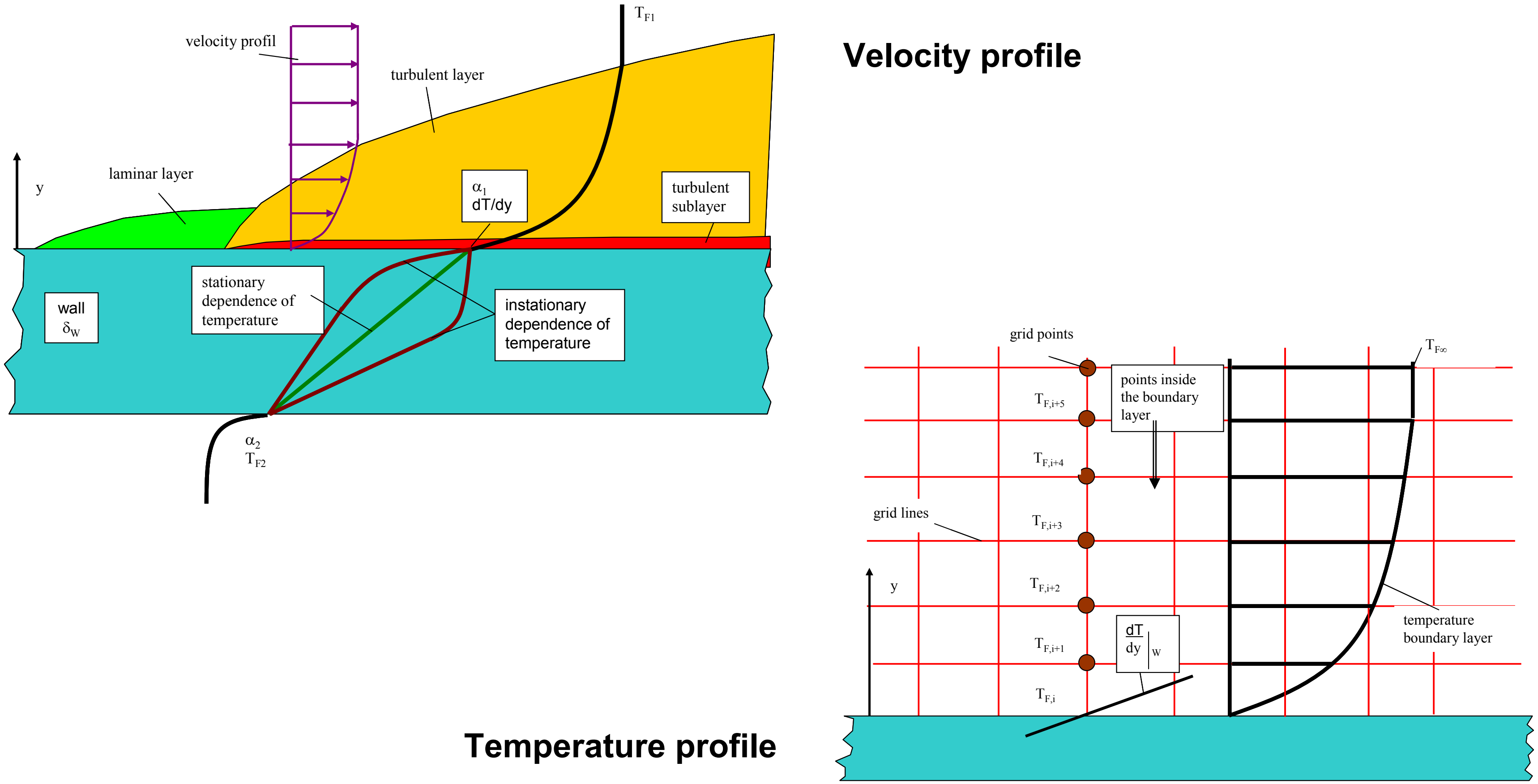


Figure 15: CFD calculation, fluid/wall-transition modelling parameter

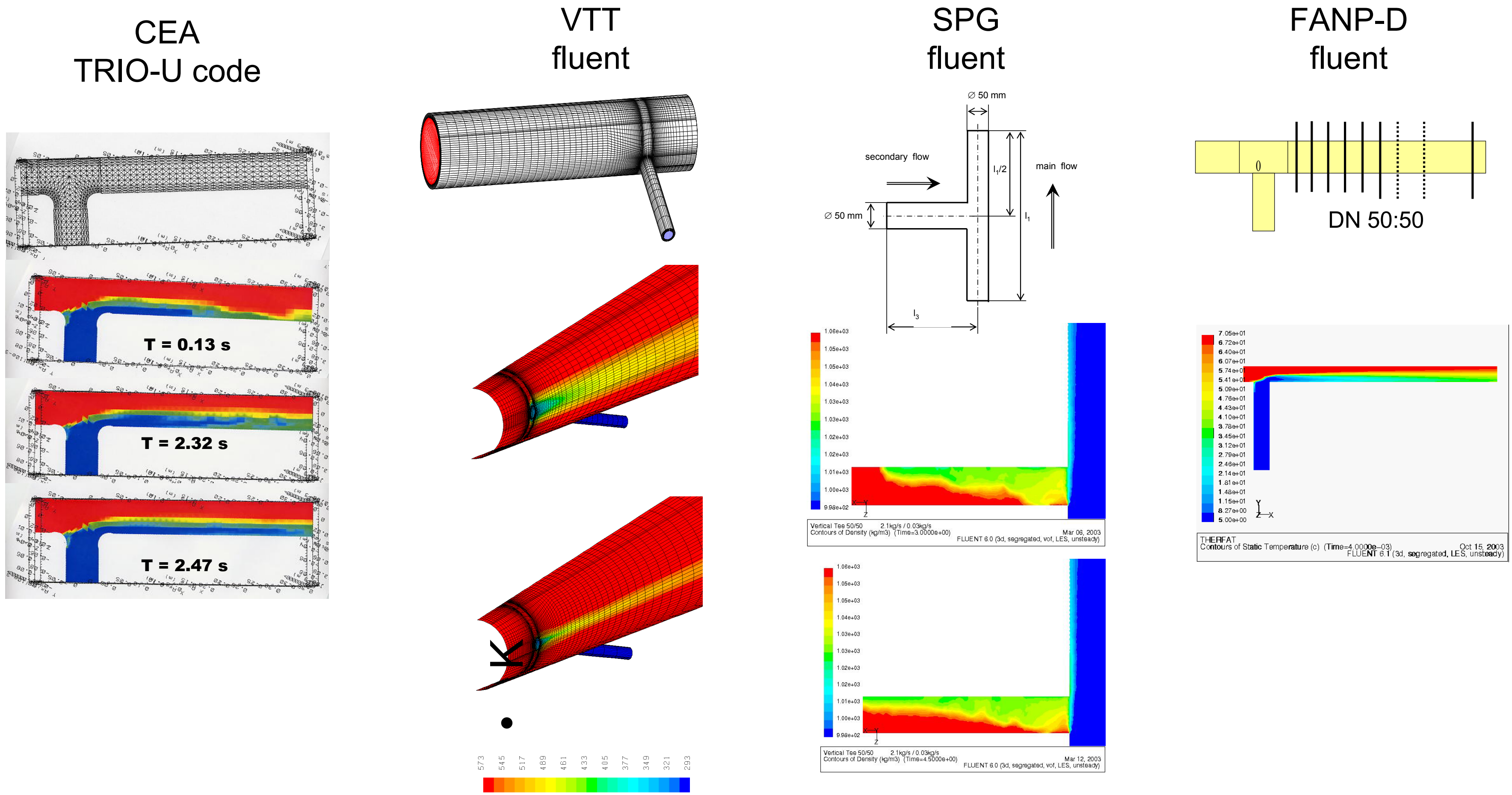


Figure 16: CFD calculations by different partners

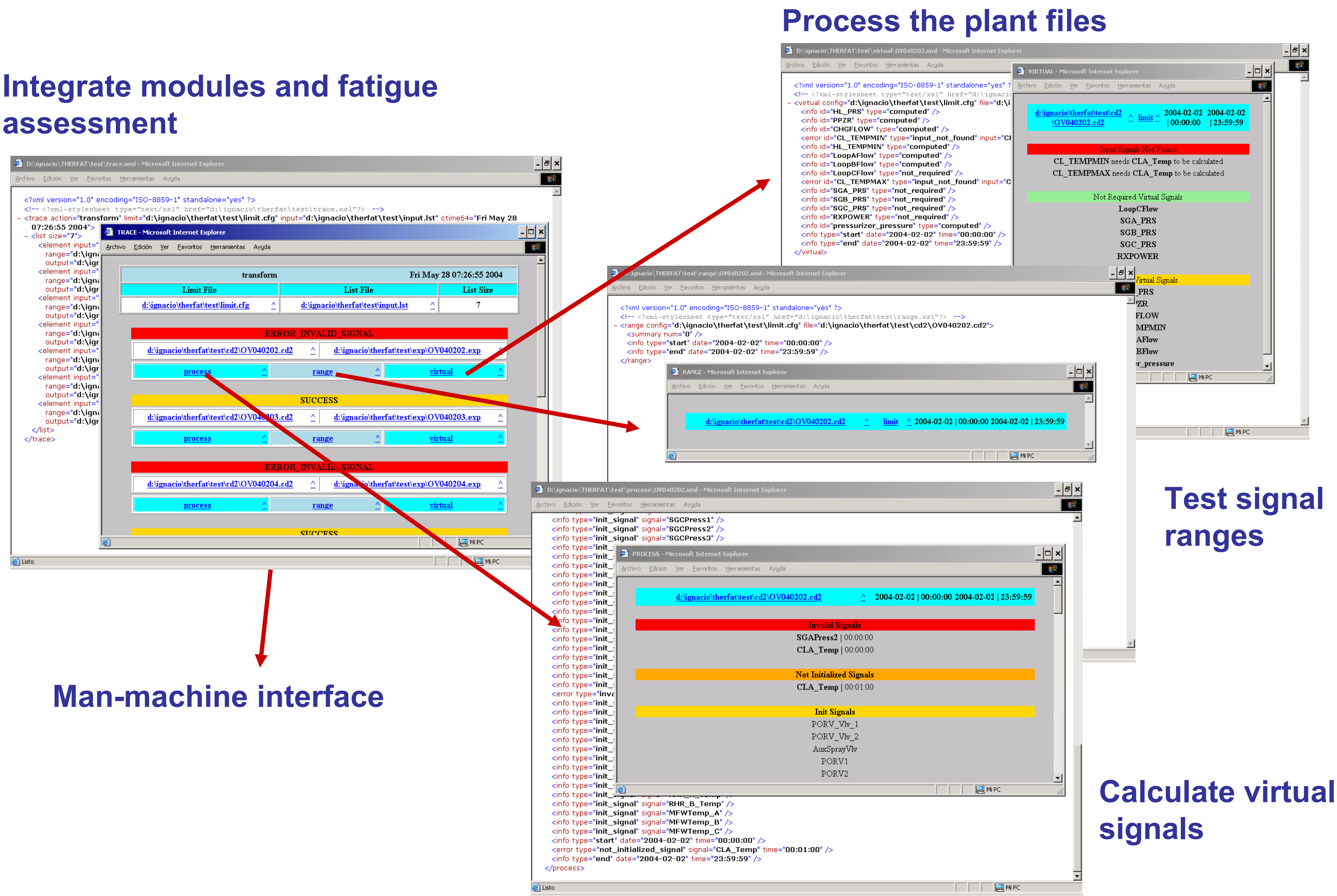


Figure 17: Virtual sensors, software application

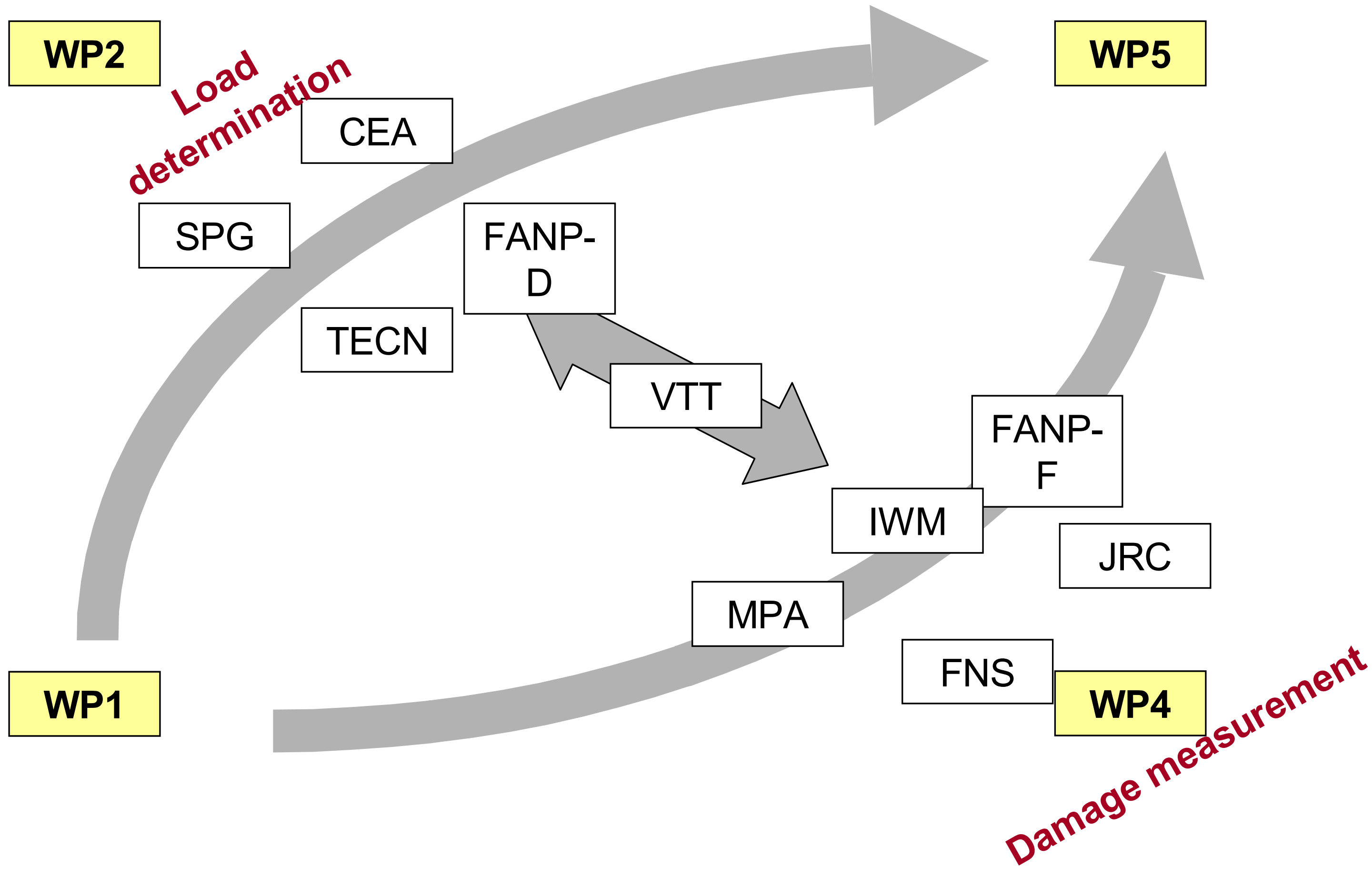


