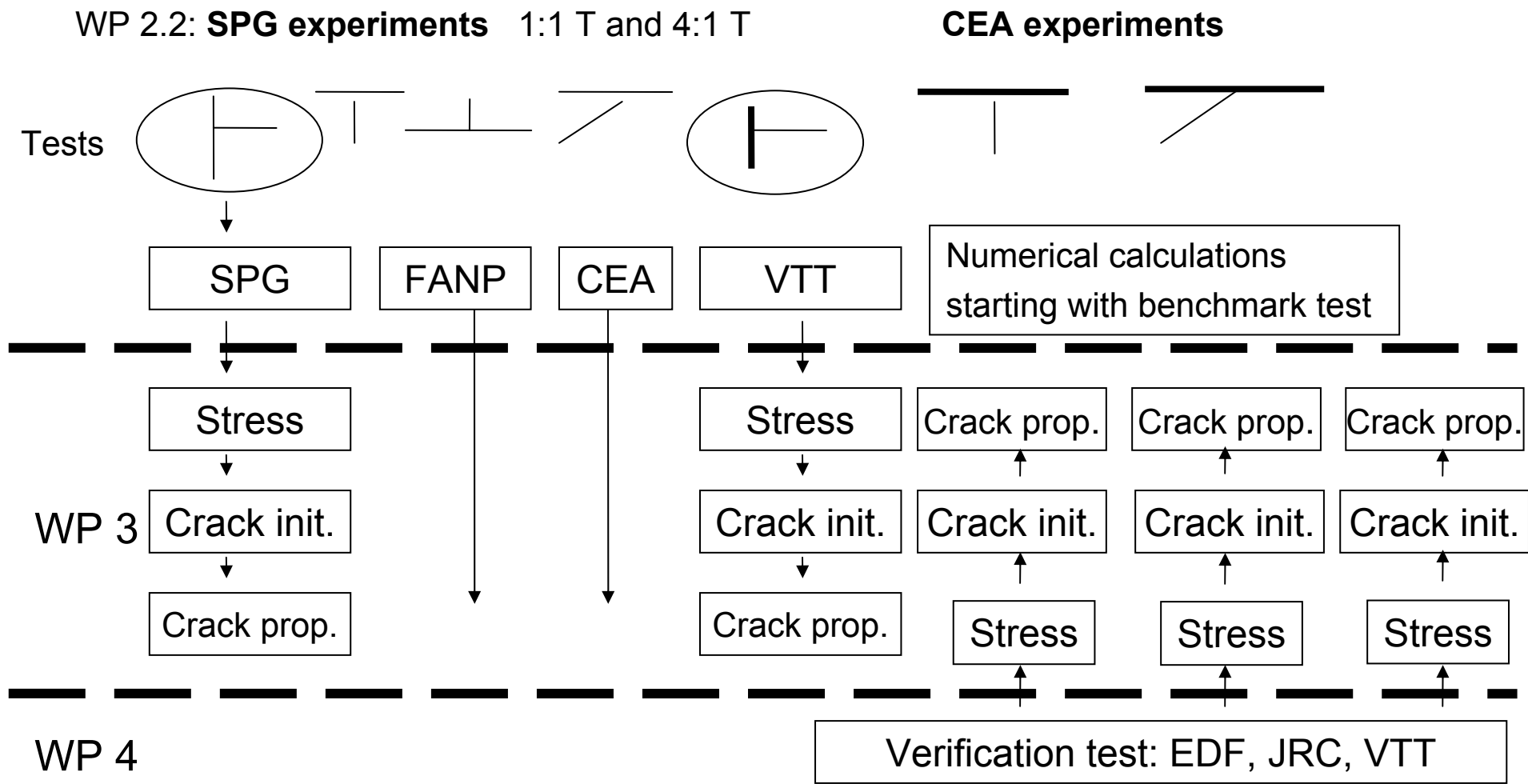


Figure 19: Integrity evaluation (“forward” and “backward” approach)

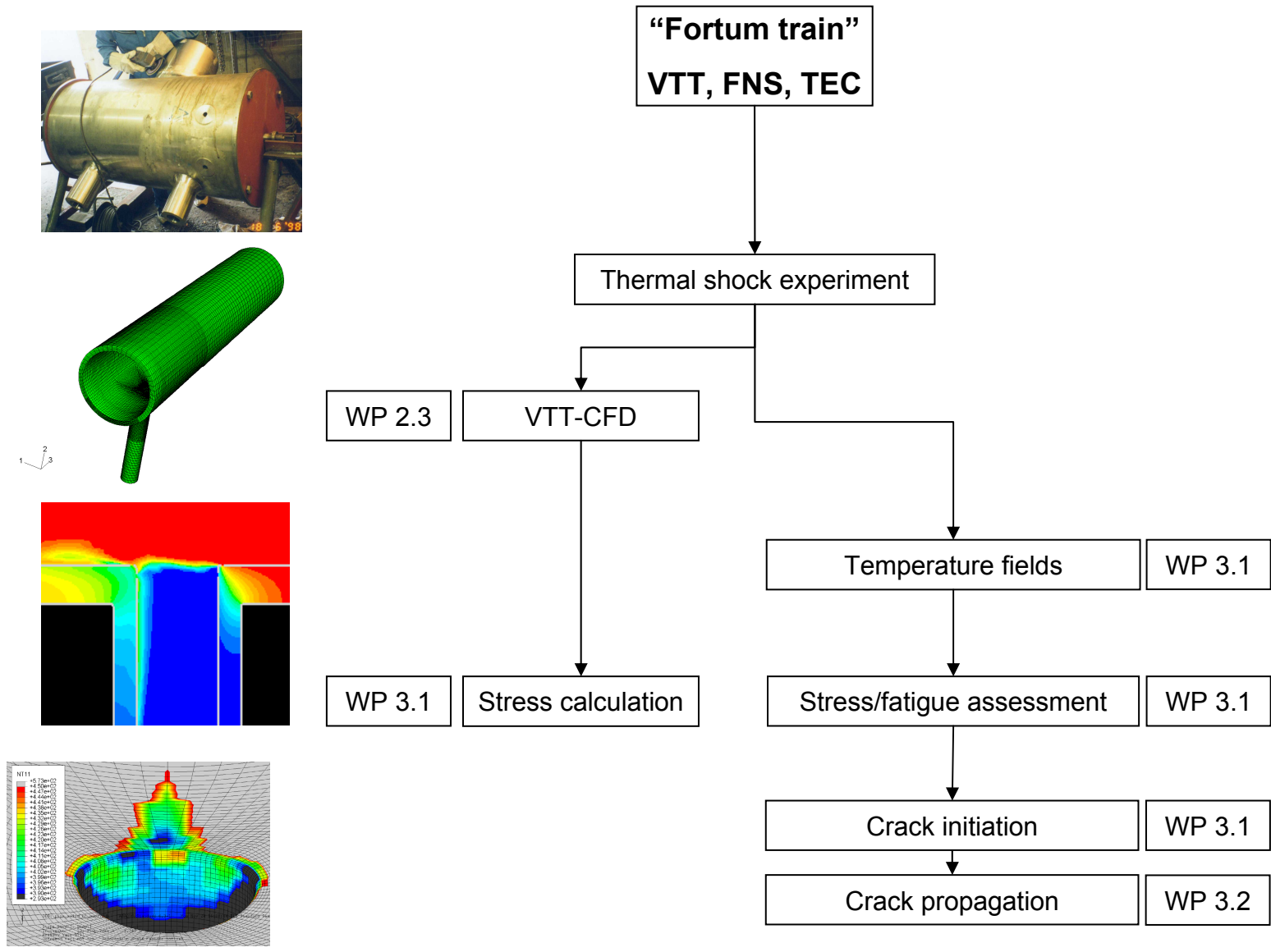
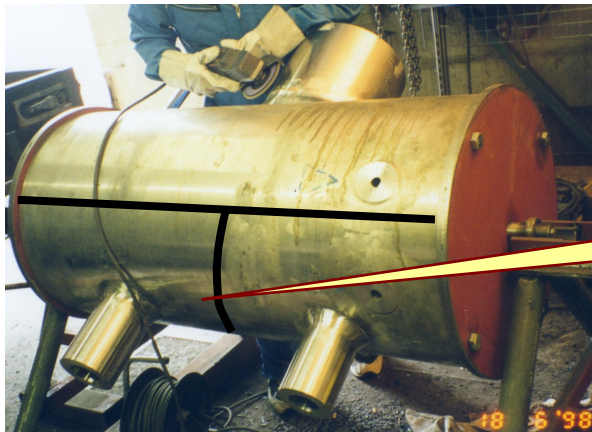
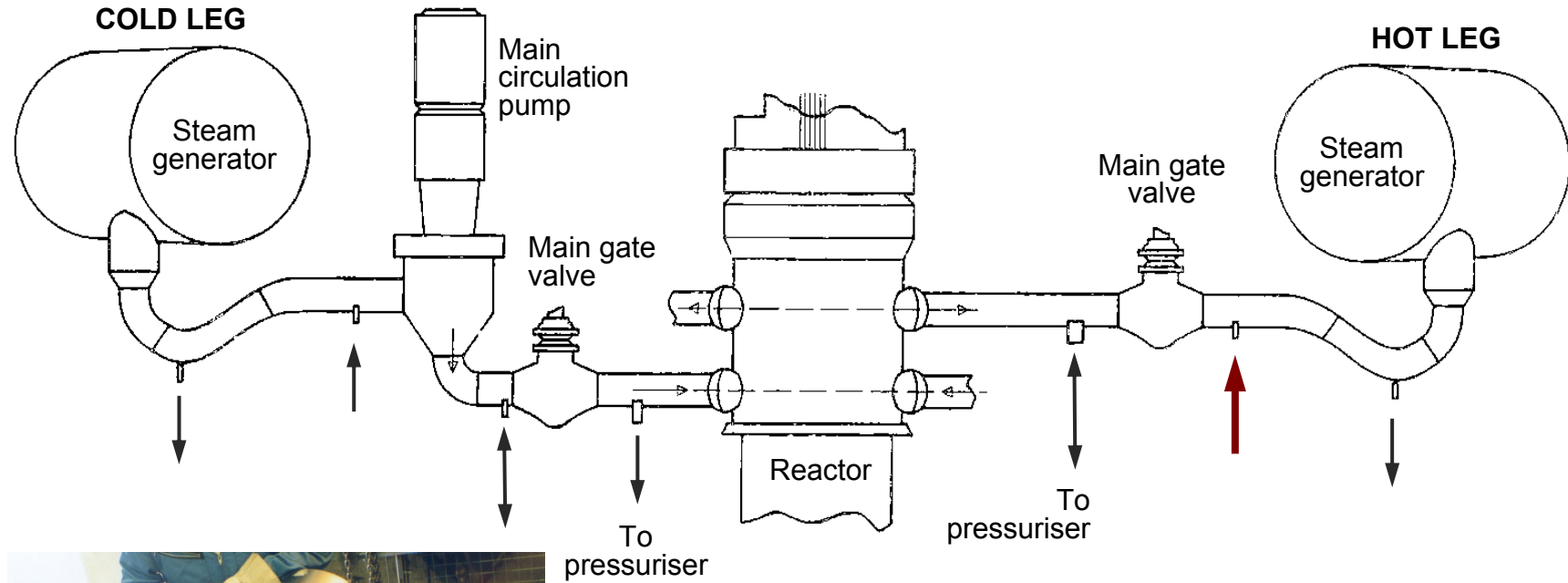


Figure 20: "Fortum train" workflow, VTT, FNS, TEC

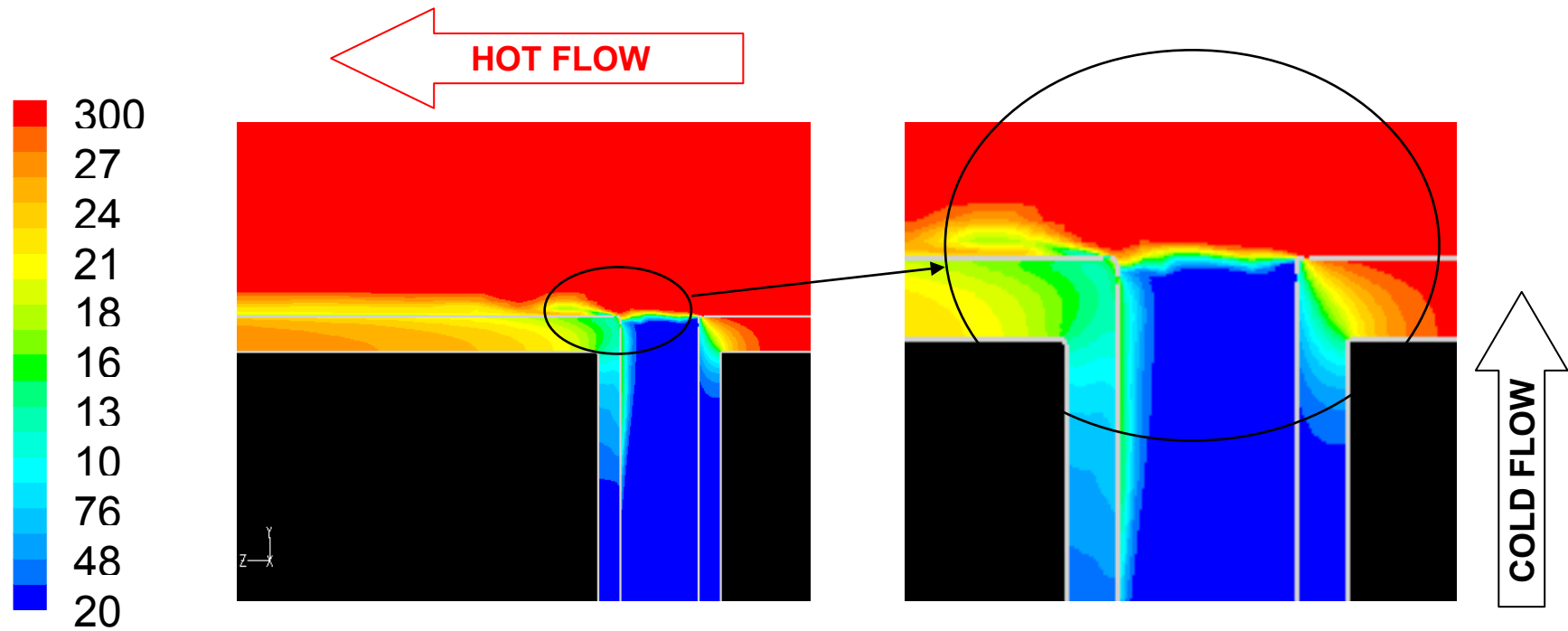
Fortum train: Mock-up



**Purification
line nozzle**

Figure 21: "Fortum train", thermal shock experiment mock-up

Cold jet penetrating into the primary pipe



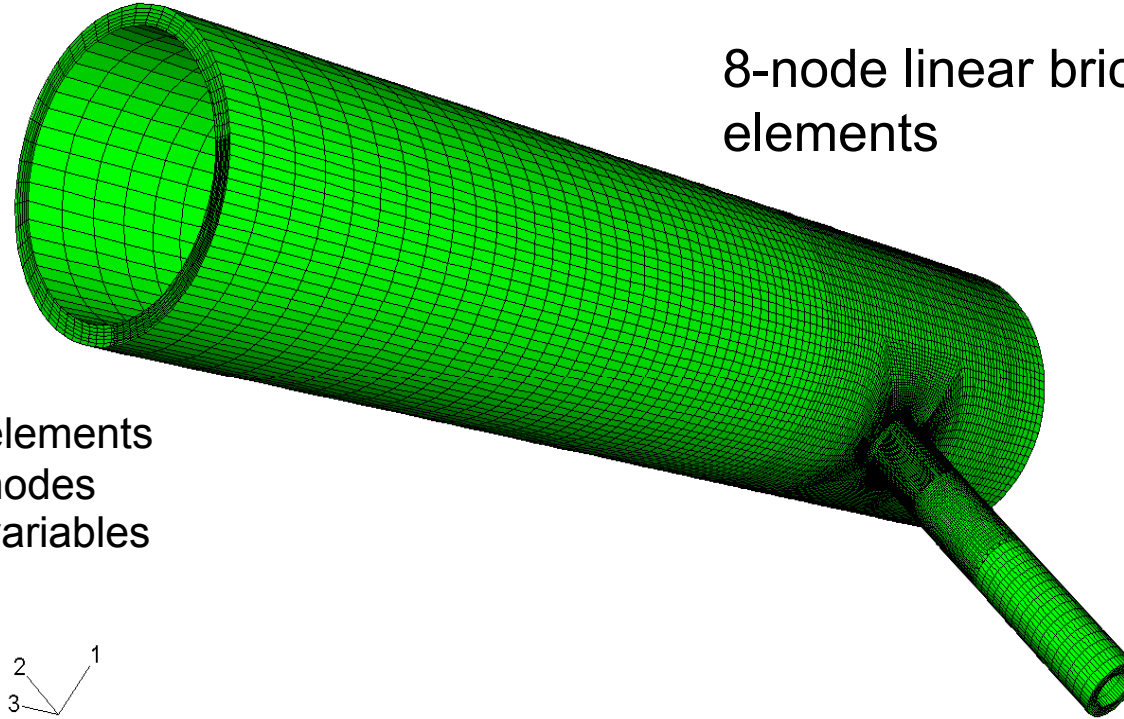
Steep oscillating temperature gradient in the round-off region of the T joint

Figure 22: VTT, CFD analysis on pipe/nozzle connection

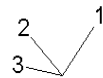
FEA: The full model (CFD + pressure)

Material
properties
temperature
dependant

8-node linear brick
elements

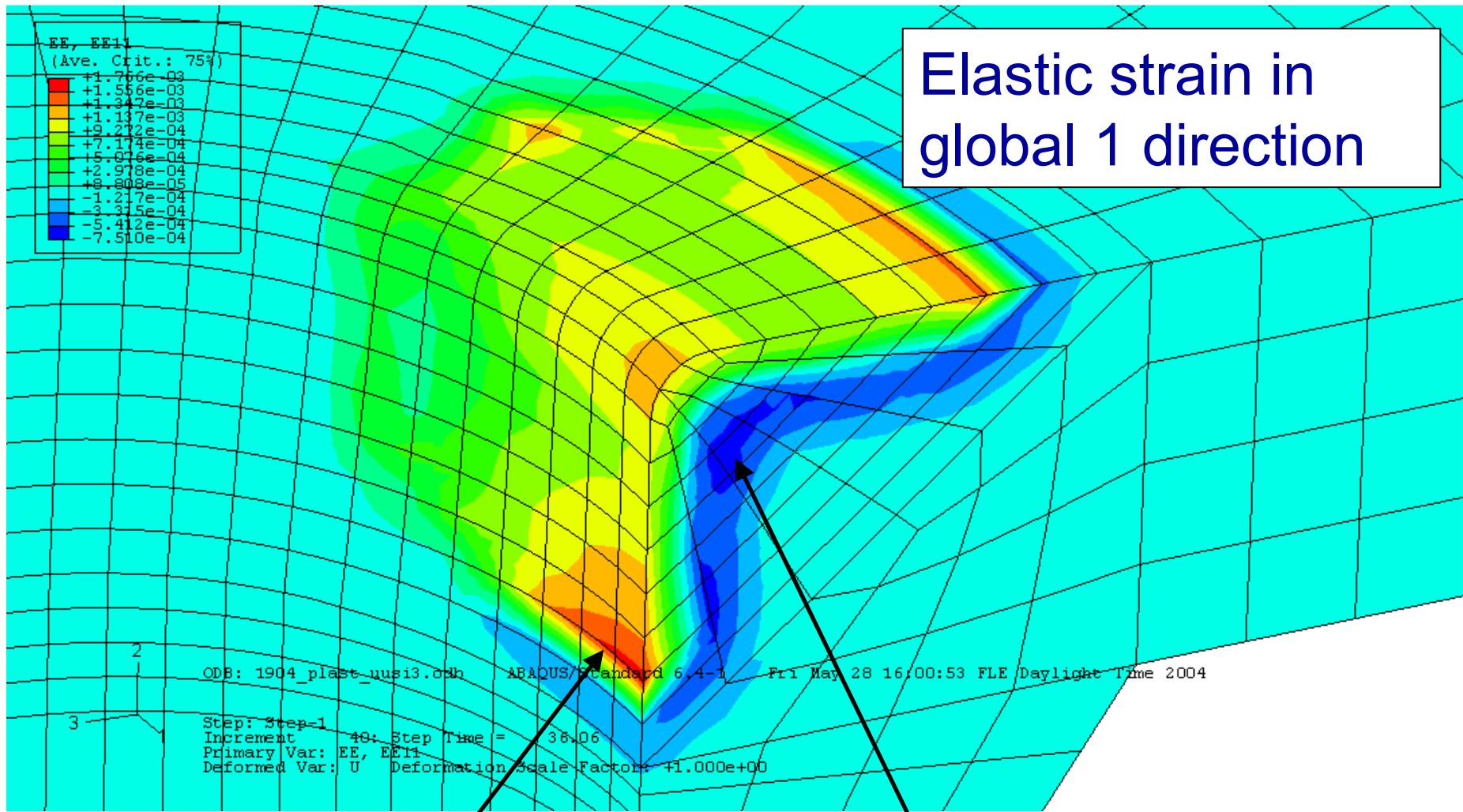


218 880 elements
241 863 nodes
725 589 variables



- overpressure 122.6 bar
- main pipe temperature 300 °C
- cold-leg temperature 20 °C
- turbulent cycle 50 Hz

Figure 23: “Fortum train”, FE model and loads

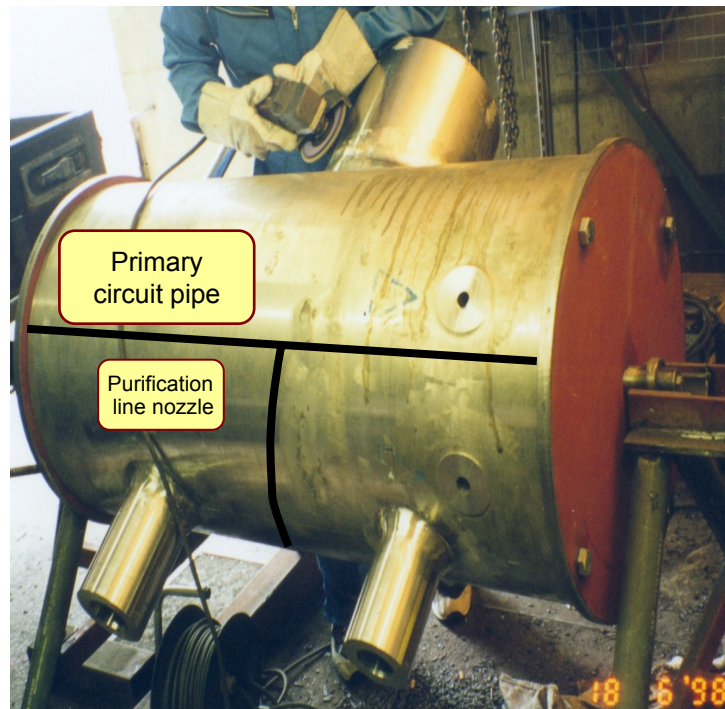


Elastic strain in global 1 direction

Max. strain = 0.18 %

Min. strain = 0.08 %

Figure 24: "Fortum train", stress analysis, elastic strains



First cracks occurred after more than 10 000 load cycles
Final condition: crack length: 34.5 mm (estimated depth: 15 mm)