Figure 18: WP 3 partner roles

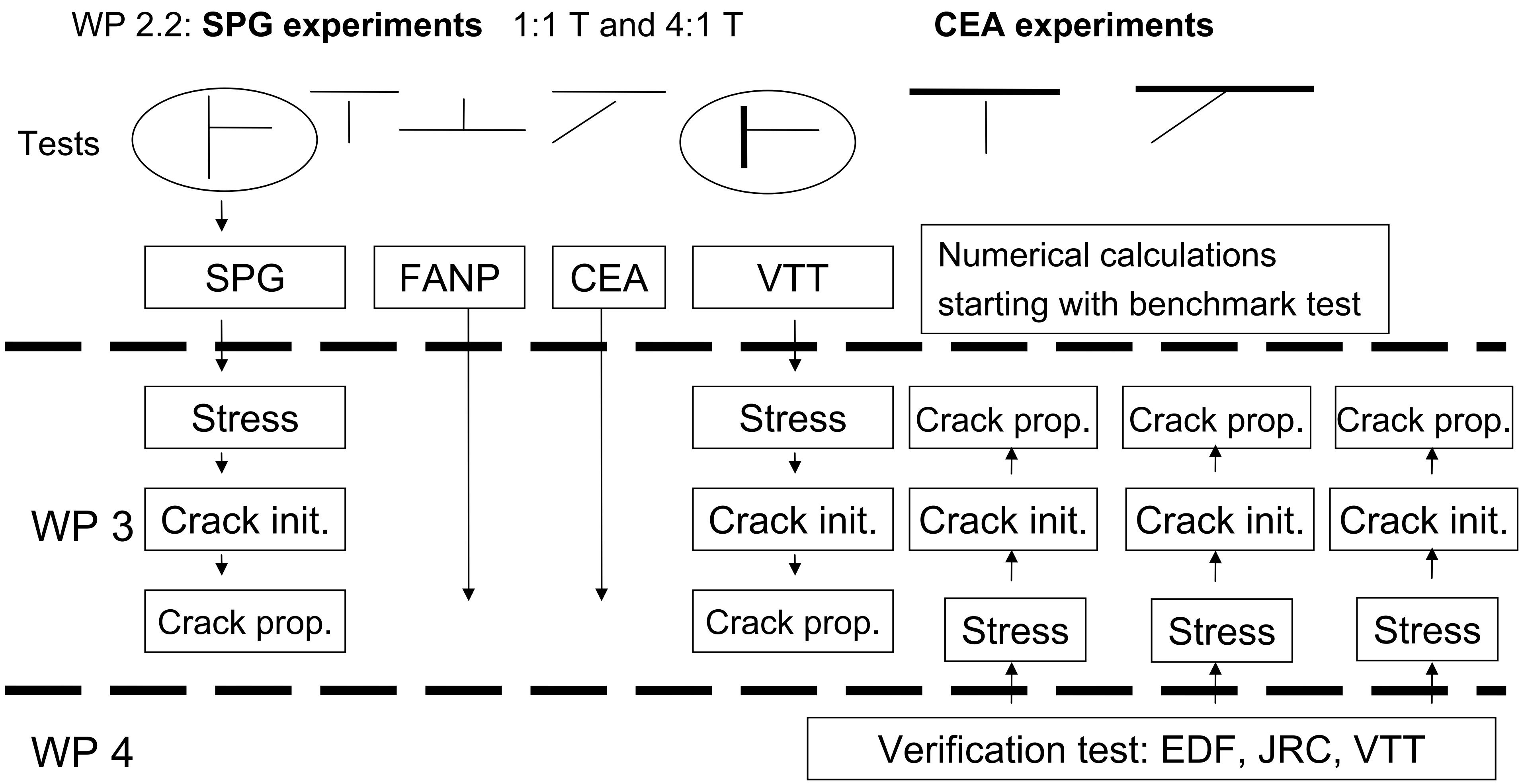


Figure 19: Integrity evaluation ("forward" and "backward" approach)

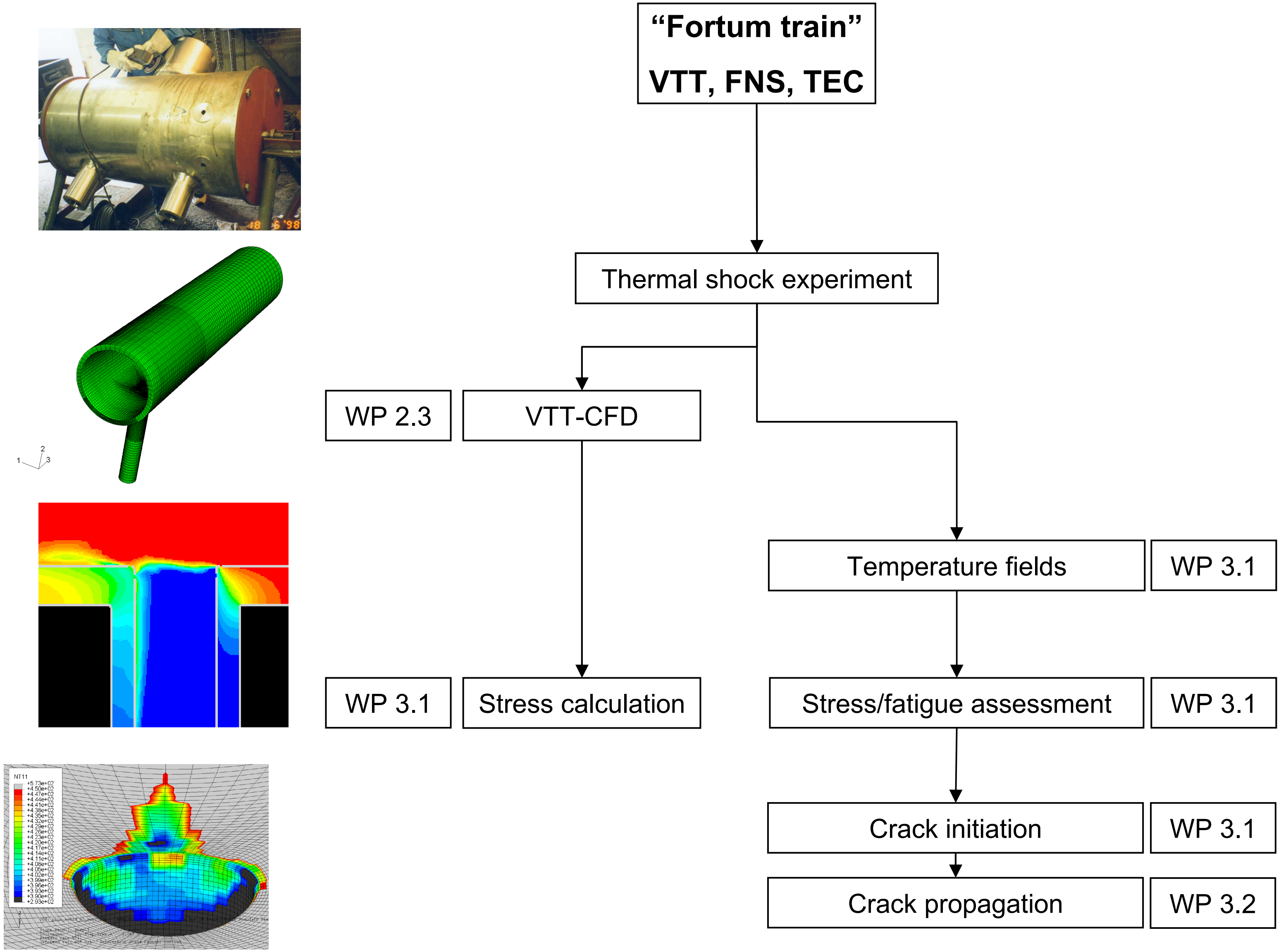


Figure 20: "Fortum train" workflow, VTT, FNS, TEC

Fortum train: Mock-up

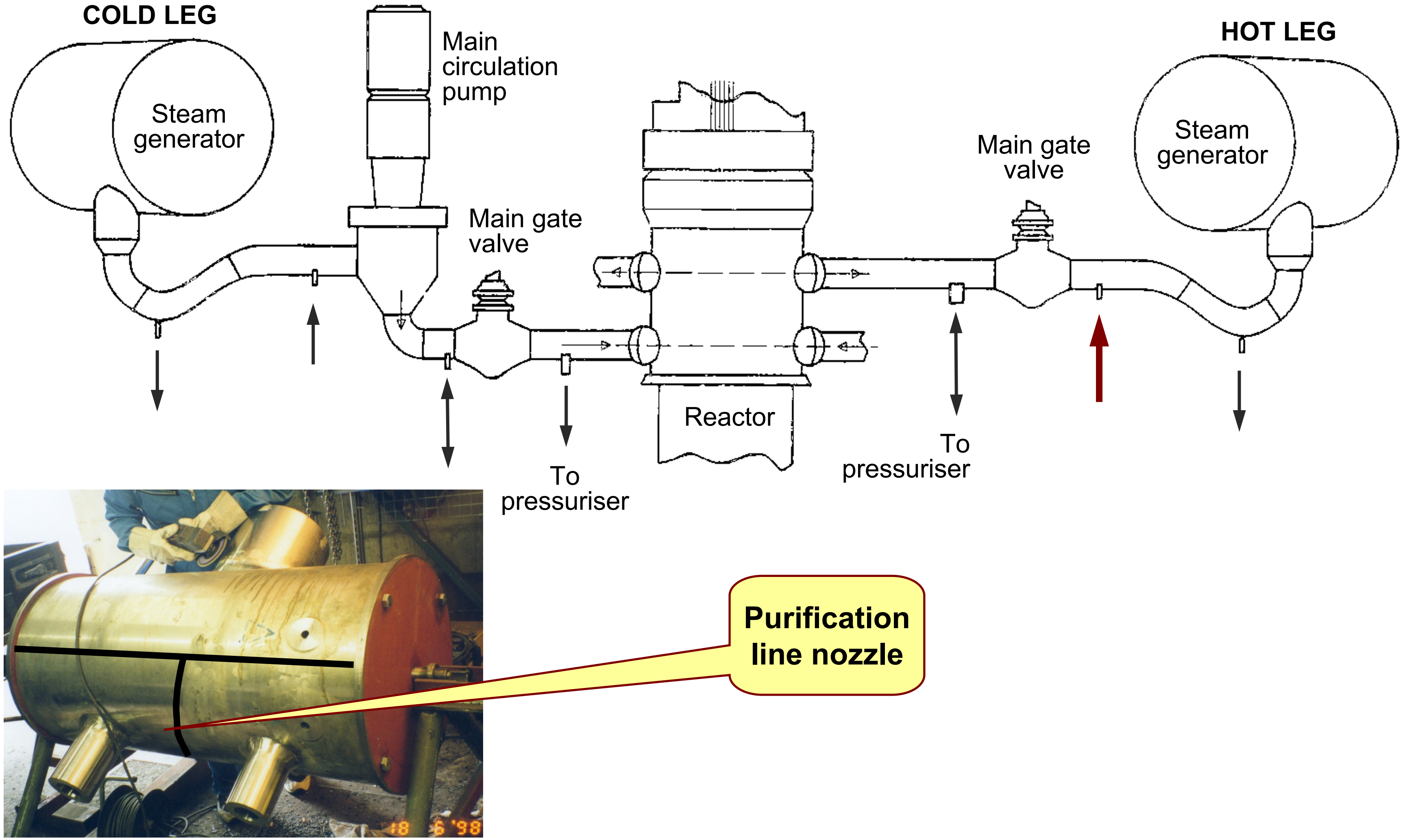
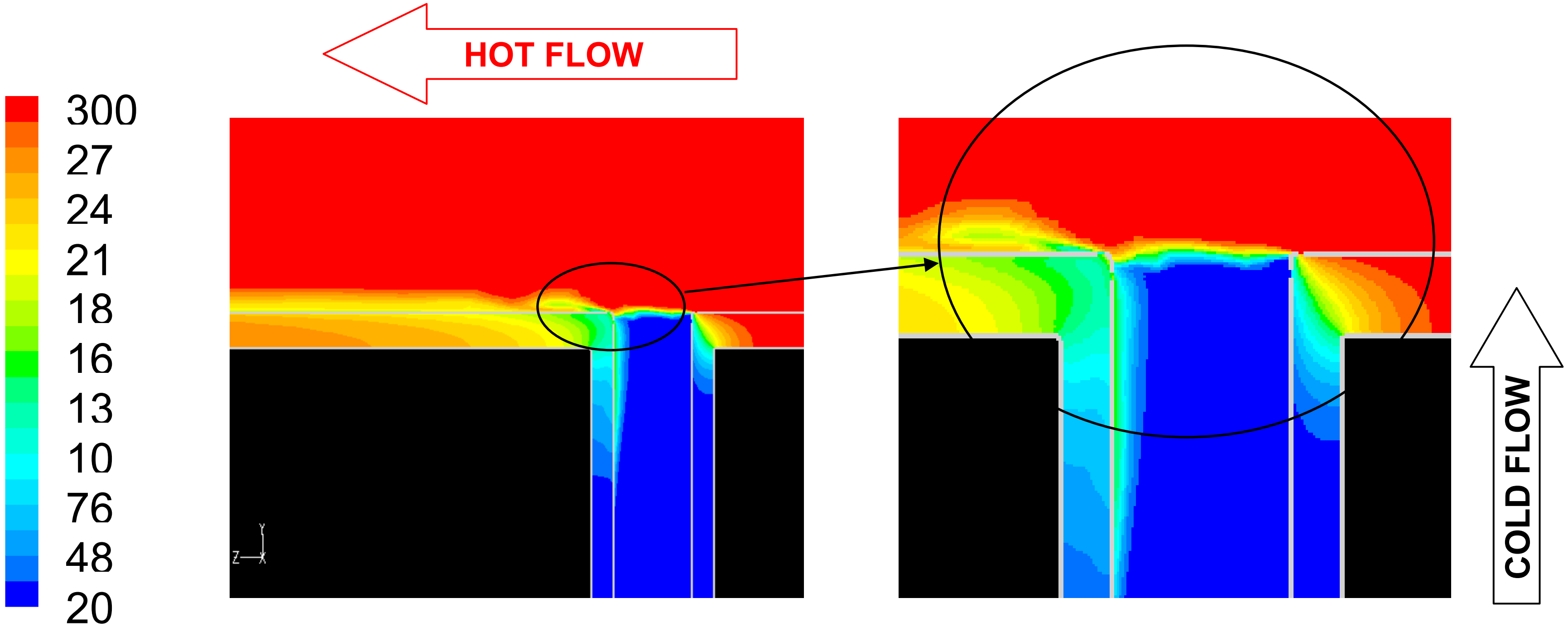


Figure 21: "Fortum train", thermal shock experiment mock-up

Cold jet penetrating into the primary pipe



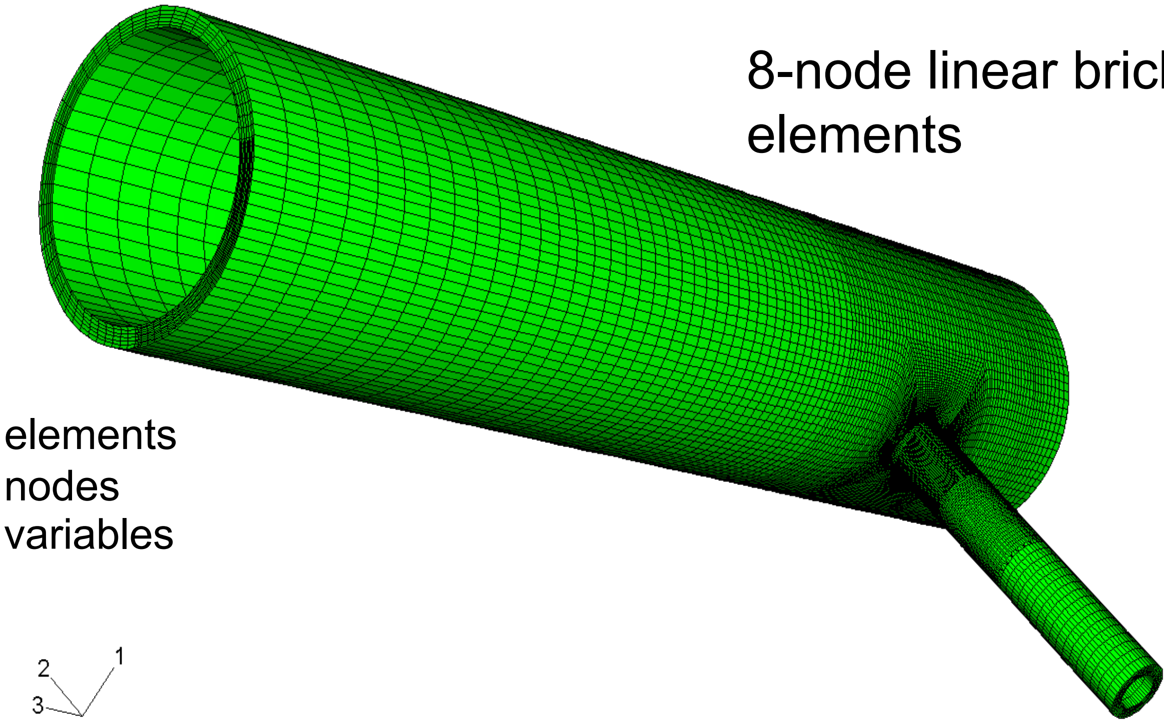
Steep oscillating temperature gradient in the round-off region of the T joint

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 ^{o}C**
- **cold-leg temperature 20 ^{o}C**
- **turbulent cycle 50 Hz**

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

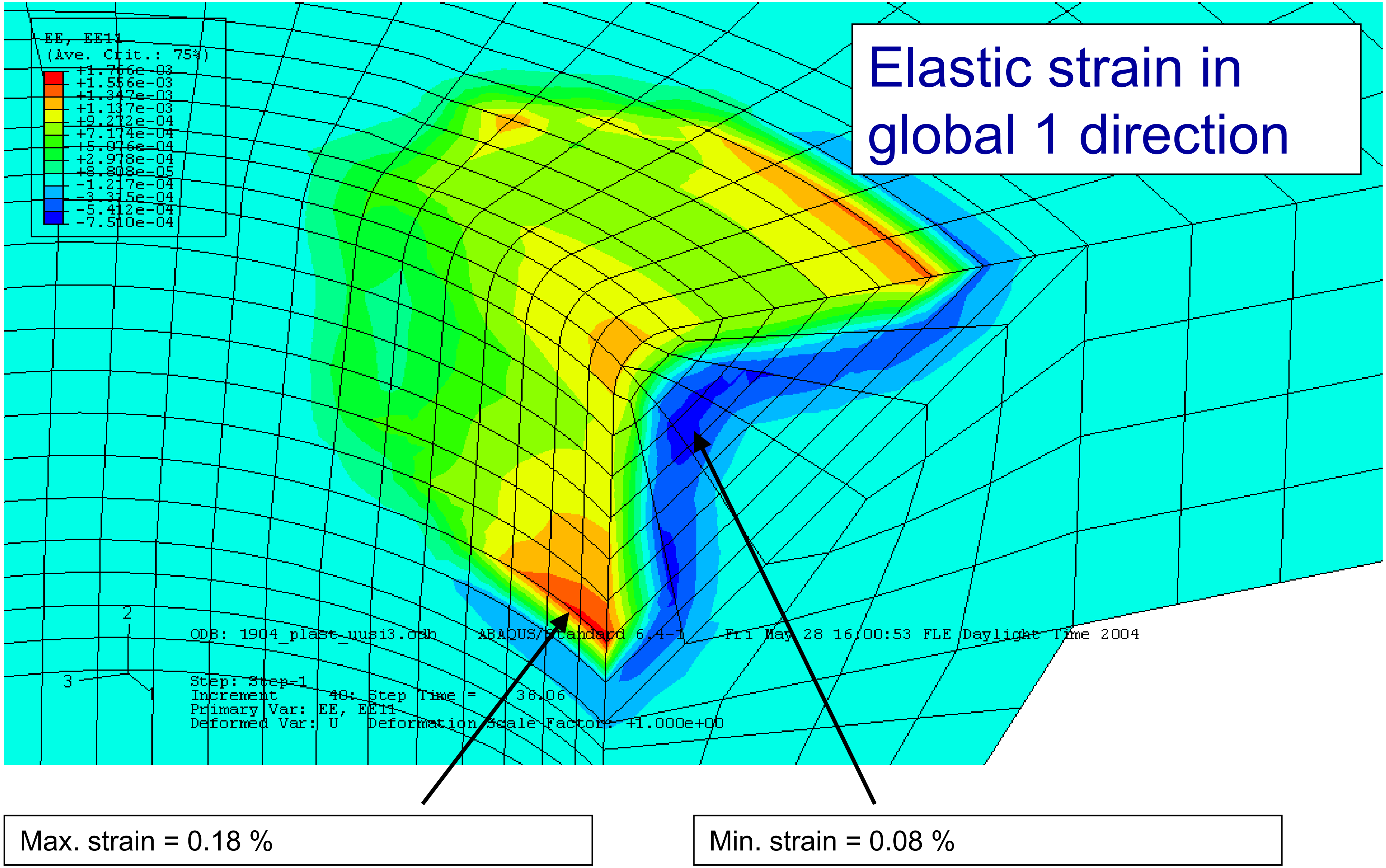
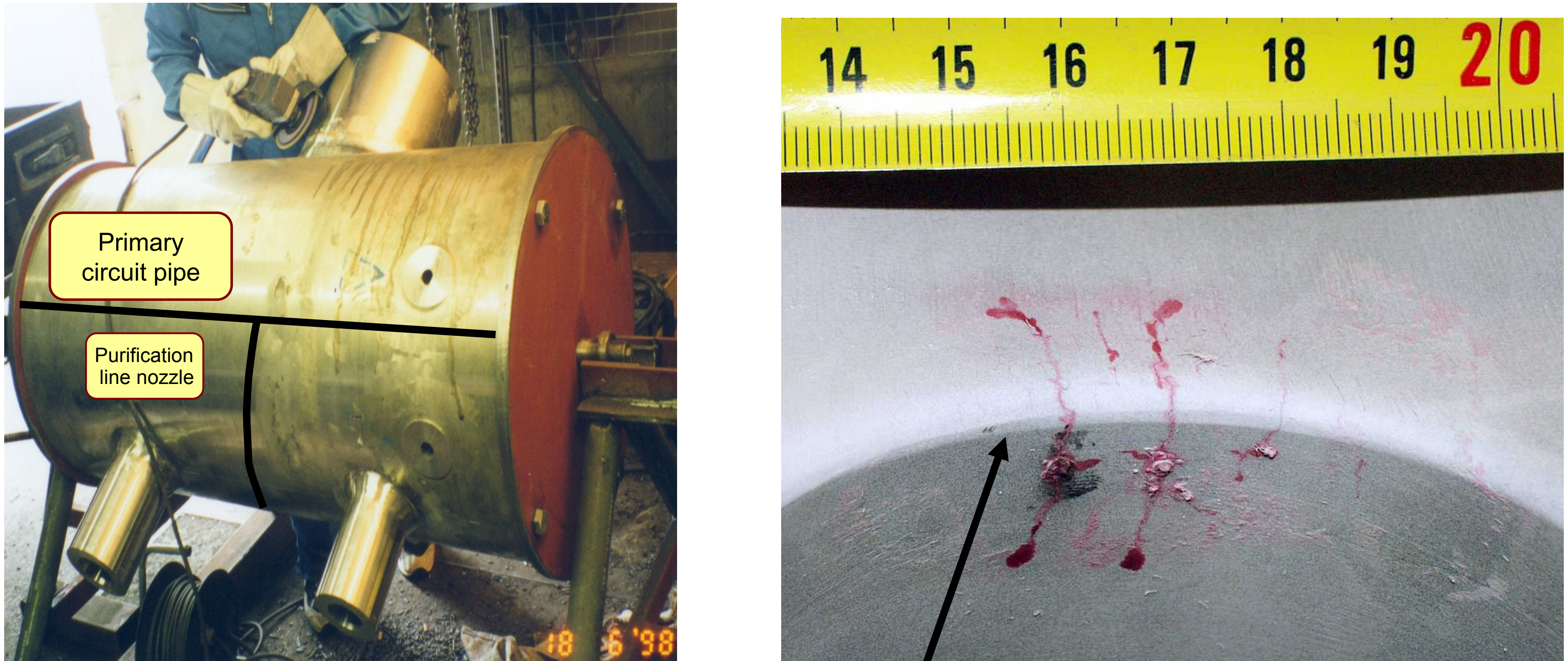