Figure 25: “Fortum train”, thermal shock experiment



Figure 26: “Fortum train”, thermal shock experiment, crack monitoring

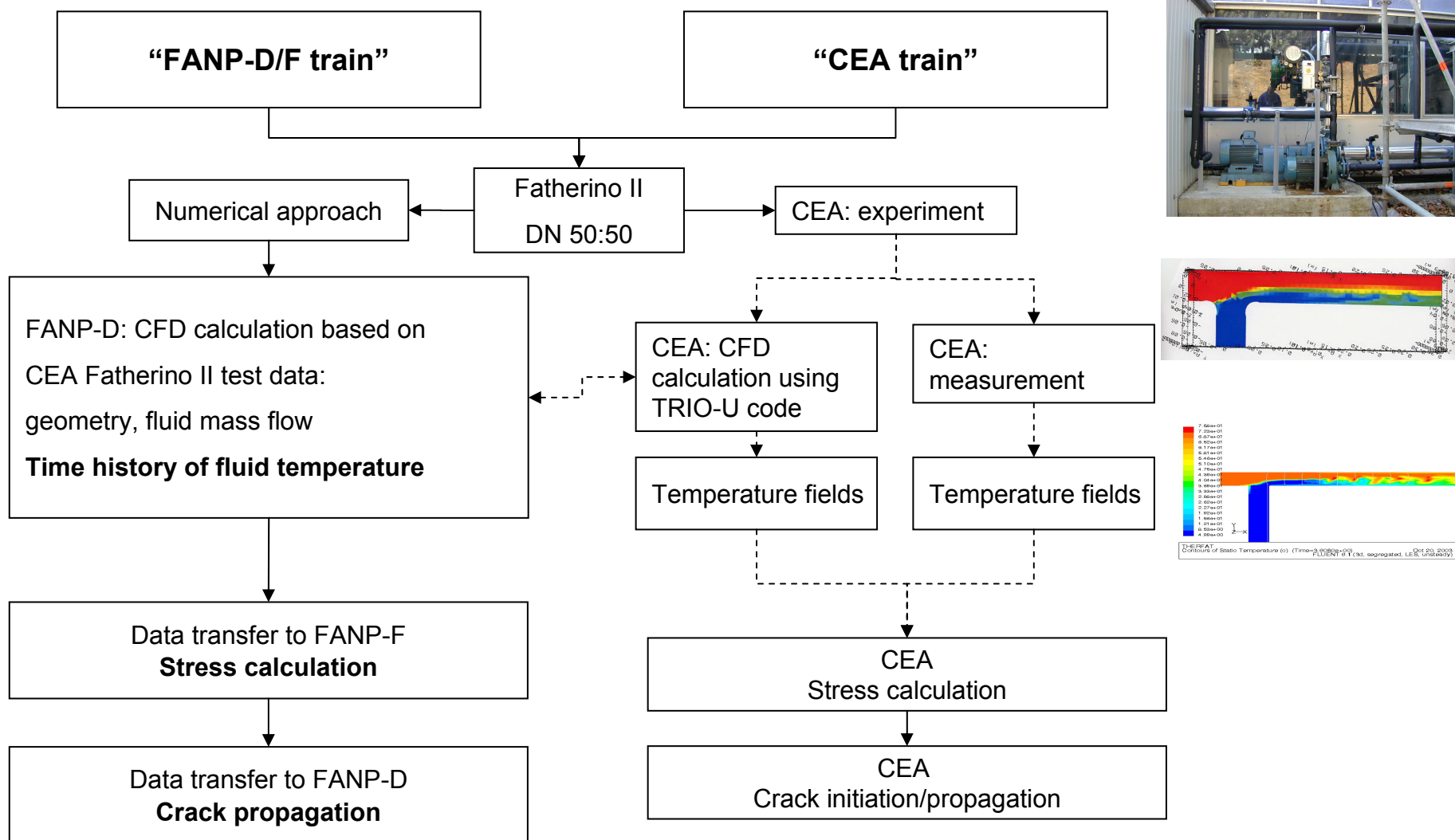


Figure 27: “FANP-D/F train” and “CEA train” workflow

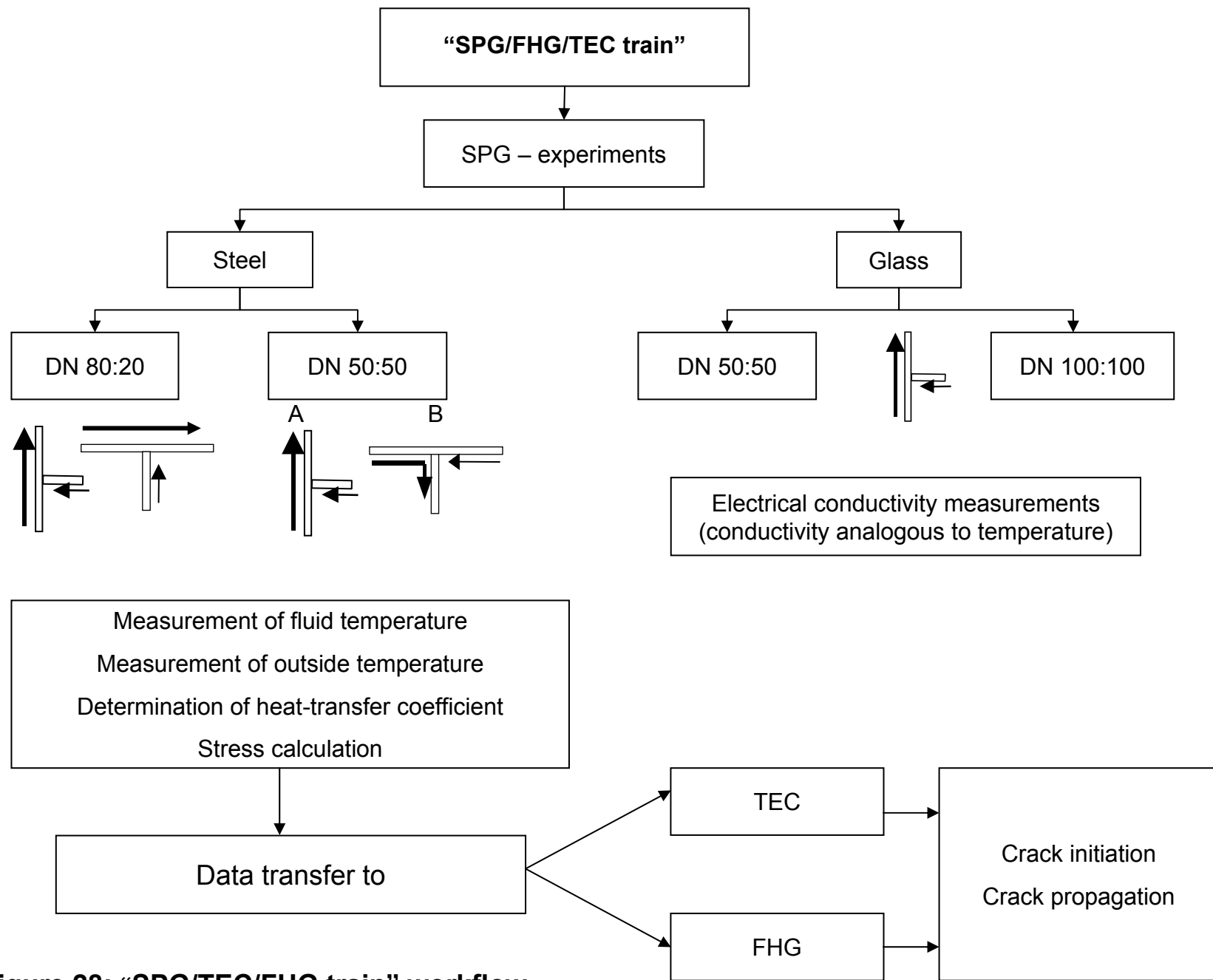


Figure 28: “SPG/TEC/FHG train” workflow

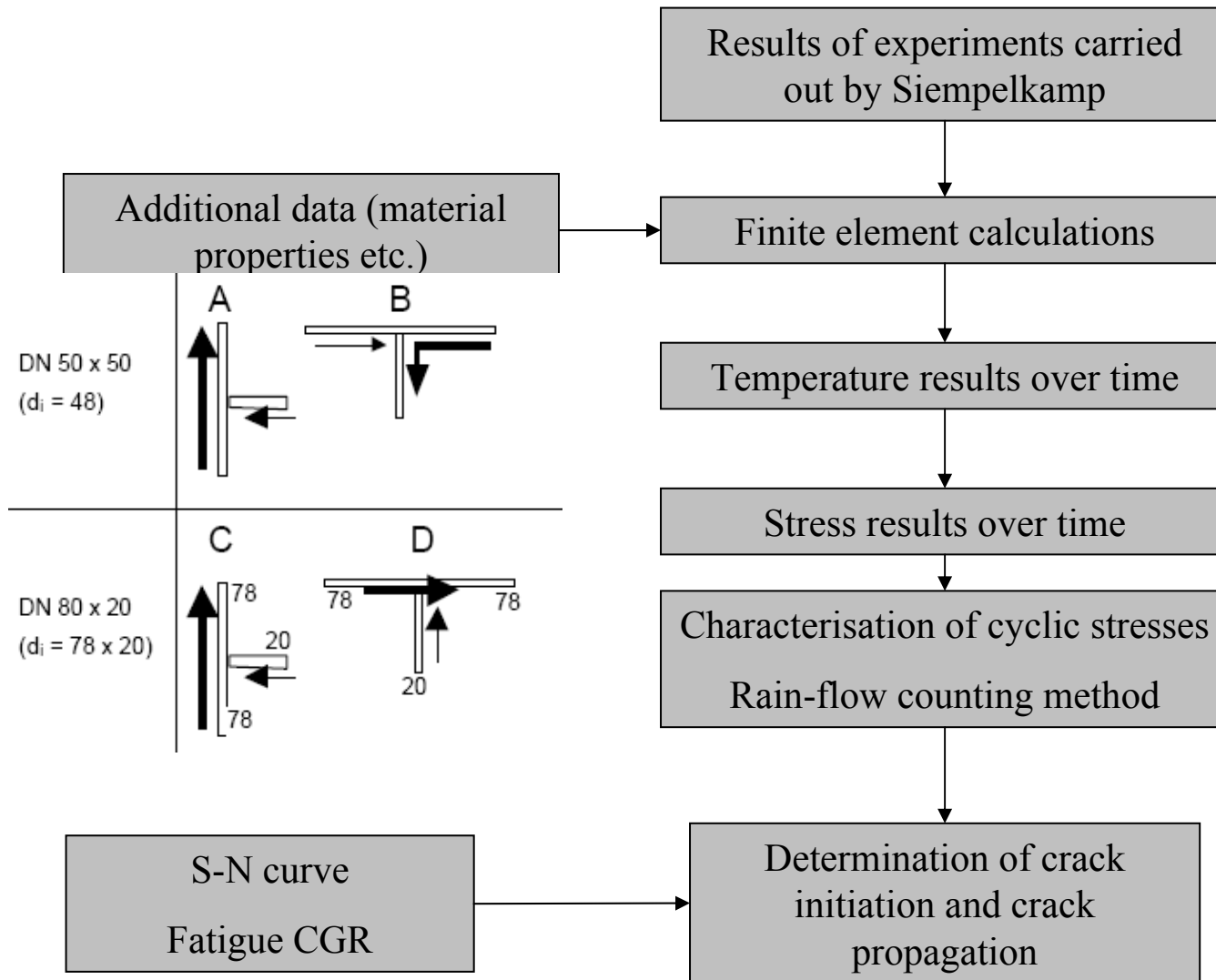


Figure 29: TEC, stress/crack analysis based on SPG Data

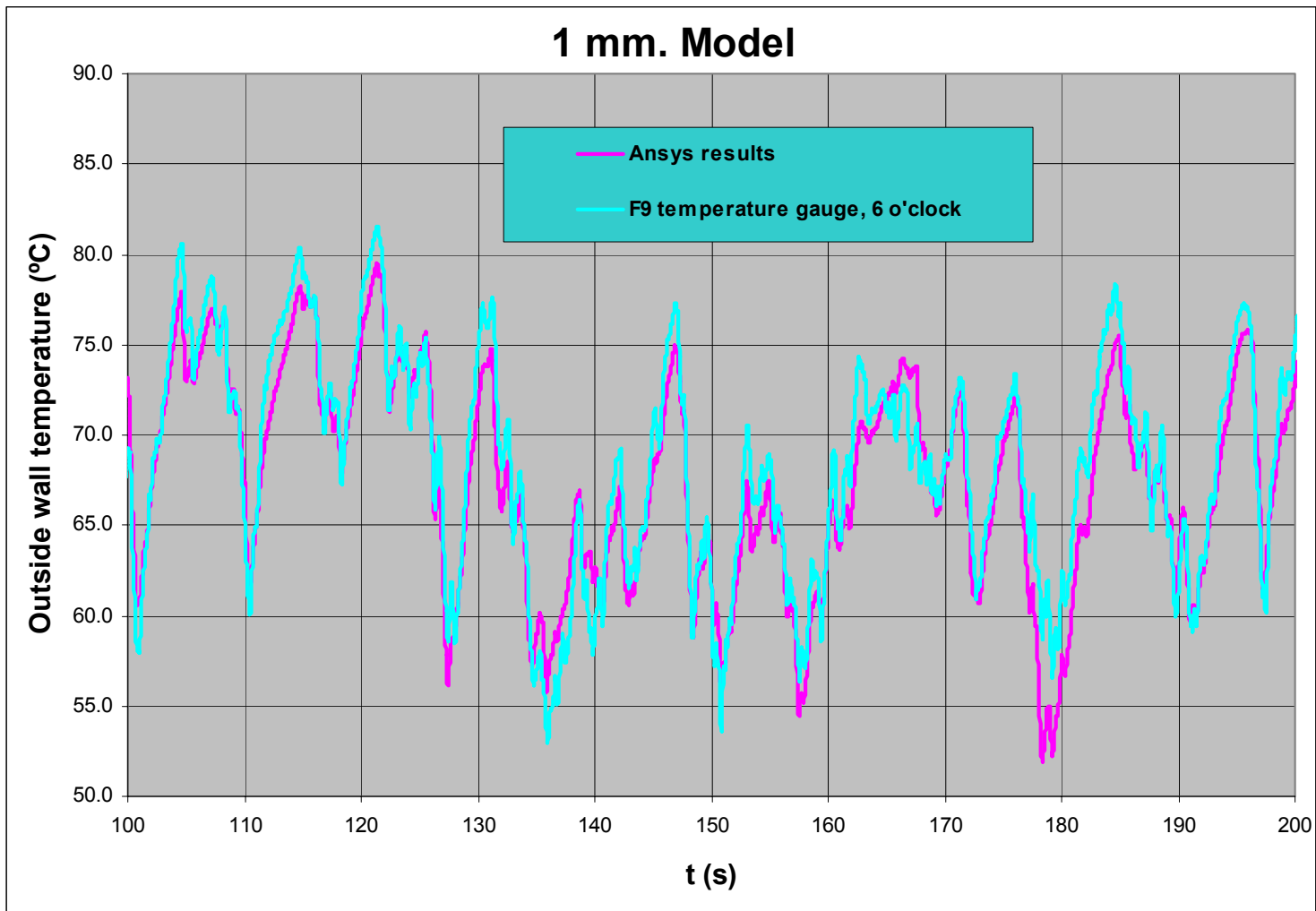