Figure 24: "Fortum train", stress analysis, elastic strains



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

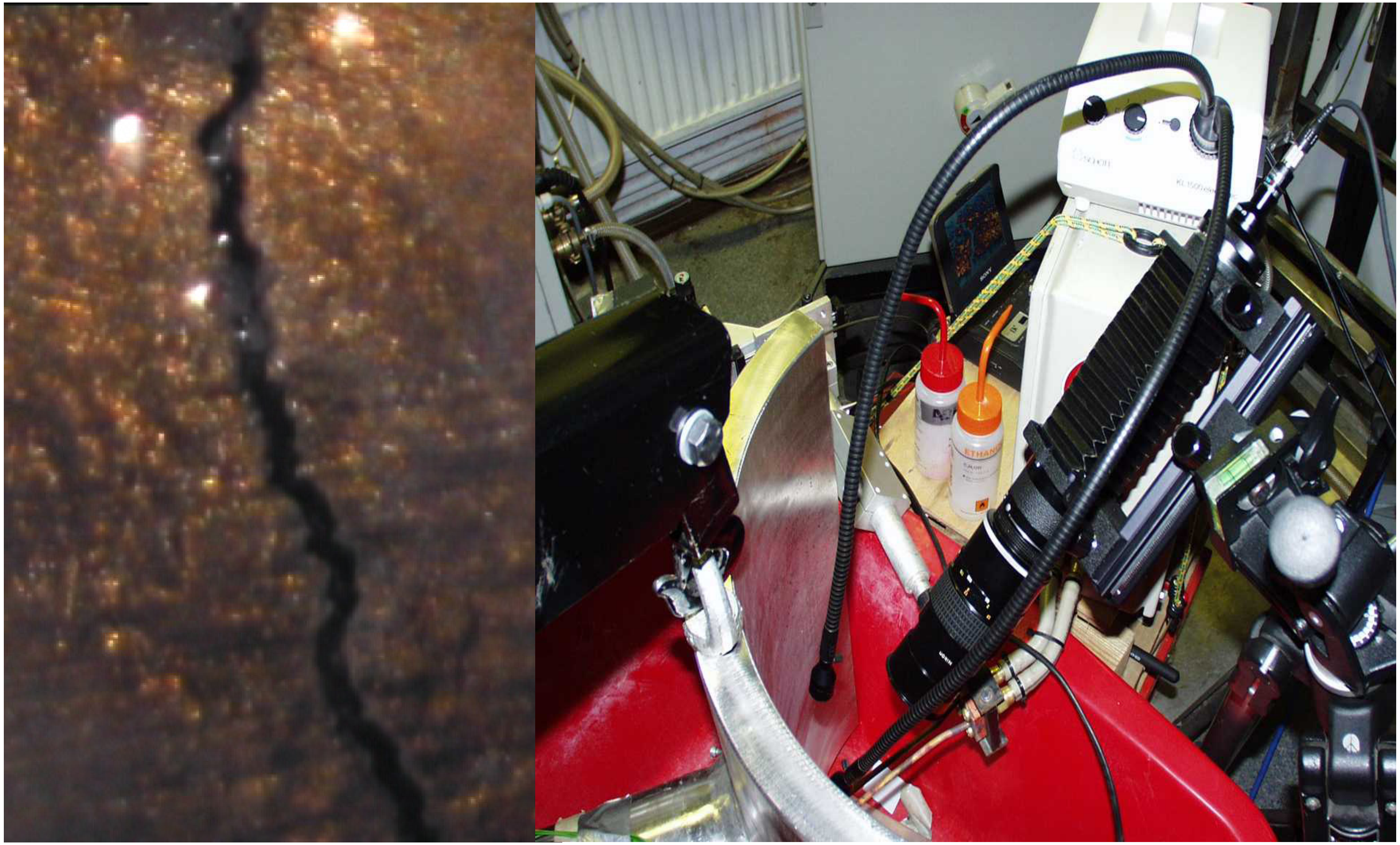


Figure 26: “Fortum train”, thermal shock experiment, crack monitoring

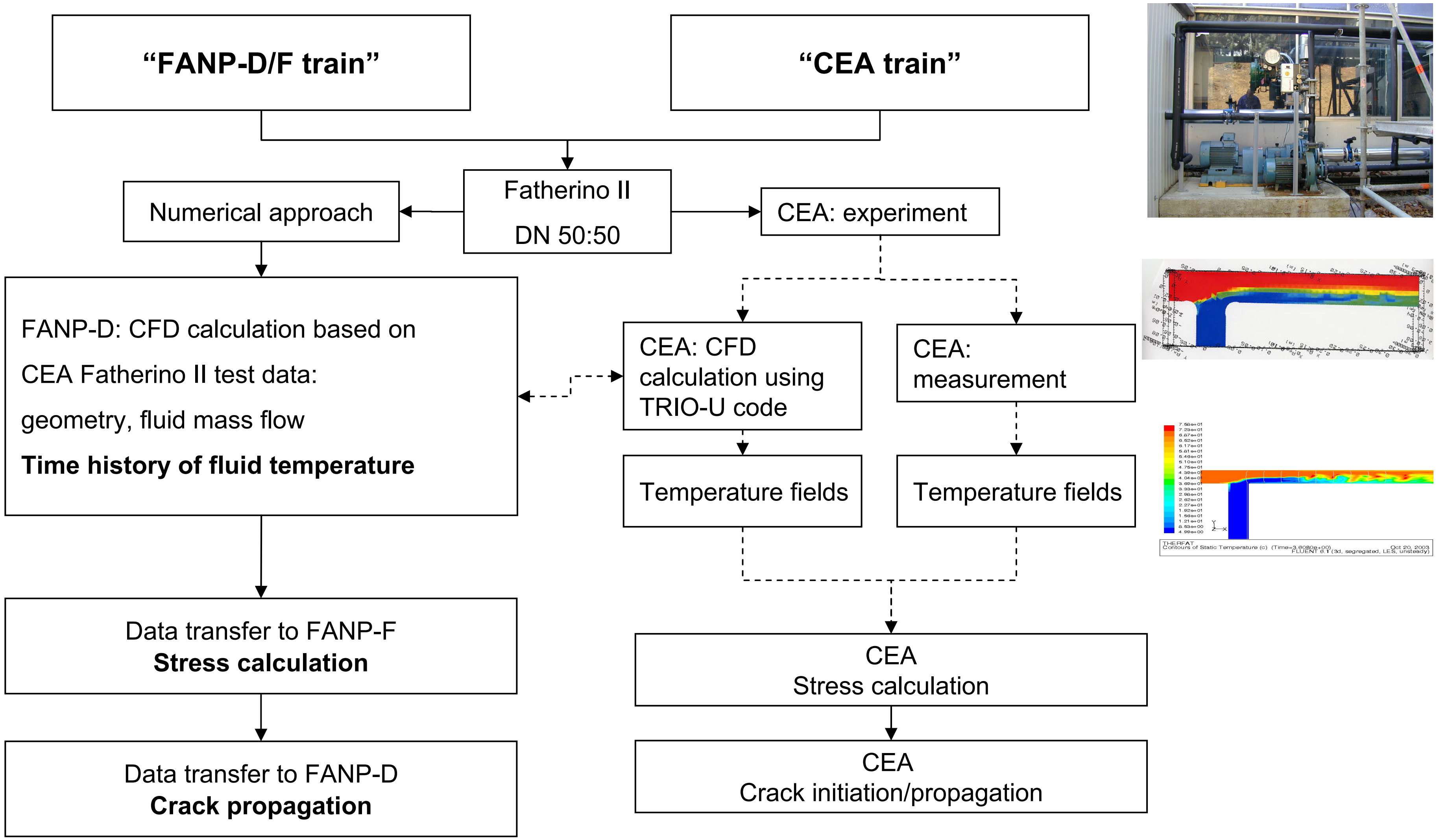


Figure 27: "FANP-D/F train" and "CEA train" workflow

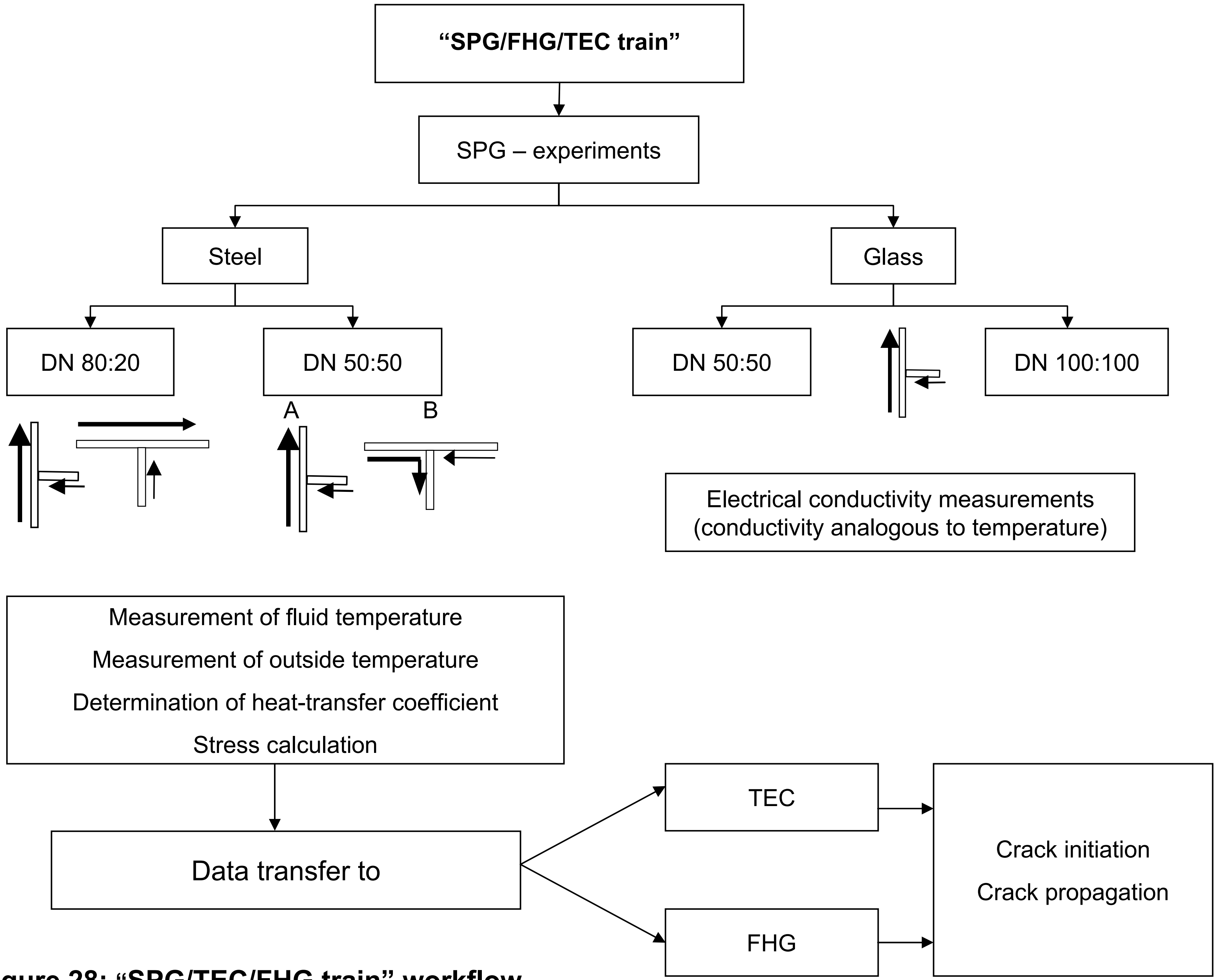


Figure 28: "SPG/TEC/FHG train" workflow

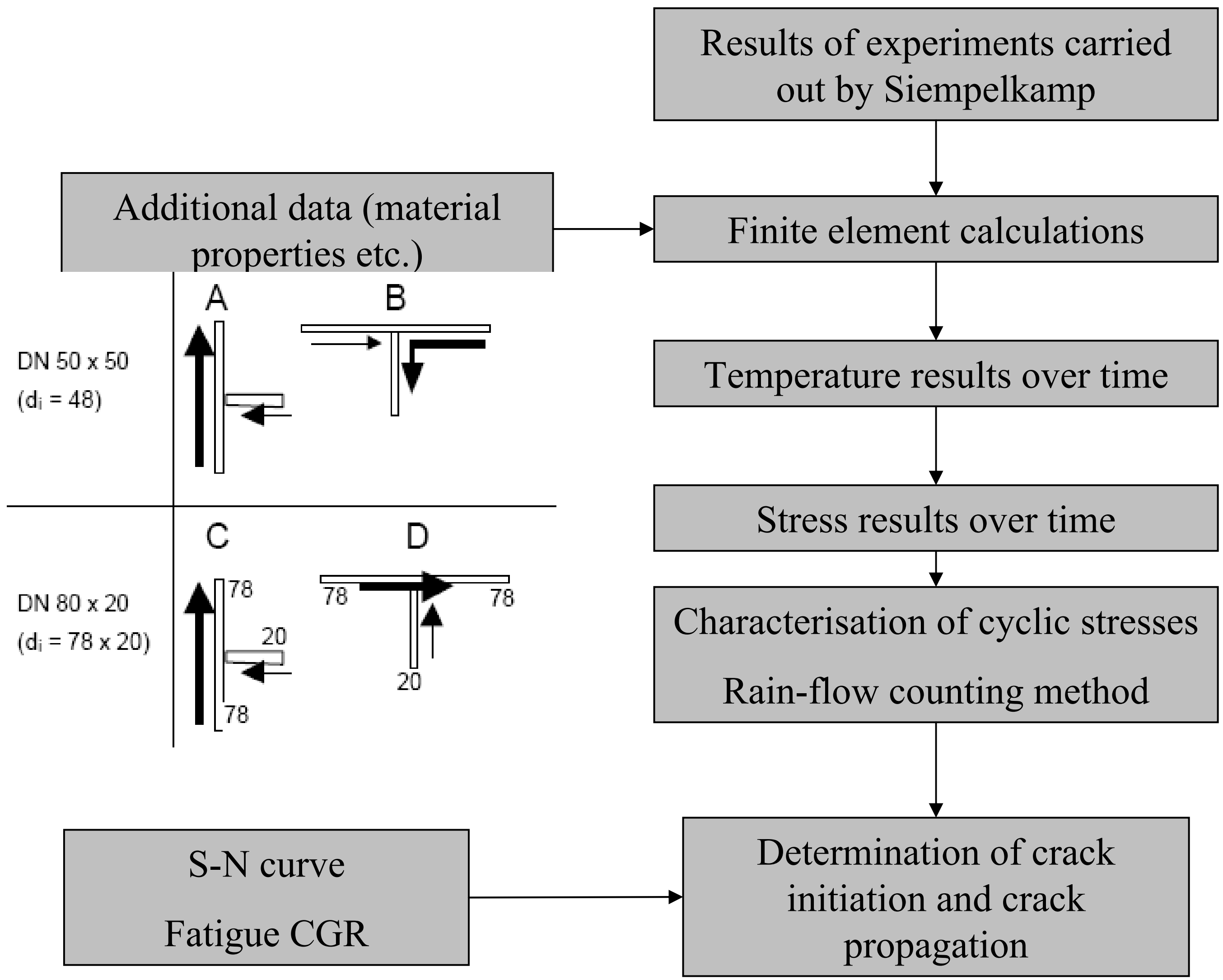


Figure 29: TEC, stress/crack analysis based on SPG Data