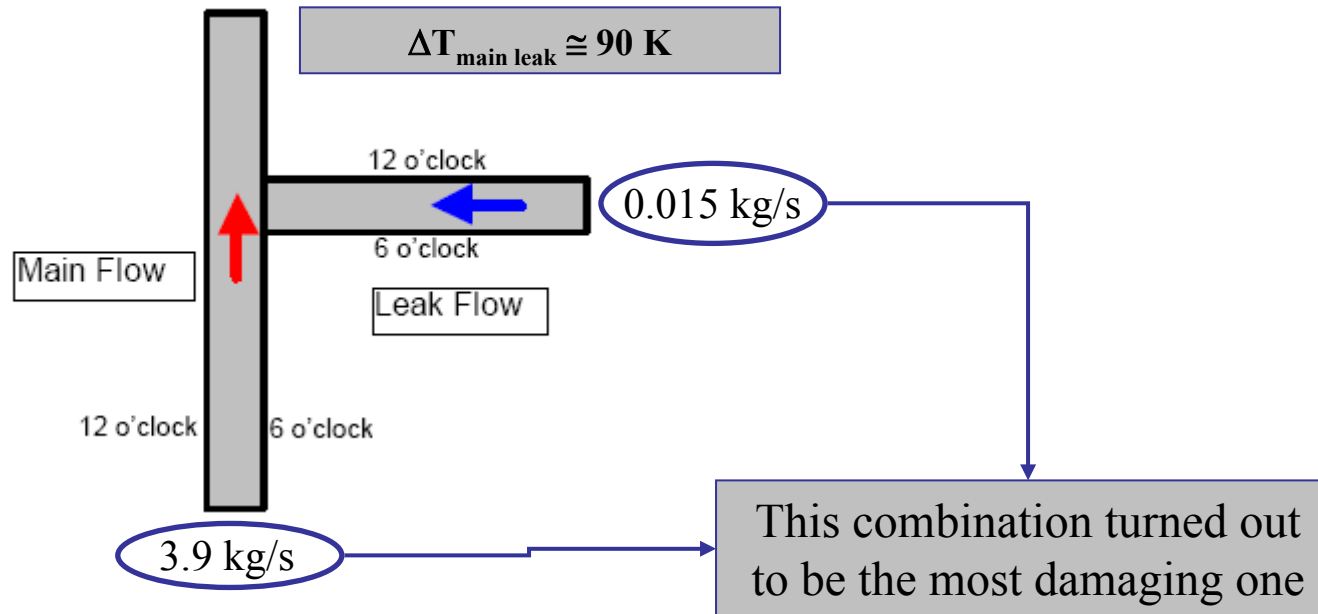


Figure 30: TEC, experimental versus analytical results

Configuration analysed by FEM



- Austenitic steel piping
- Wall thickness
 - experiments: 1 mm
 - calculations: 10 mm

Figure 31: TEC, relevant T configuration analysed by FE analysis

Fatigue analysis

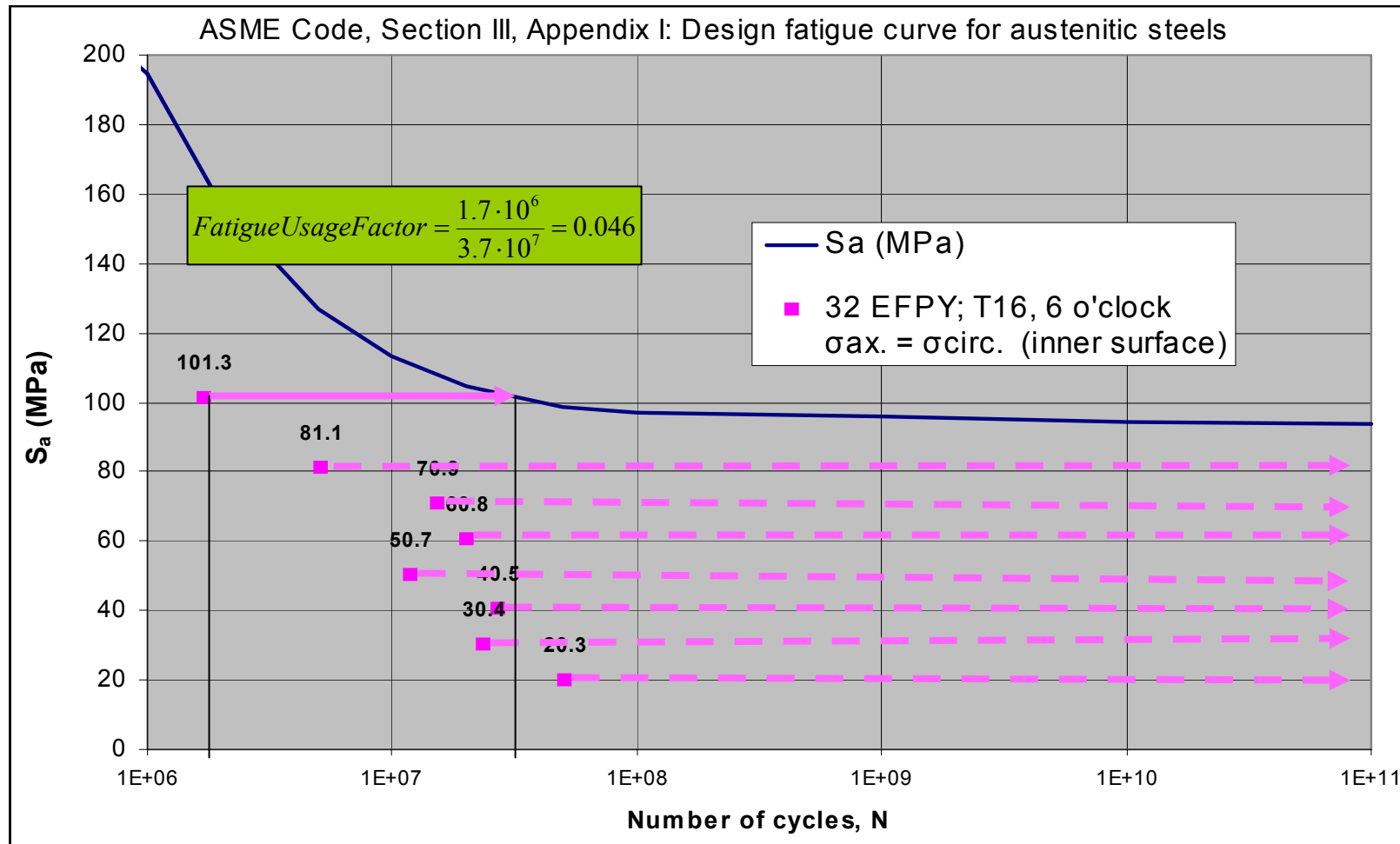


Figure 32: TEC; fatigue analysis of through-wall stresses; α experiment = 2000 W/(m²K)

Fatigue analysis

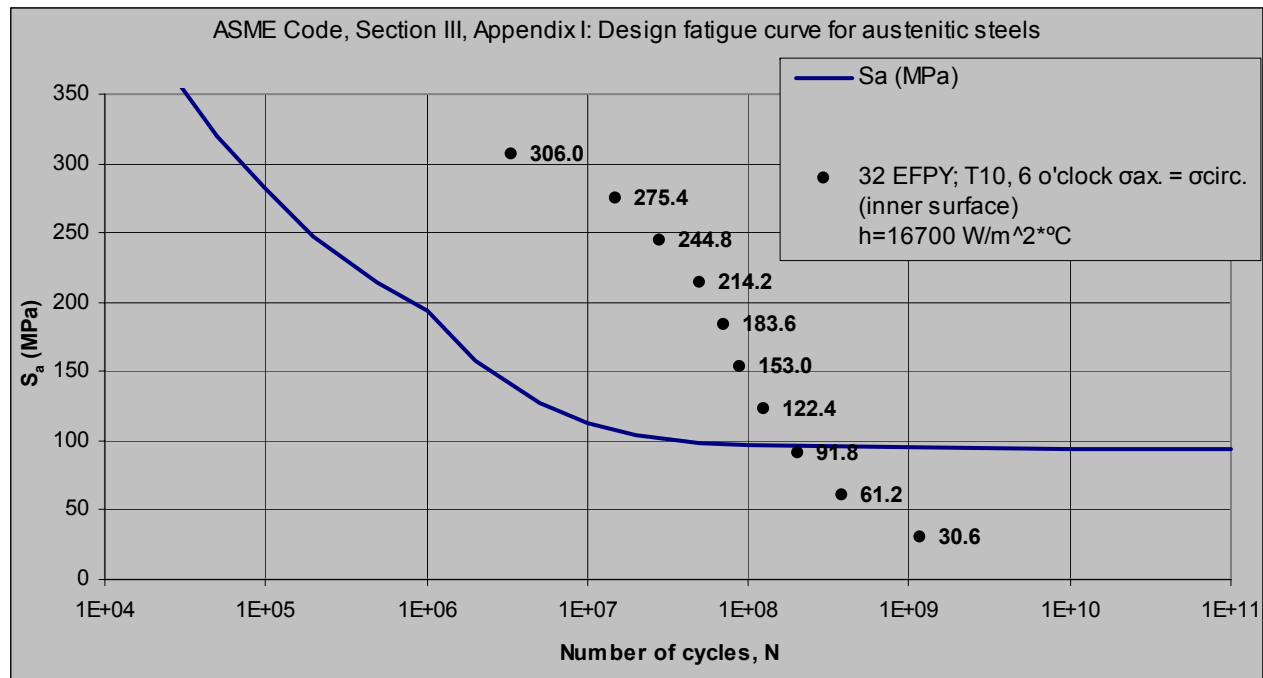


Figure 33: TEC; fatigue analysis of through-wall stresses; α Colburn = 16 700 W/(m²K)

Temperature and stress for the SPG geometry

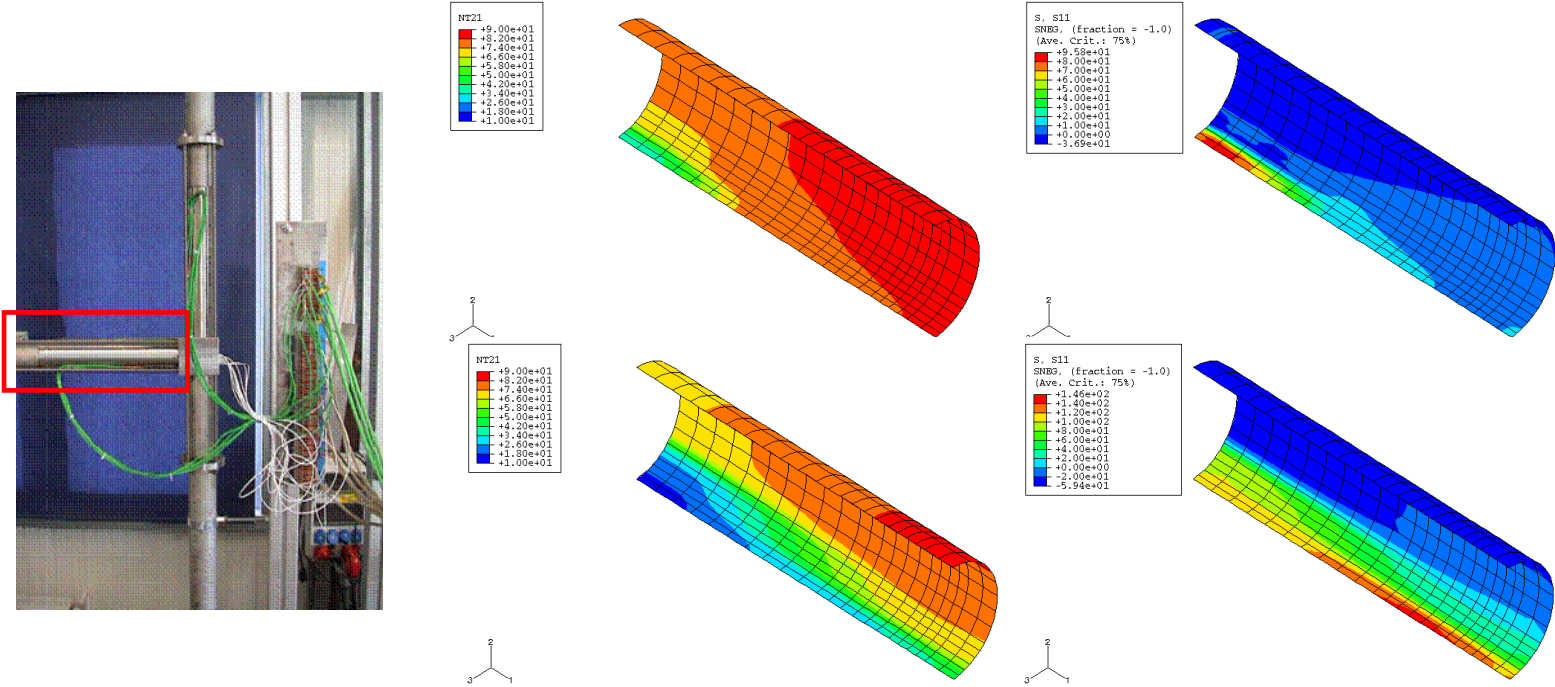
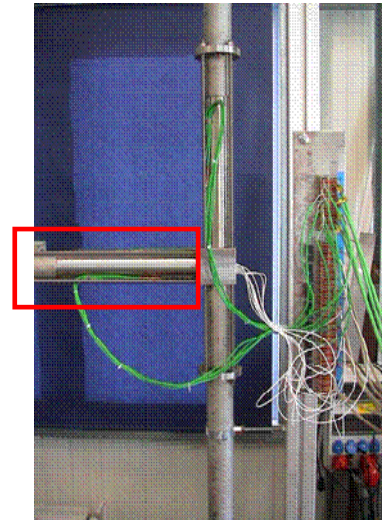
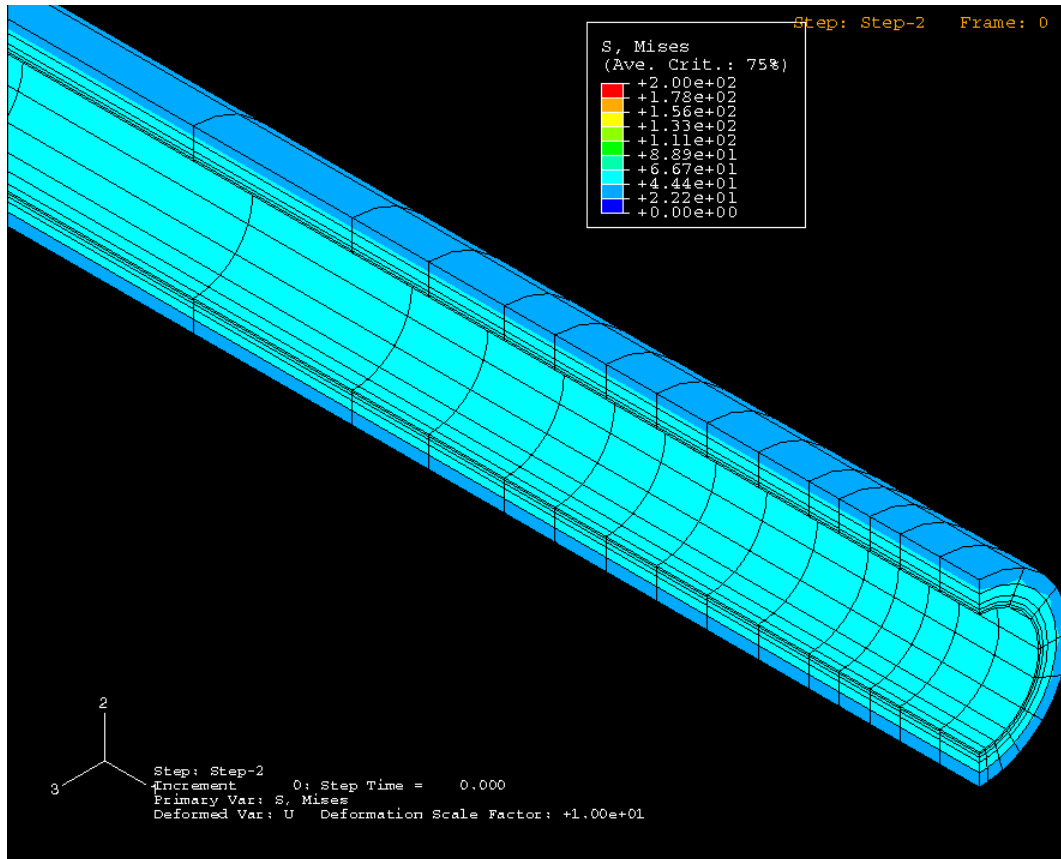