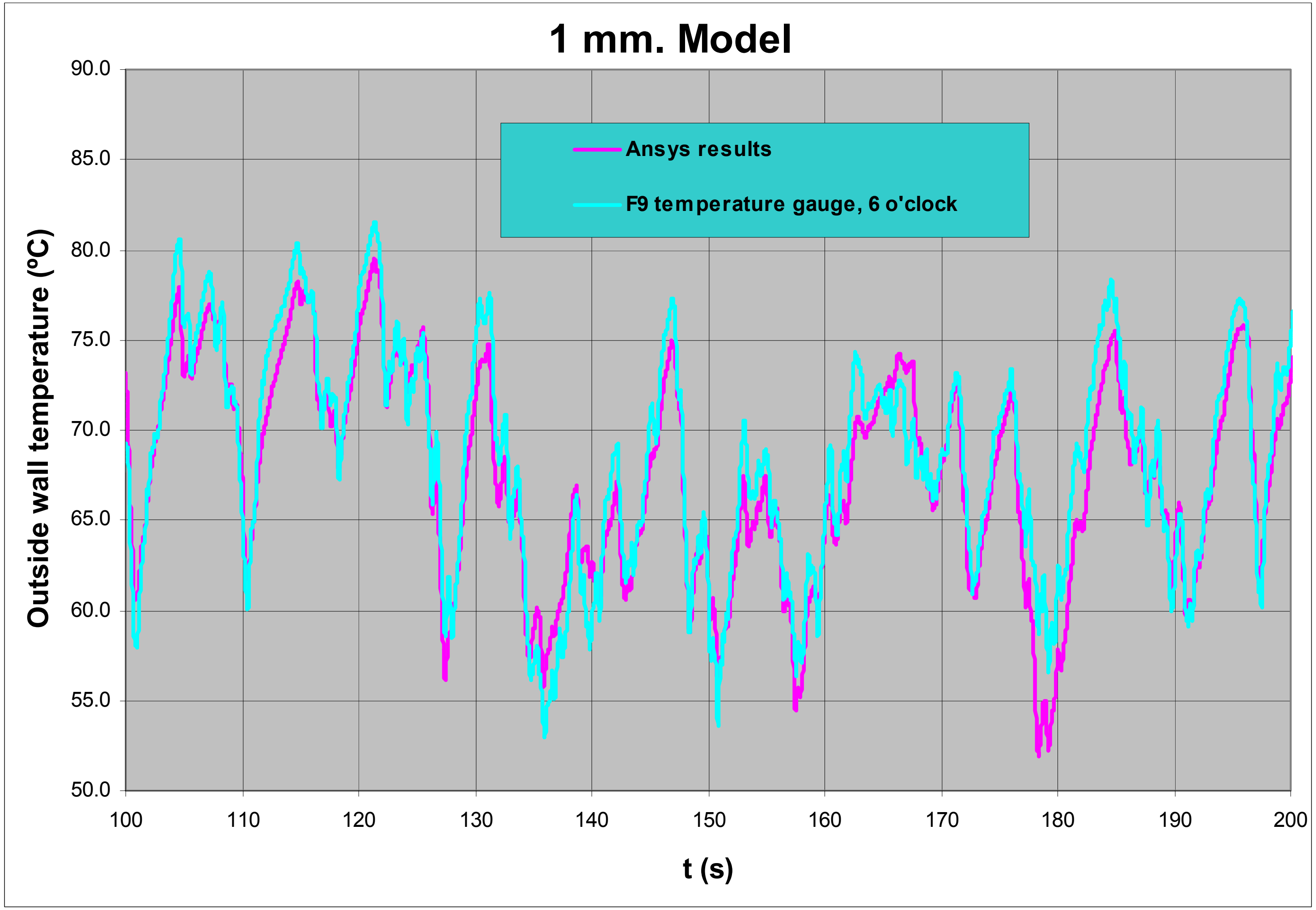
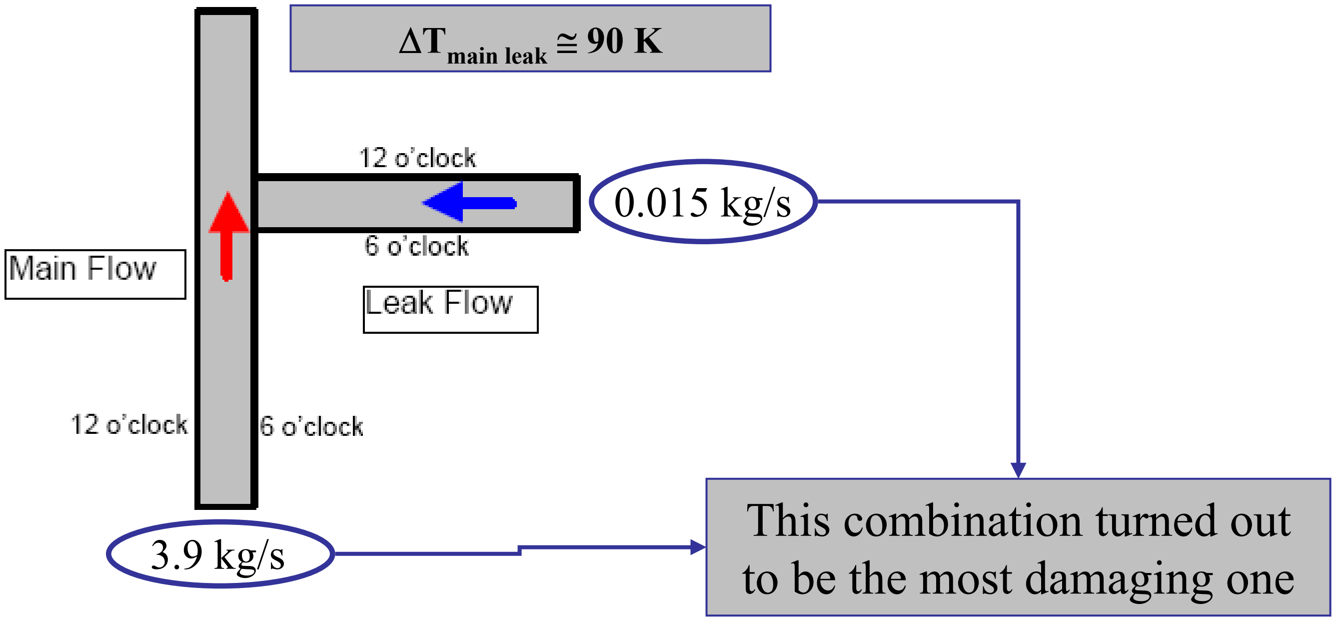


Figure 30: TEC, experimental versus analytical results

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

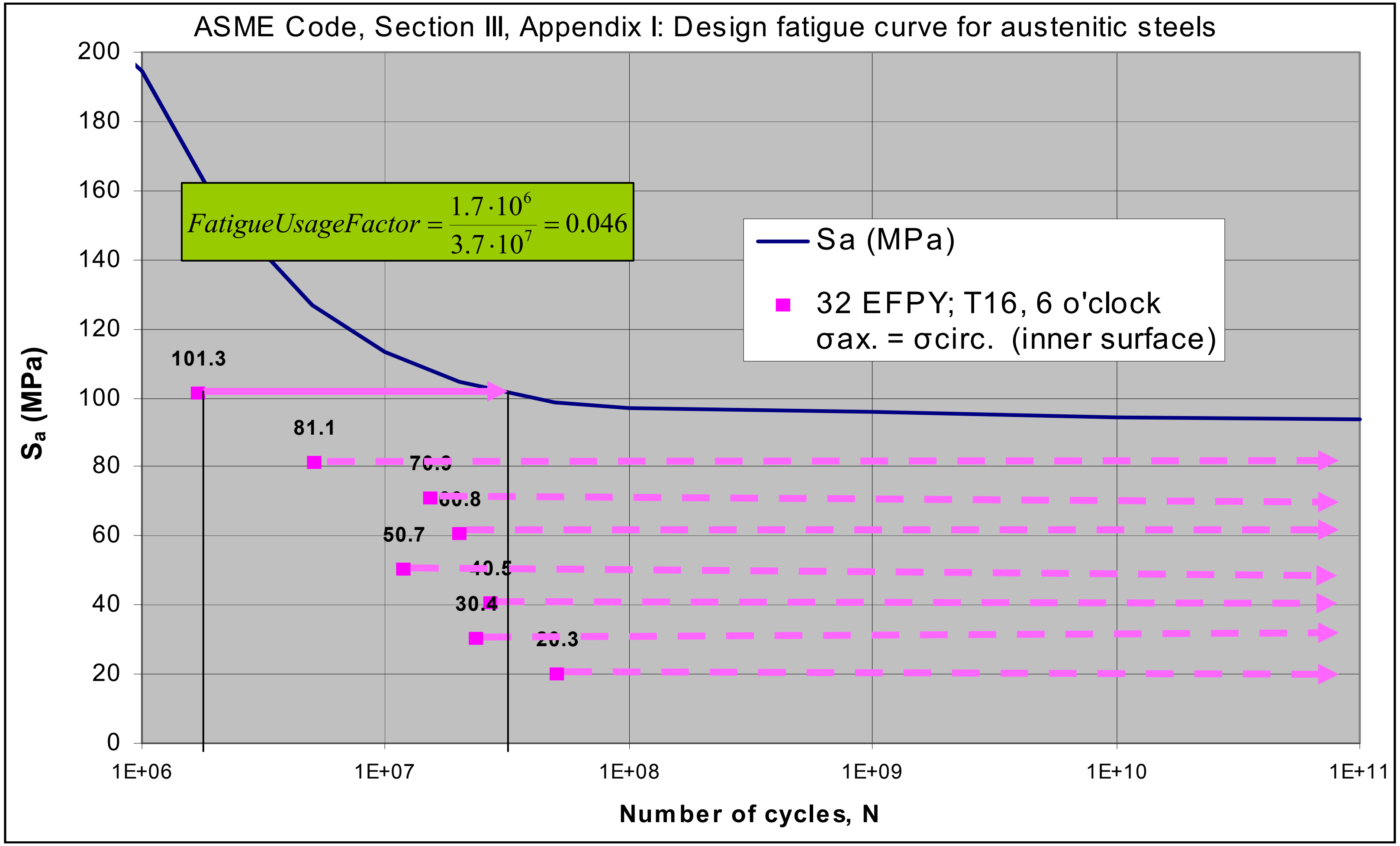


Figure 32: TEC; fatigue analysis of through-wall stresses; α experiment = 2000 W/(m²K)

Fatigue analysis

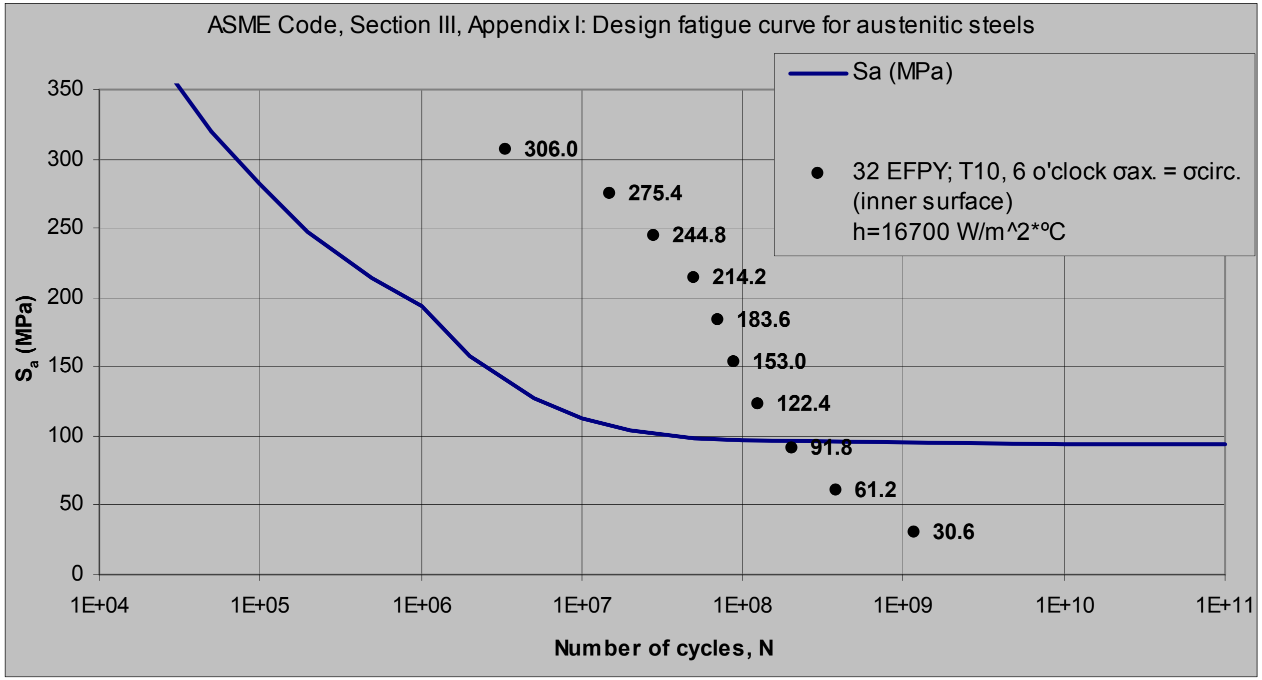


Figure 33: TEC; fatigue analysis of through-wall stresses; α Colburn = 16 700 W/(m²K)