Figure 34: FHG, 3D-FE model for stress analysis and crack initiation/propagation

Stress variation: elastic-plastic analysis



$$\Delta T = 250 \text{ } ^\circ\text{C}$$

$$D_a = 59 \text{ mm}, t = 10 \text{ mm}$$

$$\alpha = 5 \text{ kW}/(\text{m}^2\text{K}), f = 0.1 \text{ Hz}$$

Figure 35: FHG, elastic-plastic analysis

EDF: WP4 test mock-up INTHERPOL description

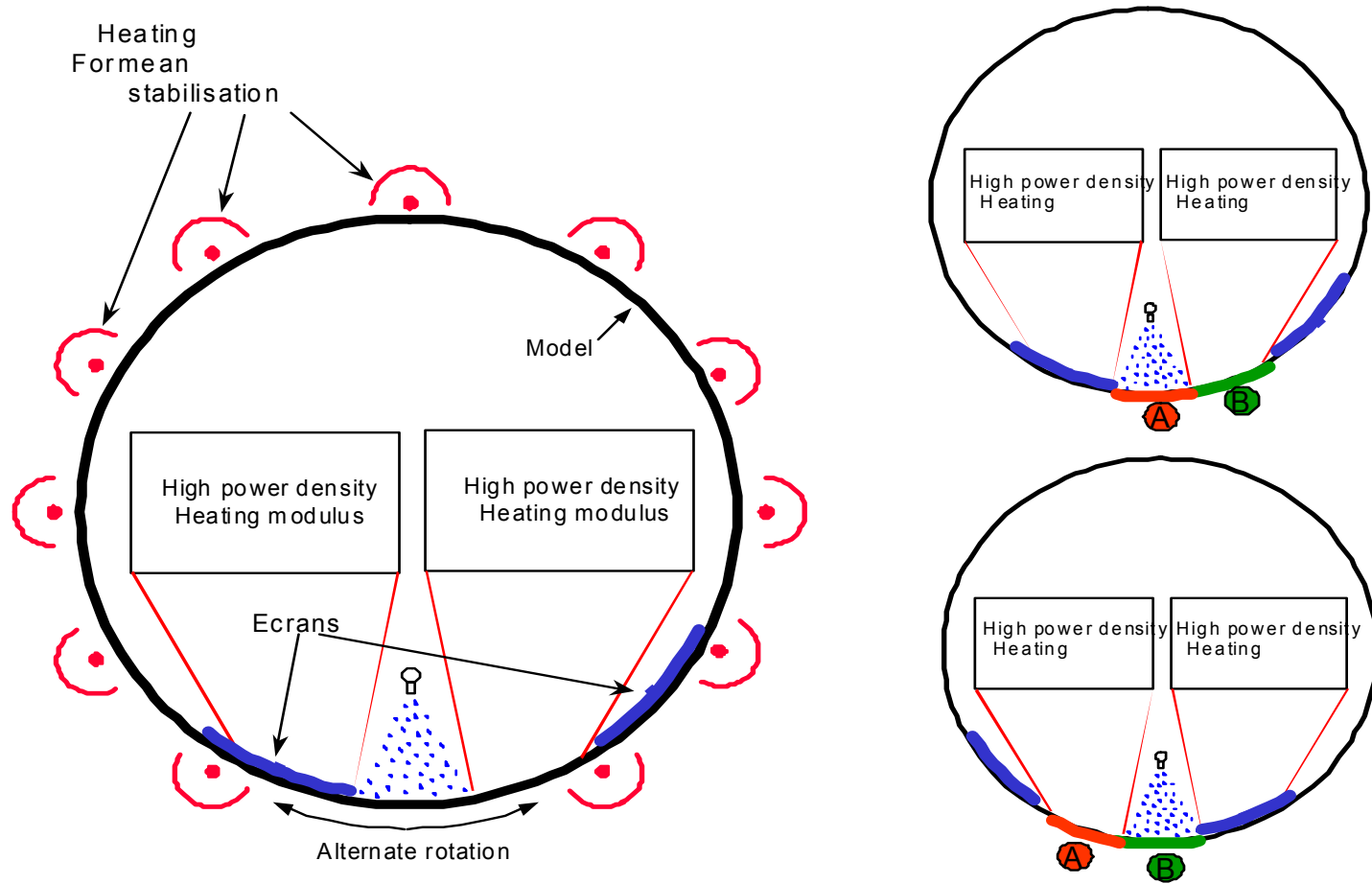
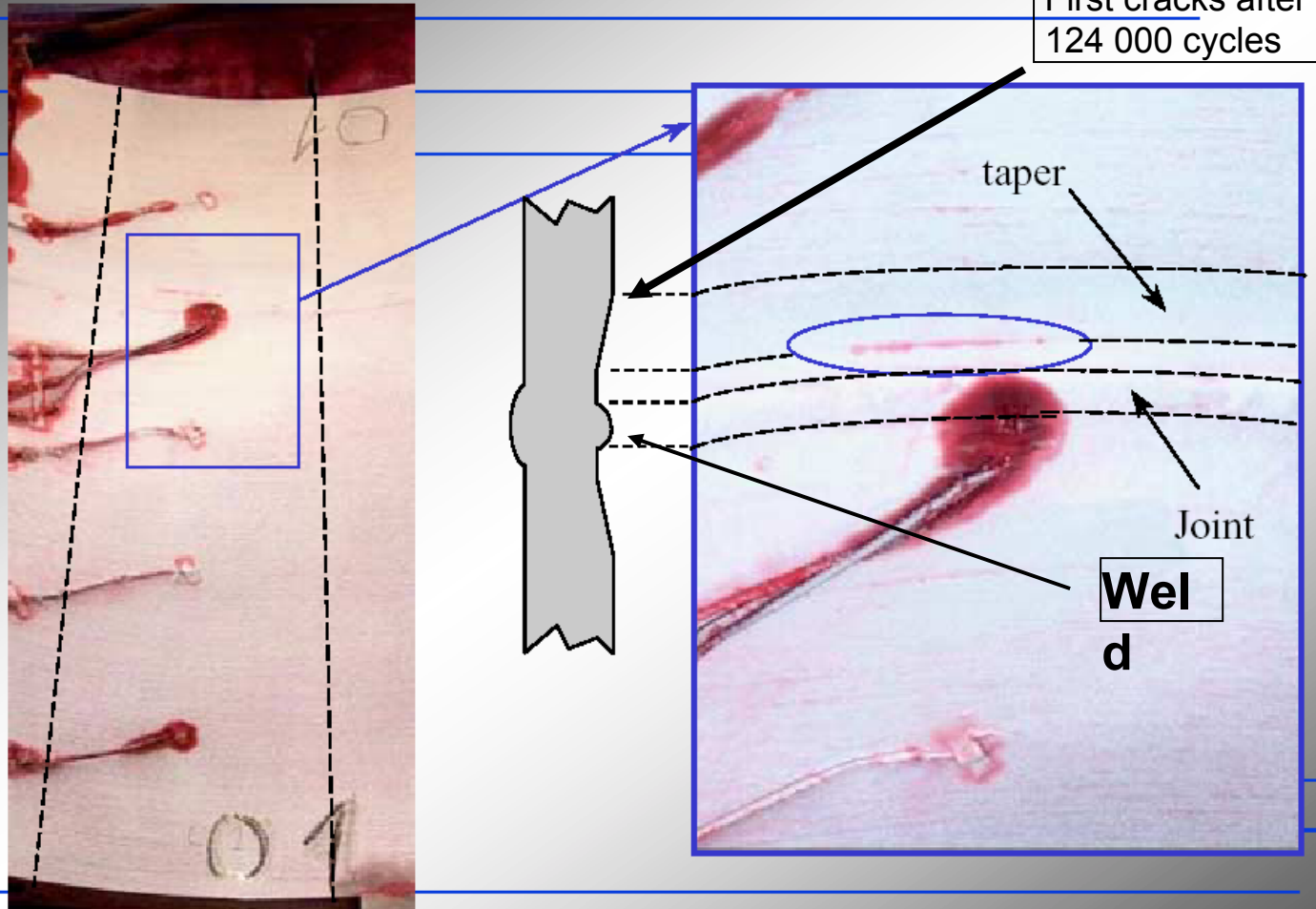


Figure 36: EDF-INTHERPOL "turning cylinder" test

Maquette 01 - Ressuage à 124 300 cycles



EDF R&D

THERFAT meeting - Cadarache - June 2003



Figure 37: EDF, long-term damage test results

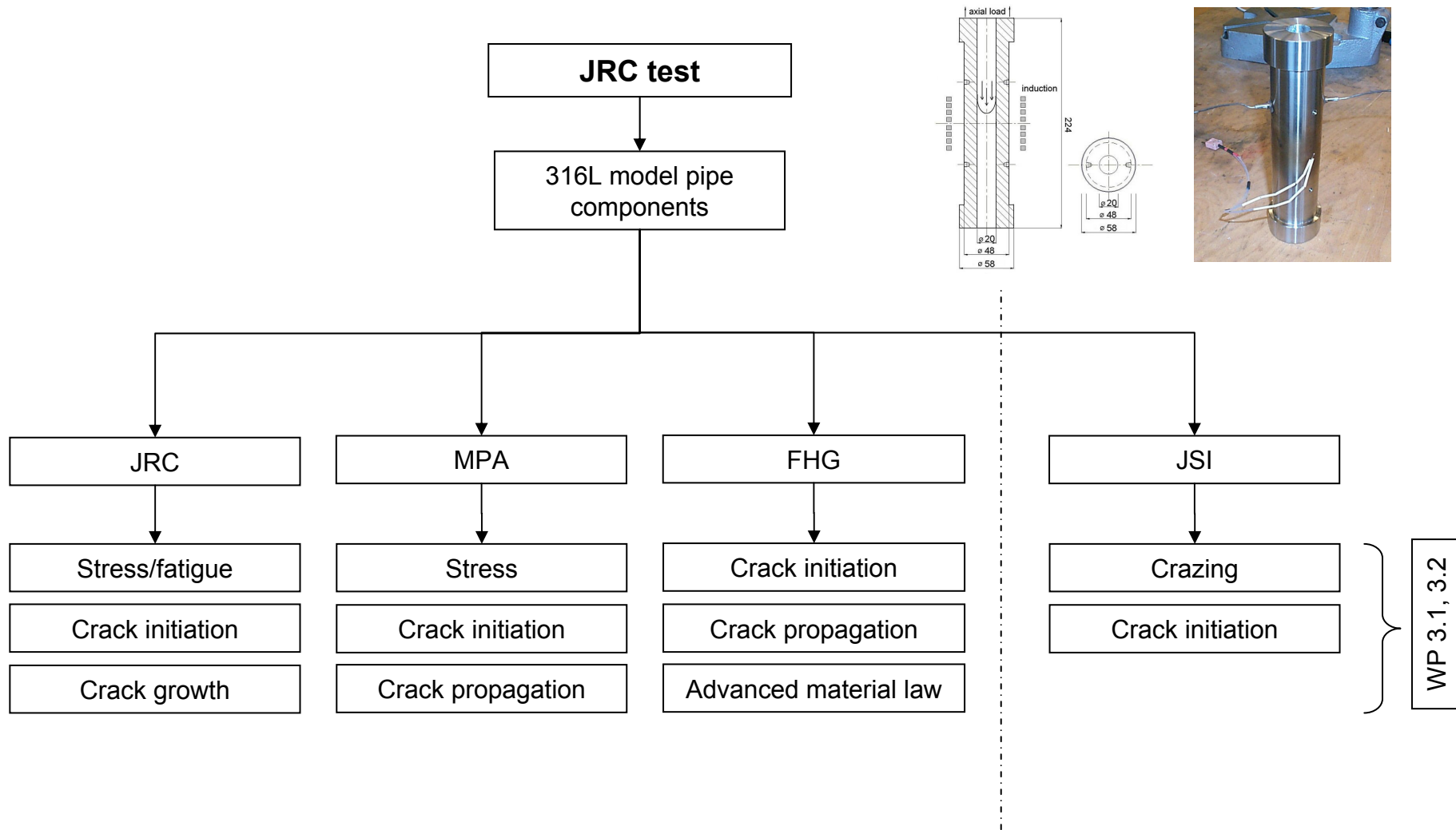
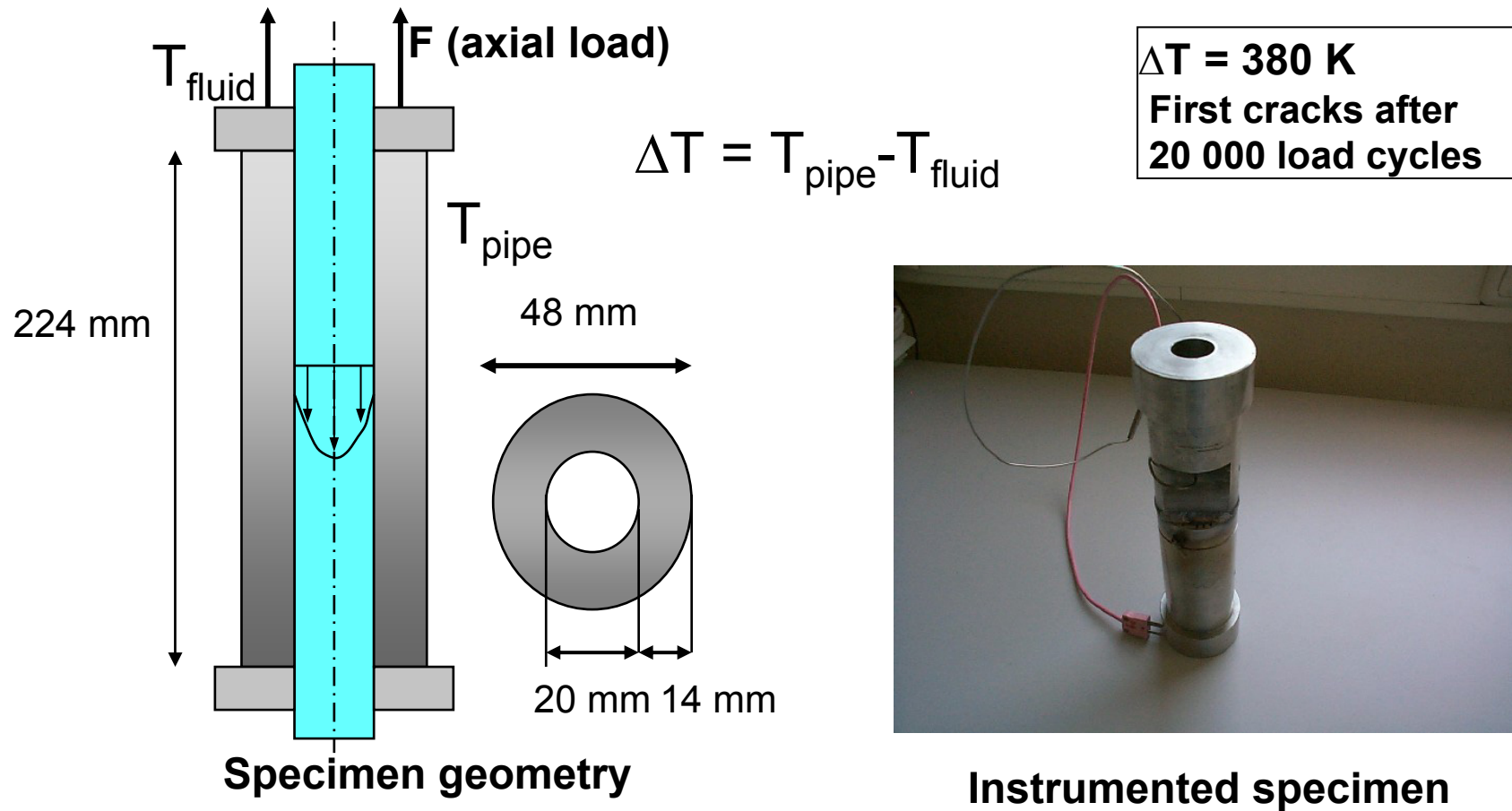


Figure 38: JRC test workflow, JRC, JSI, MPA, FHG

JRC thermal shock experiment (pipe specimen)



Material: A316L austenitic steel

Figure 39: JRC, long-term damage tests

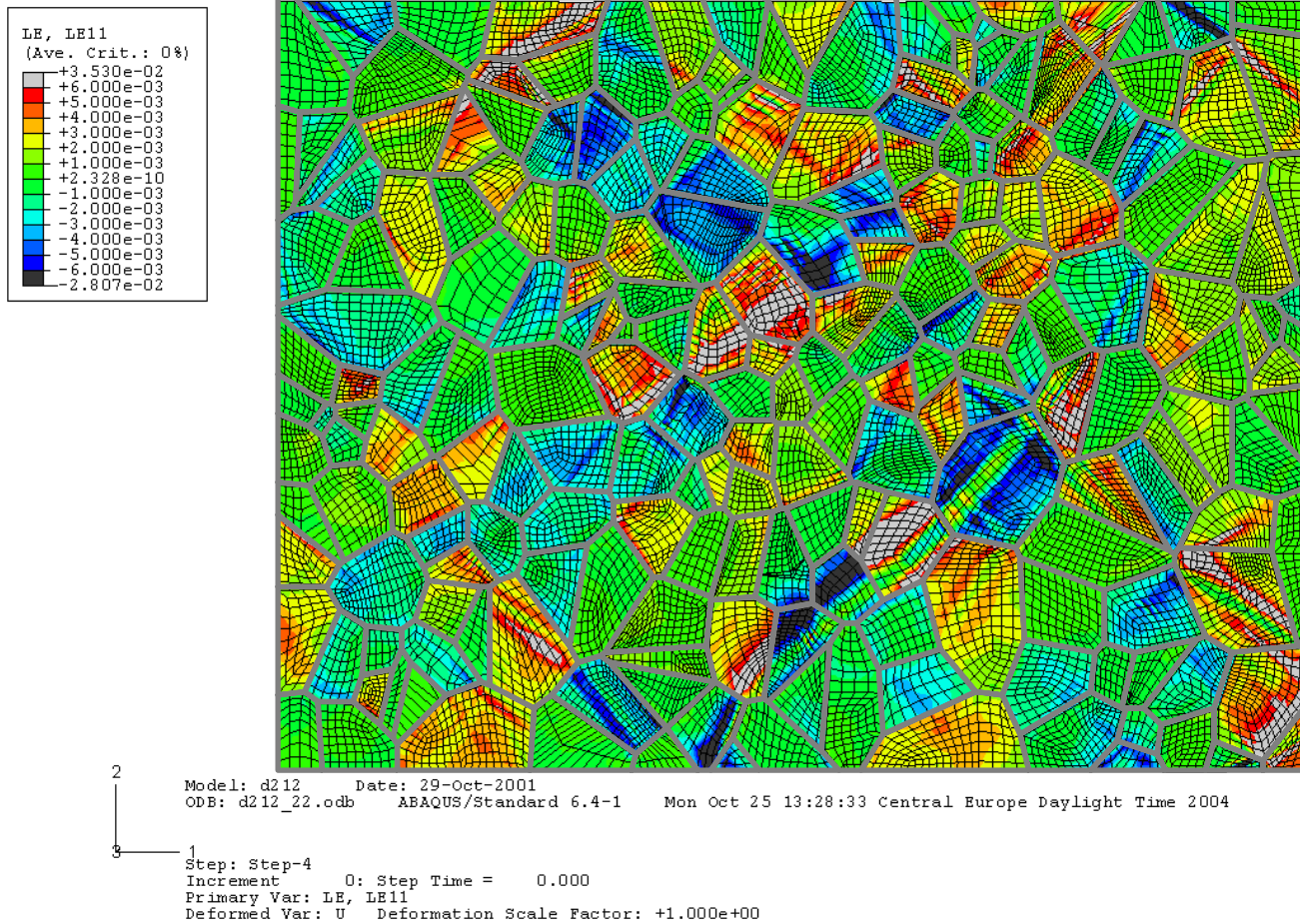
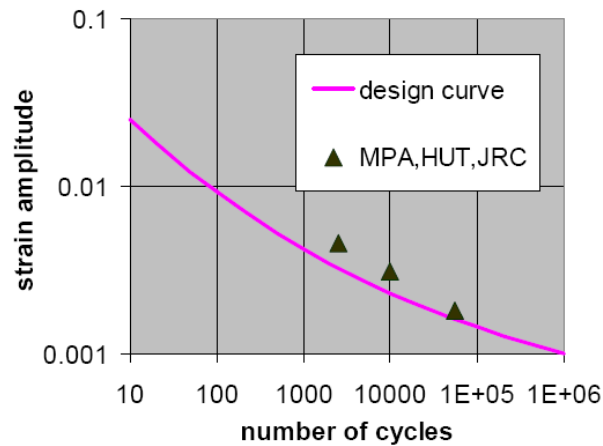
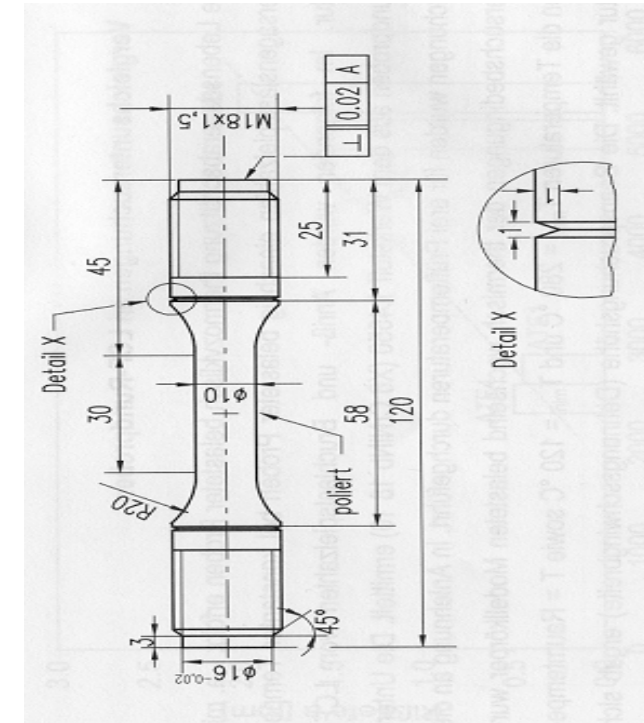


Figure 40: JSI, micro-structure modeling, analysis of the JRC experiment

Institution	EdF	MPA (not within THERFAT)	JRC	HUT/VT (not within THERFAT)
$T_{max} / ^\circ\text{C}$	230	280	300/400	300
$T_{min} / ^\circ\text{C}$	110	120	20/20	20
$\Delta T / \text{K}$	120	160	275/375	280
$T_{mean} = 0.25T_{min} + 0.75T_{max}$	200	240	230/305	230
Axial strain amplitude / m/m	unknown	0.0046	0.0018/ \pm	0.0032
Number to Initiation /cycles	125000	2500	55600/20000	10000
Source	THERFAT, Cadarache meeting	Thesis Mangold	Paffumi, Nilsson, Taylor; ASTM2002	Thesis Virkkunen

Table 1: Compilation of experimental data from thermal fatigue tests



Test series	Strain amplitude	Expected number	Temperature
1	0.0032	10000	230
2	0.0018	50000	230
3	0.0016	100000	200
4	0.0009	2000000	200

Table 2: MPA test matrix for additional isothermal mechanical tests

Figure 41: WP 4.2 Compilation of thermal load tests and additional MPA specimen experiment