Temperature and stress for the SPG geometry

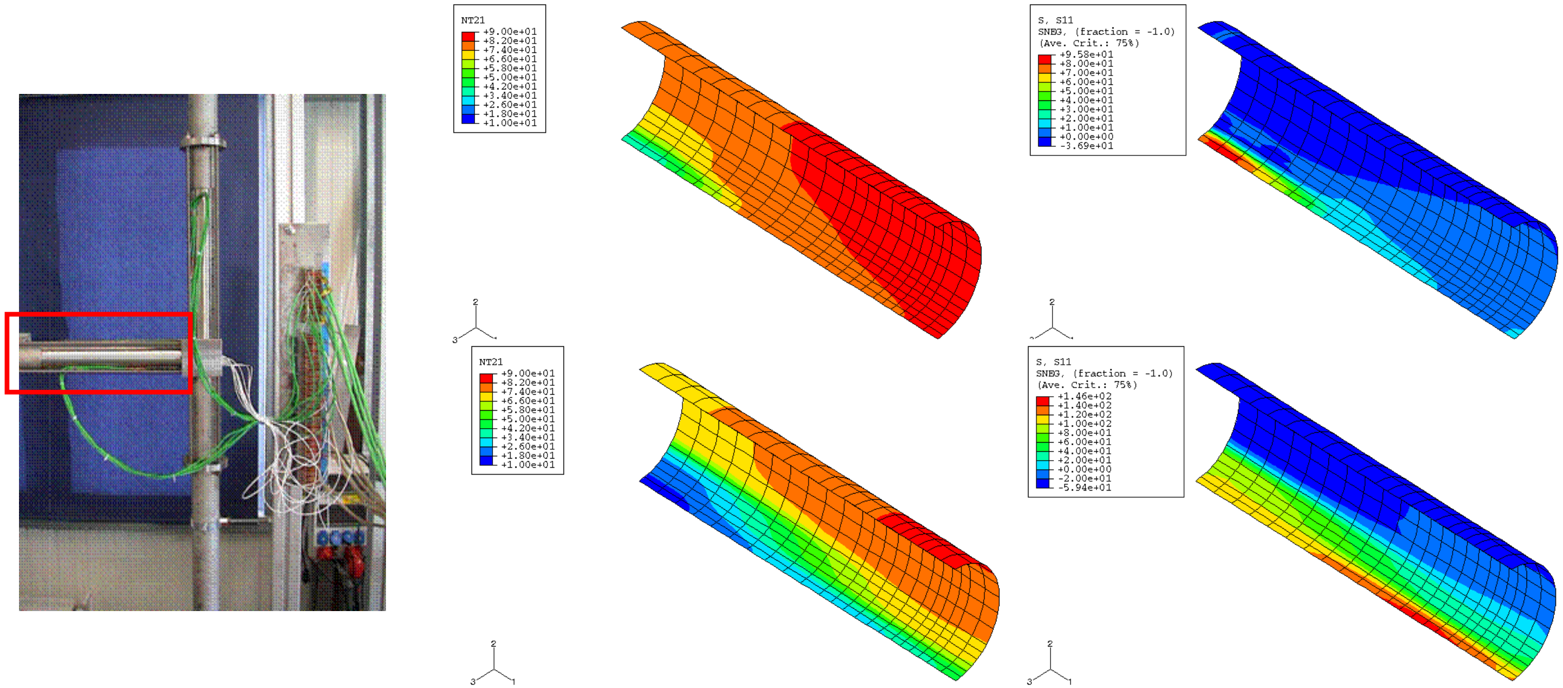
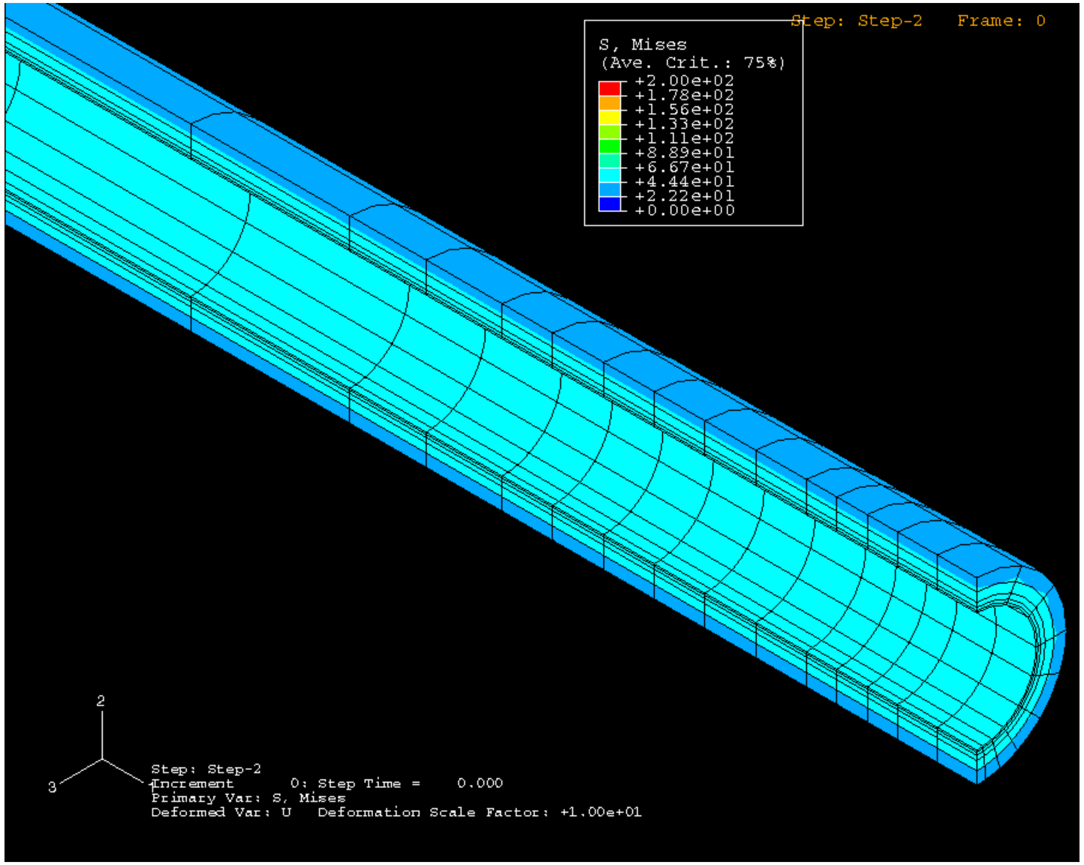
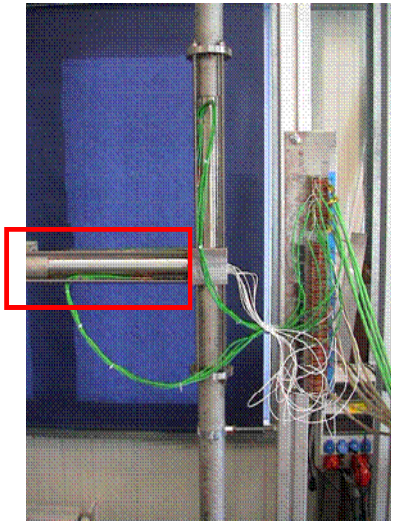