Fatigue assessment

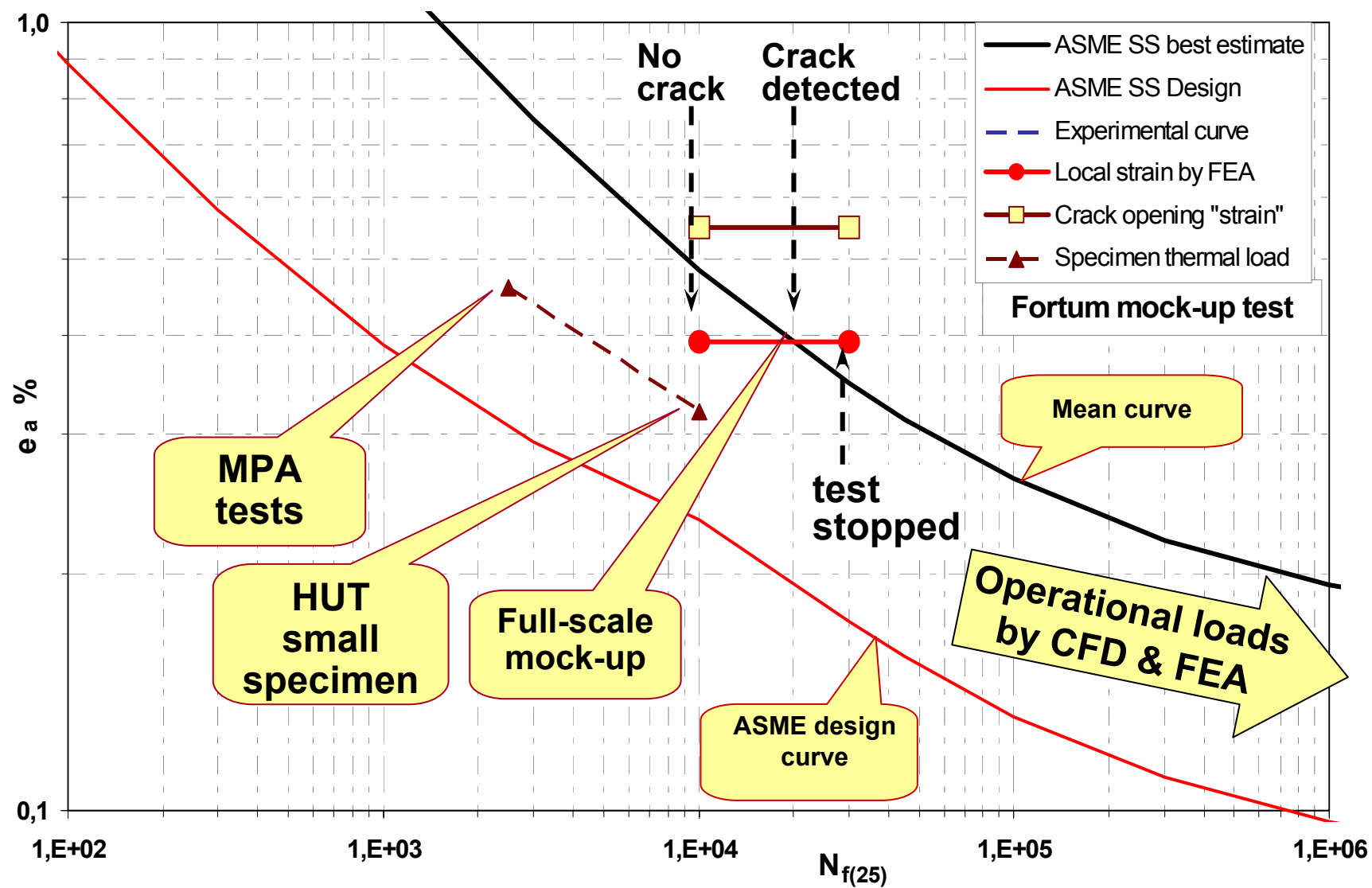


Figure 42: VTT, fatigue assessment according to experimental and analytic results

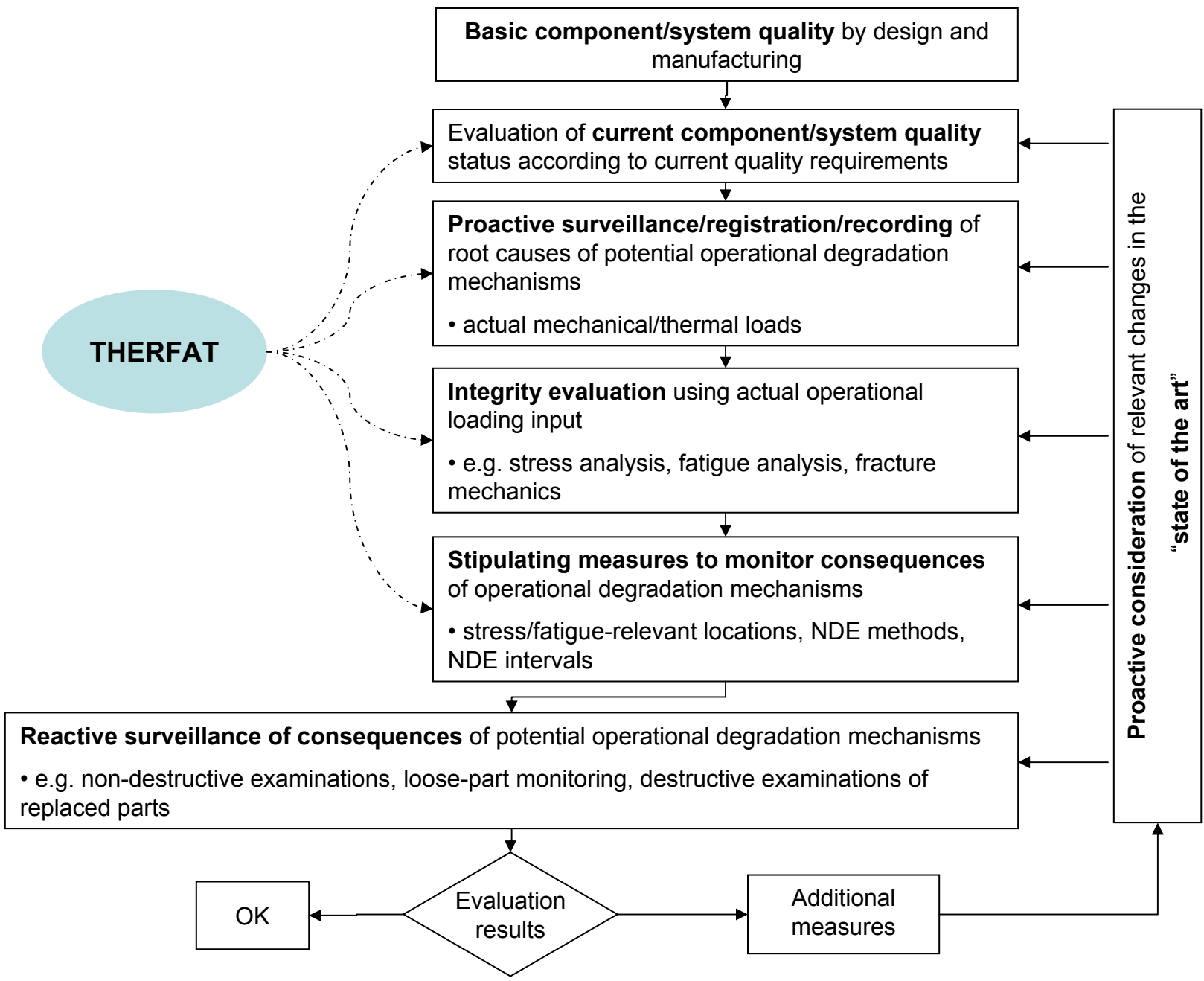


Figure 43: Overall integrity concept for safety-relevant structures in NPPs

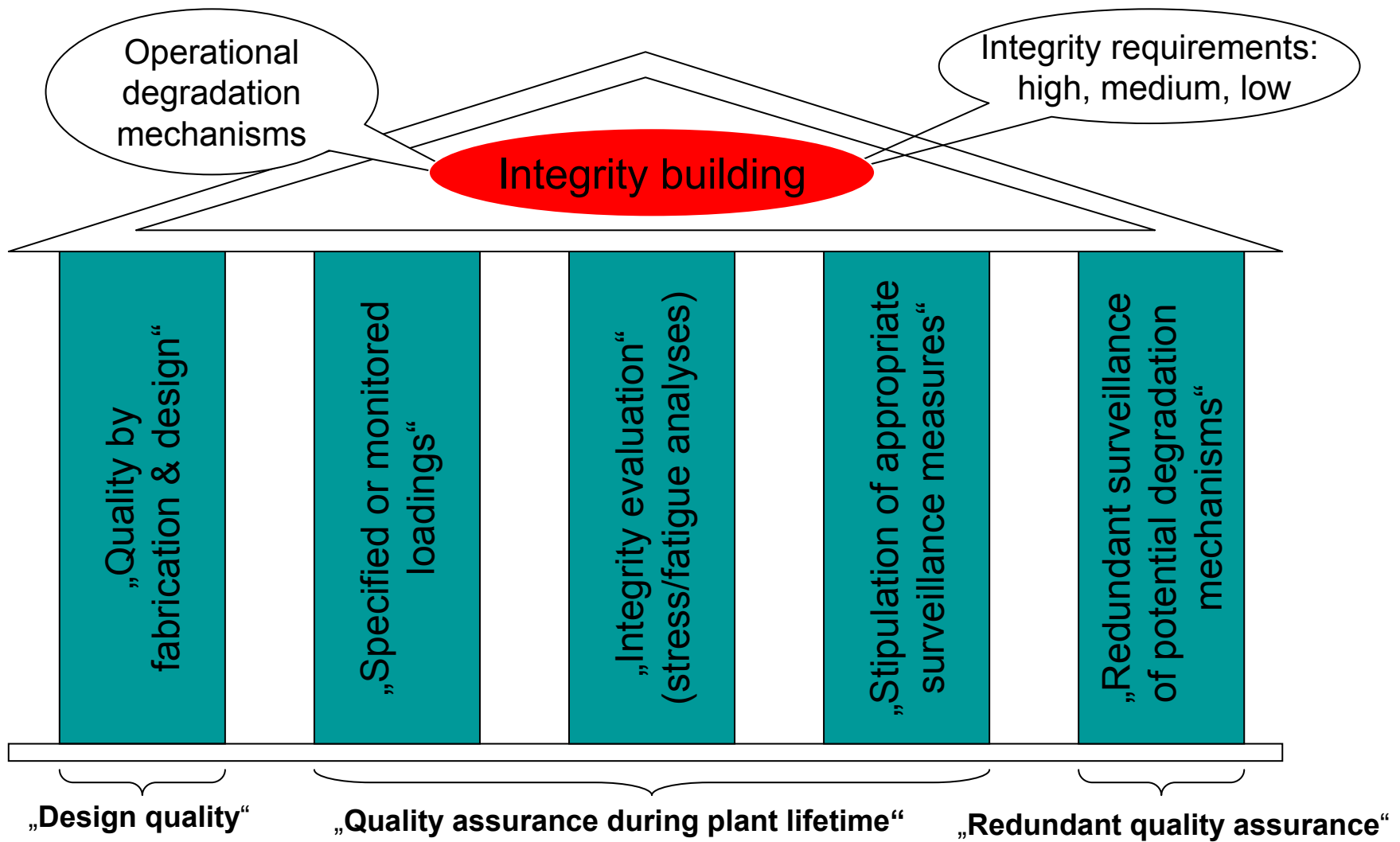


Figure 44: Integrity concept: the “integrity building”