Figure 34: FHG, 3D-FE model for stress analysis and crack initiation/propagation

Stress variation: elastic-plastic analysis





ΔT = 250 °C

D_a = 59 mm, t = 10 mm

α = 5 kW/(m^2K), f = 0.1 Hz

Figure 35: FHG, elastic-plastic analysis

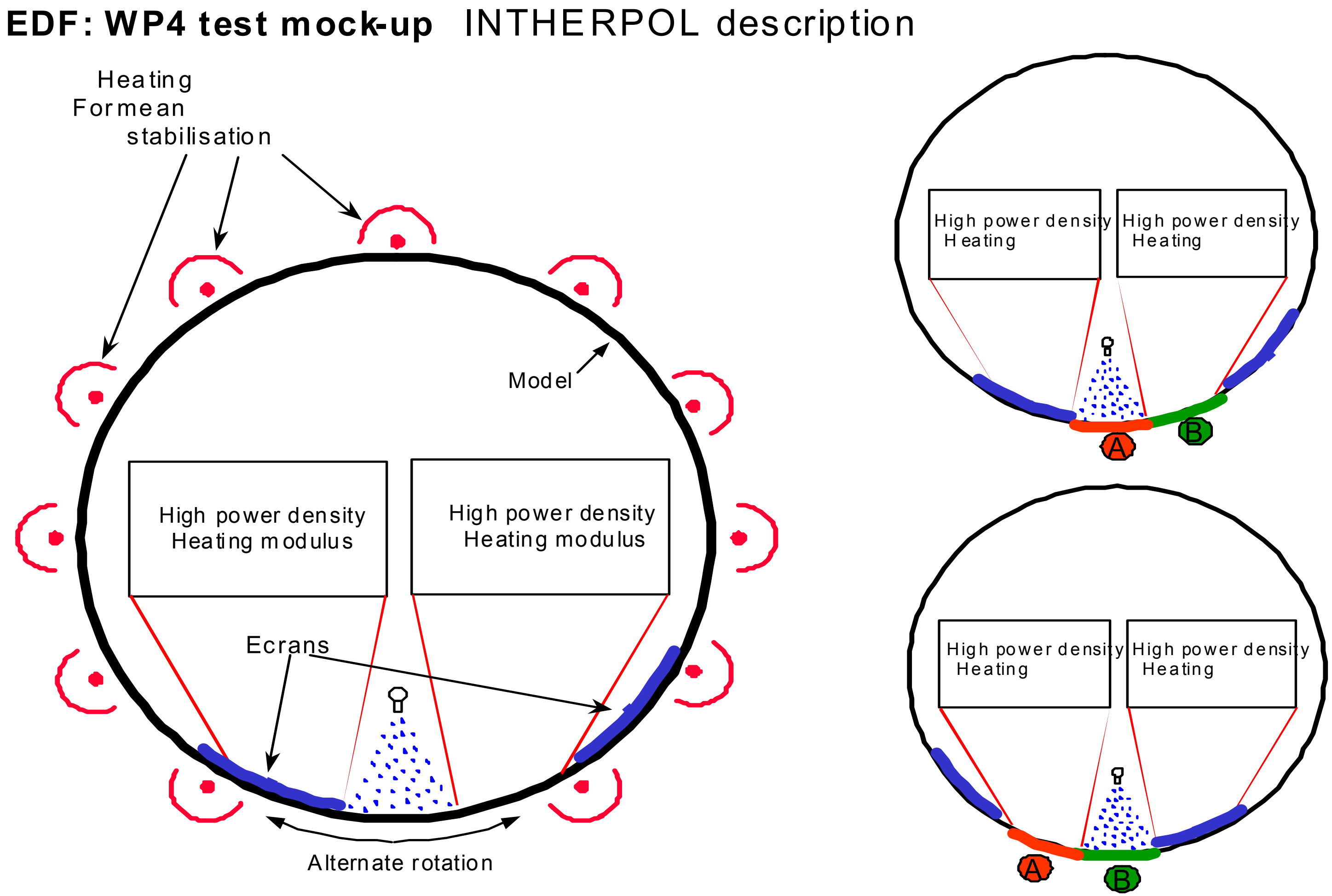


Figure 36: EDF-INTHERPOL "turning cylinder" test

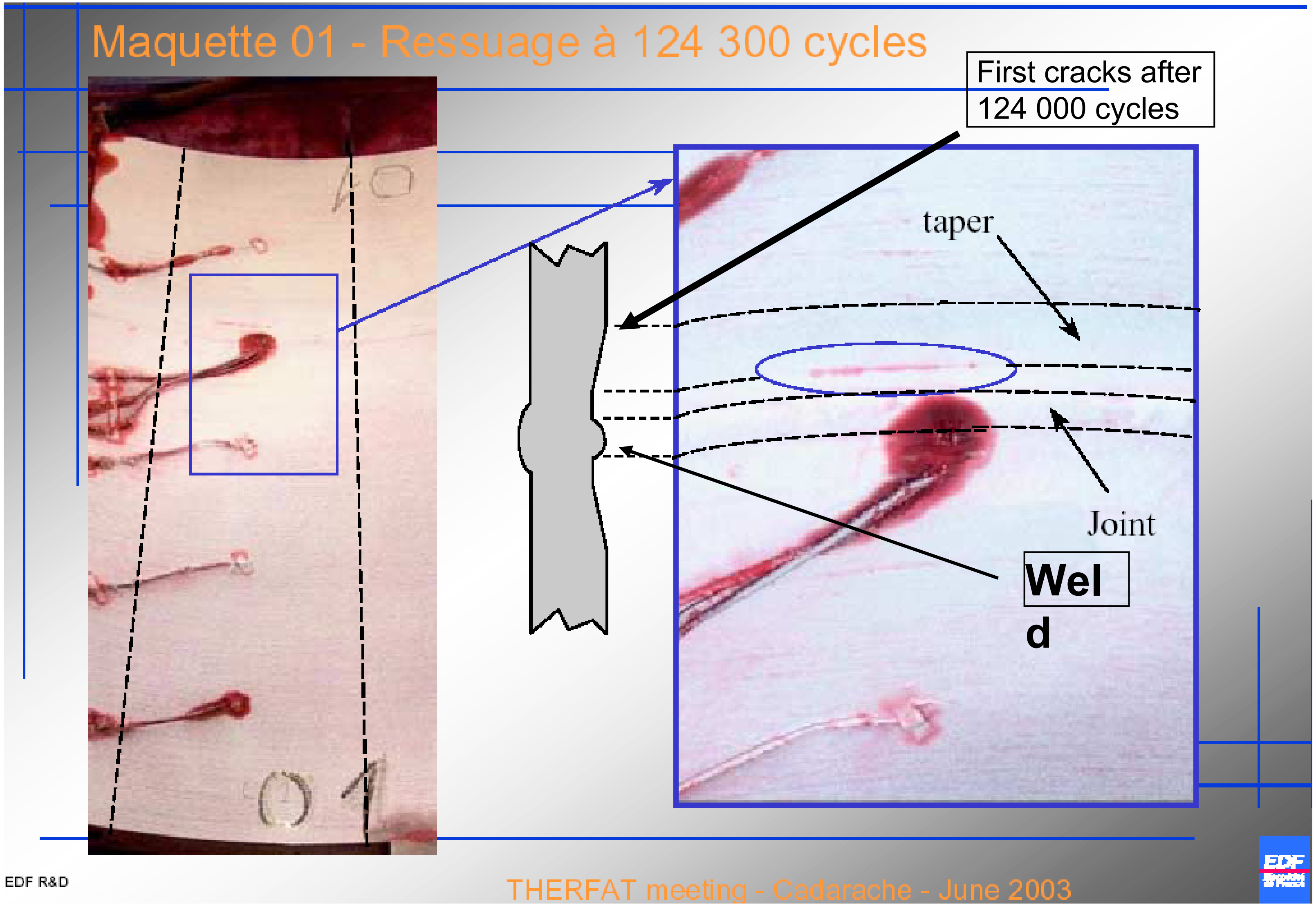


Figure 37: EDF, long-term damage test results

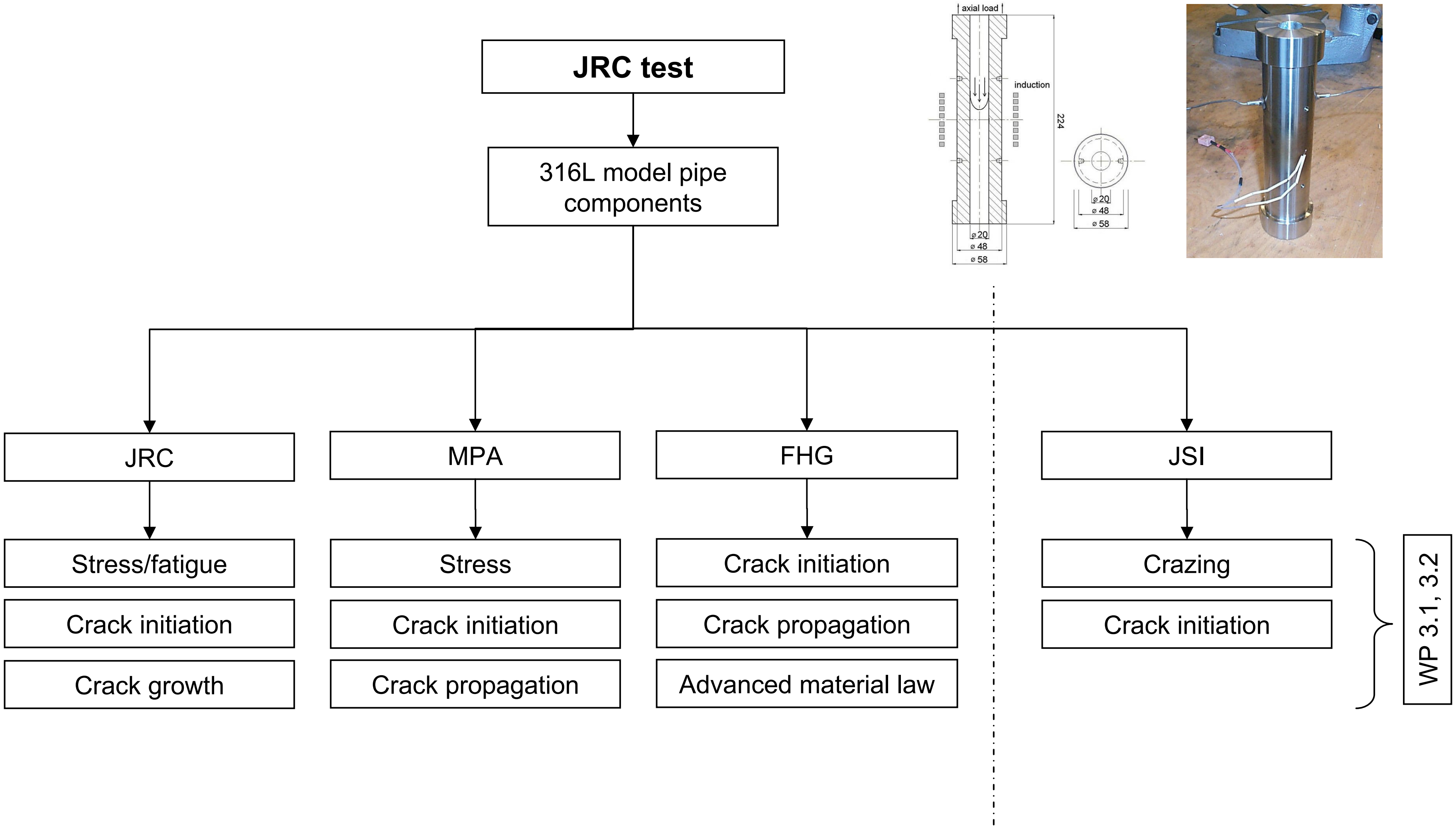
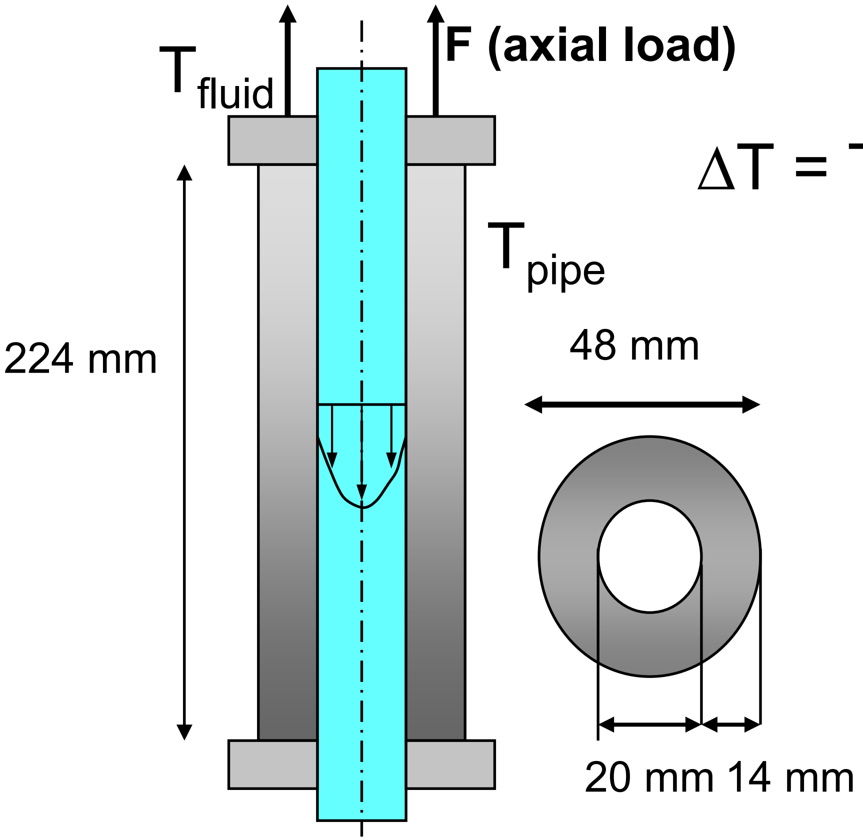


Figure 38: JRC test workflow, JRC, JSI, MPA, FHG

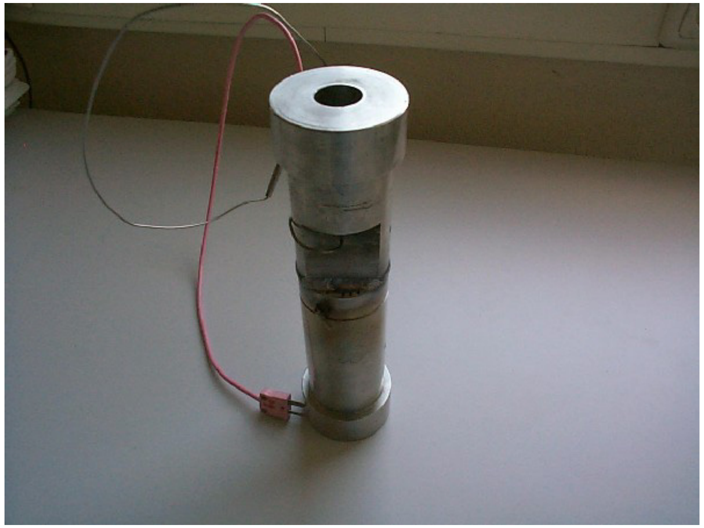
JRC thermal shock experiment (pipe specimen)



$$\Delta T = T_{pipe} - T_{fluid}$$

ΔT = 380 K
First cracks after
20 000 load cycles

Specimen geometry



Instrumented specimen

Material: A316L austenitic steel

Figure 39: JRC, long-term damage tests

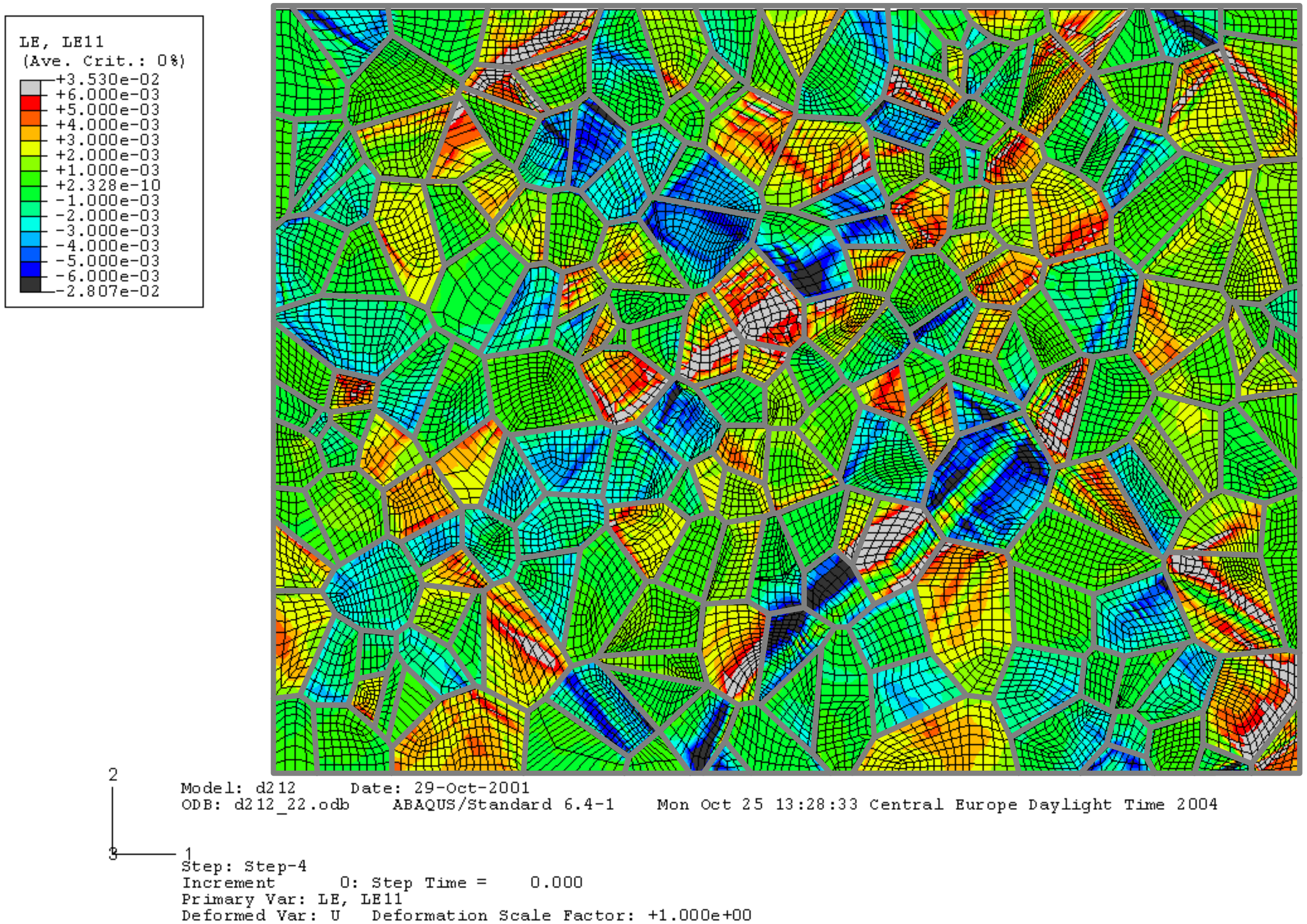
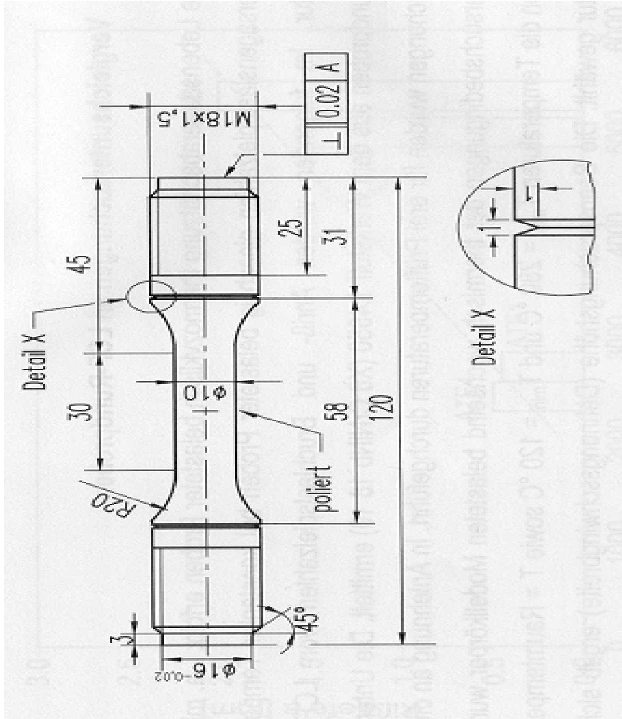
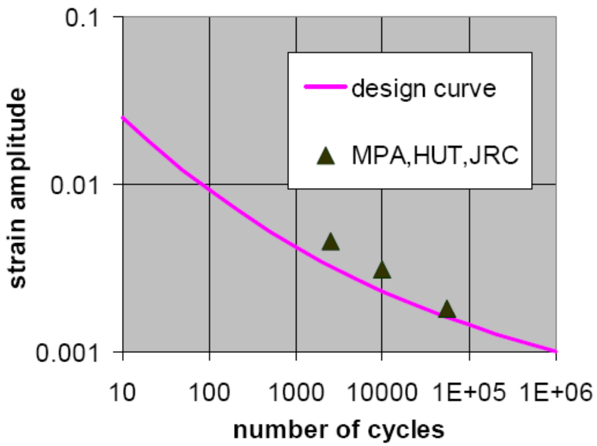


Figure 40: JSI, micro-structure modeling, analysis of the JRC experiment

Institution	EdF	MPA (not within THERFAT)	JRC	HUT/VTT (not within THERFAT)
T_{max} /°C	230	280	300/400	300
T_{min} /°C	110	120	20/20	20
ΔT / 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/÷	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

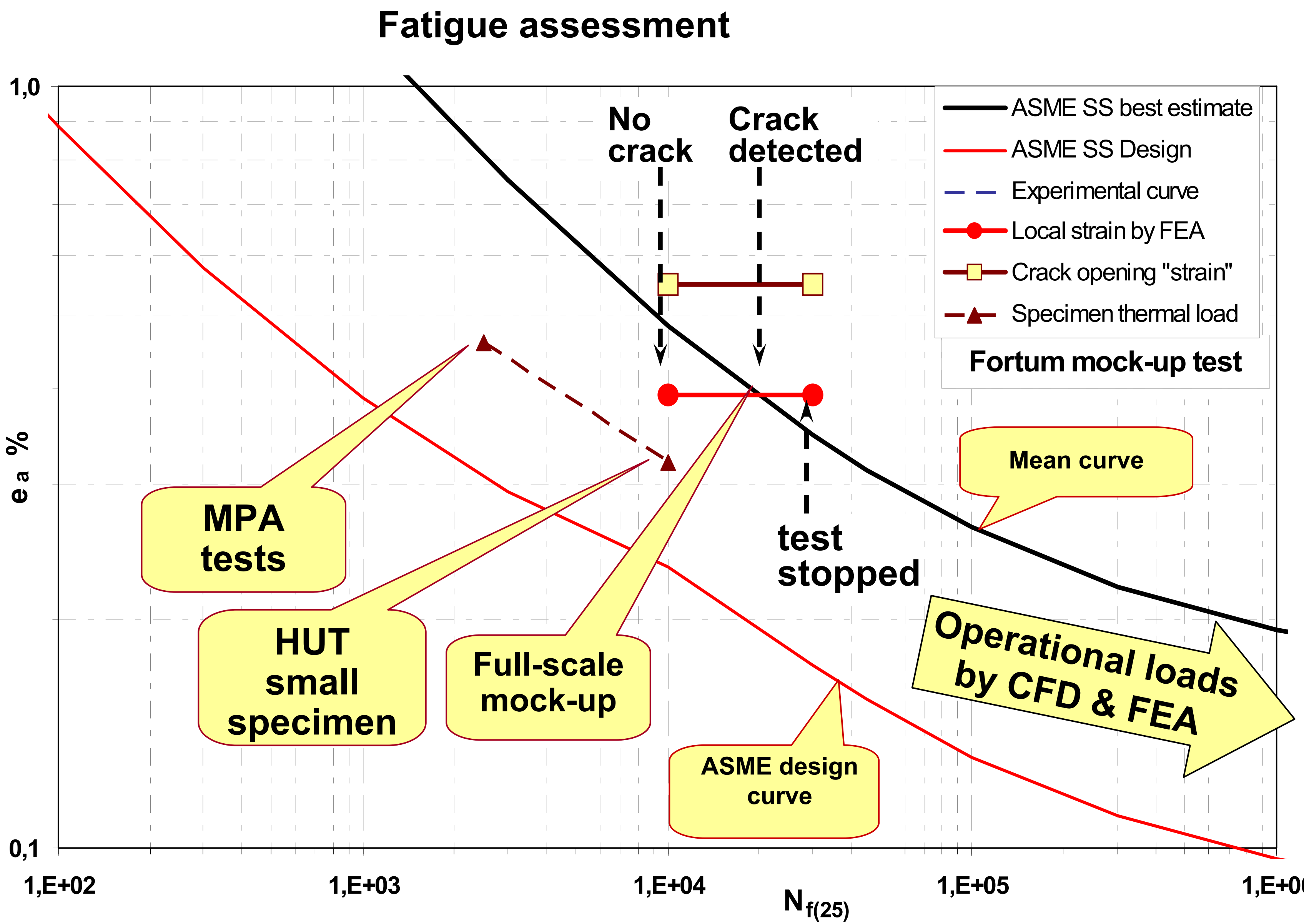


Figure 42: VTT, fatigue assessment according to experimental and analytic results

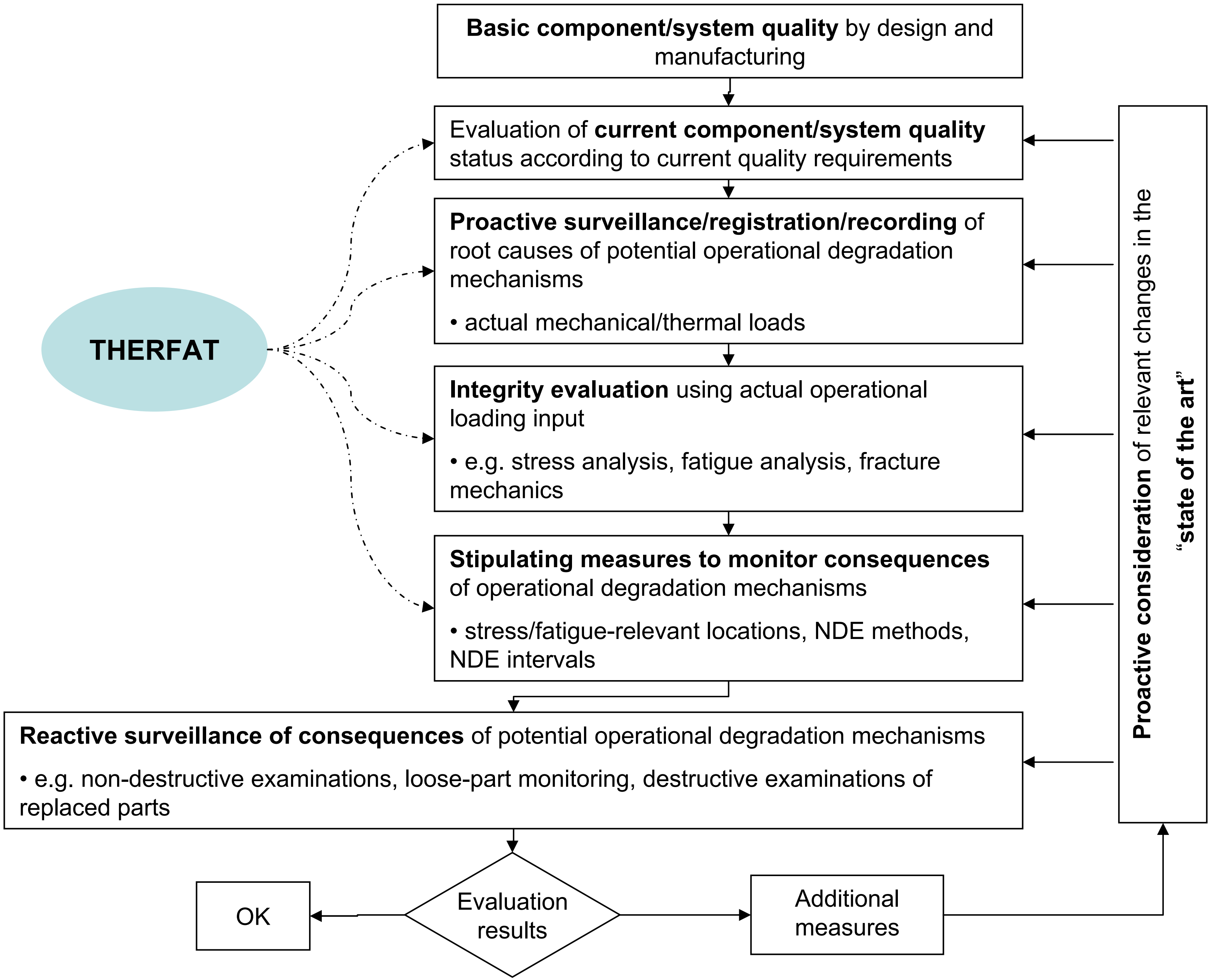


Figure 43: Overall integrity concept for safety-relevant structures in NPPs

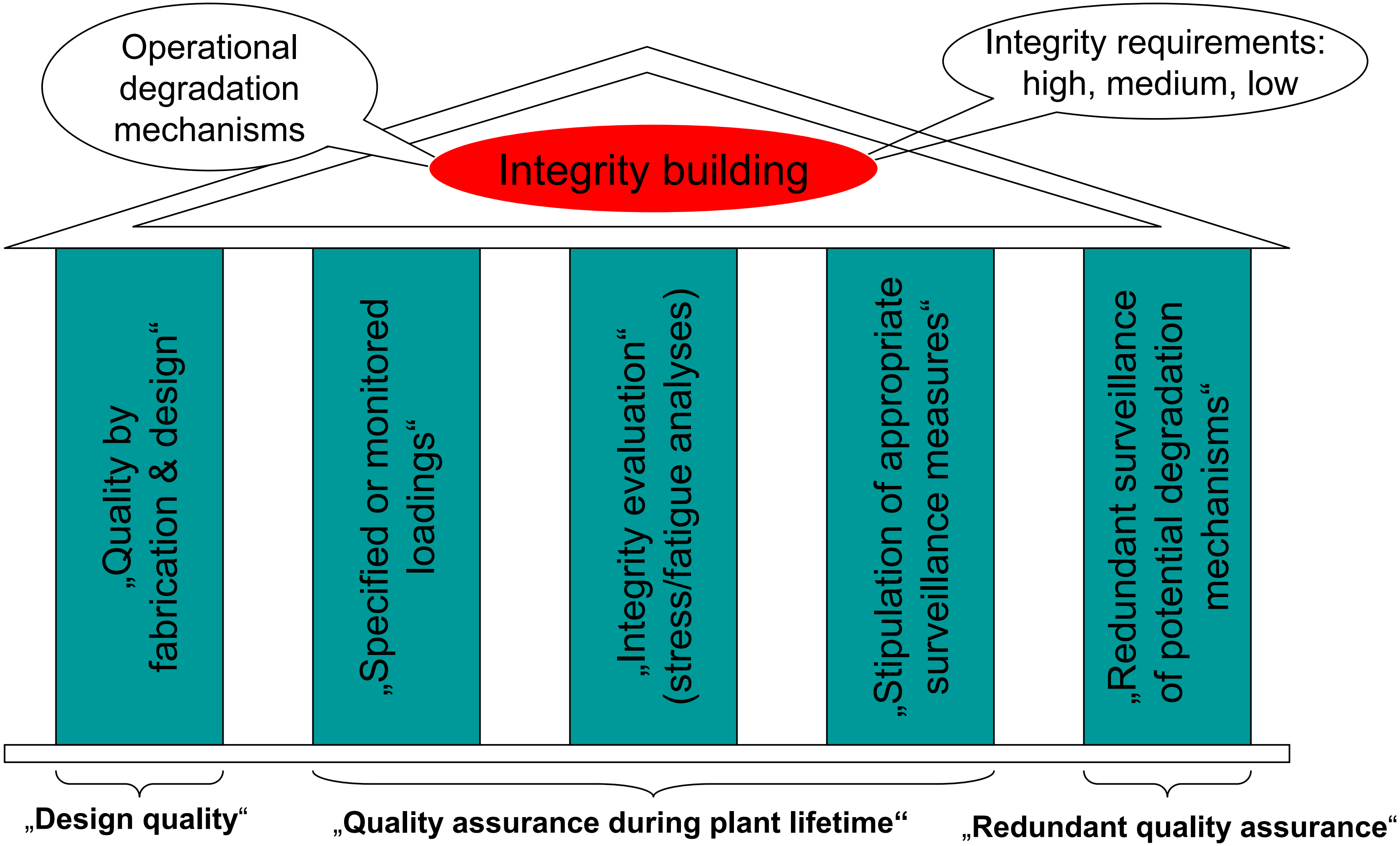


Figure 44: Integrity concept: the "integrity building"