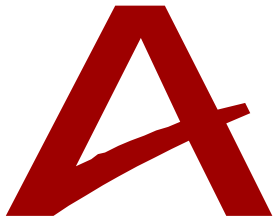


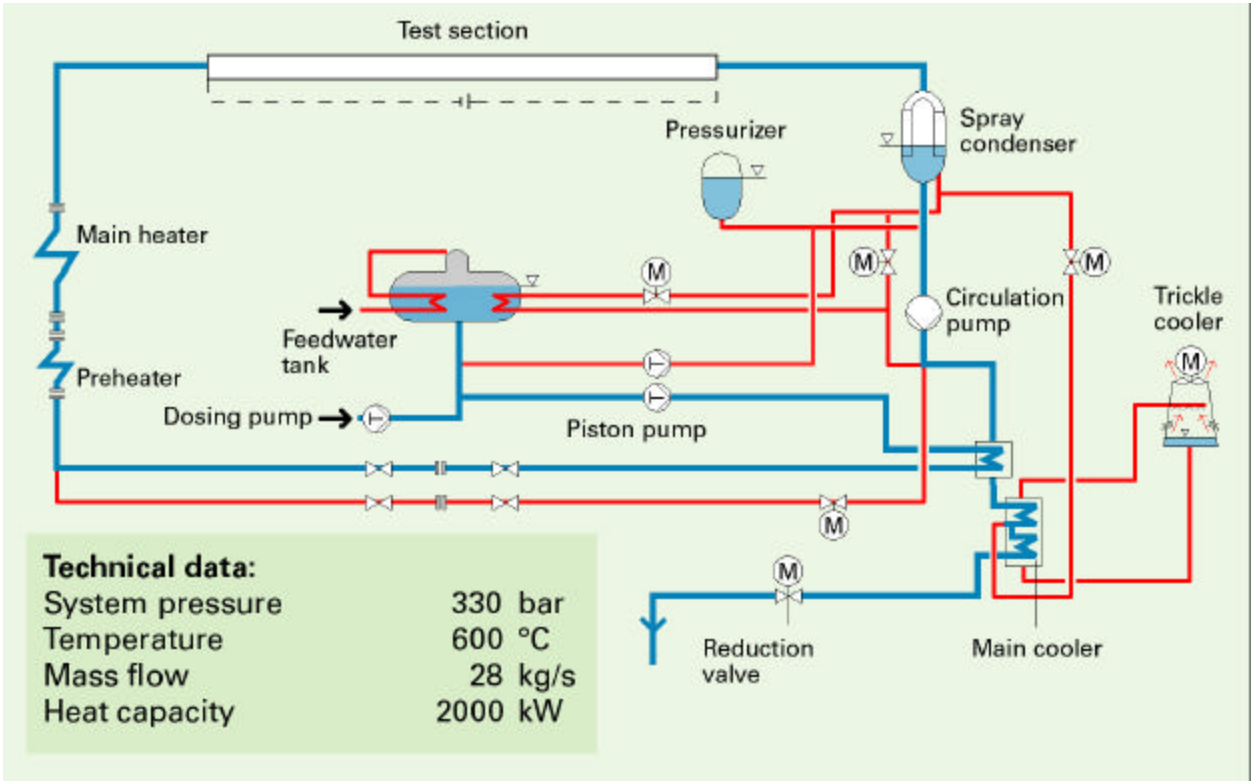
FRAMATOME ANP

High-Pressure Separate Effect Test Facility- More than 25 Years in Operation

BENSON Facility

FRAMATOME ANP

Flow diagram

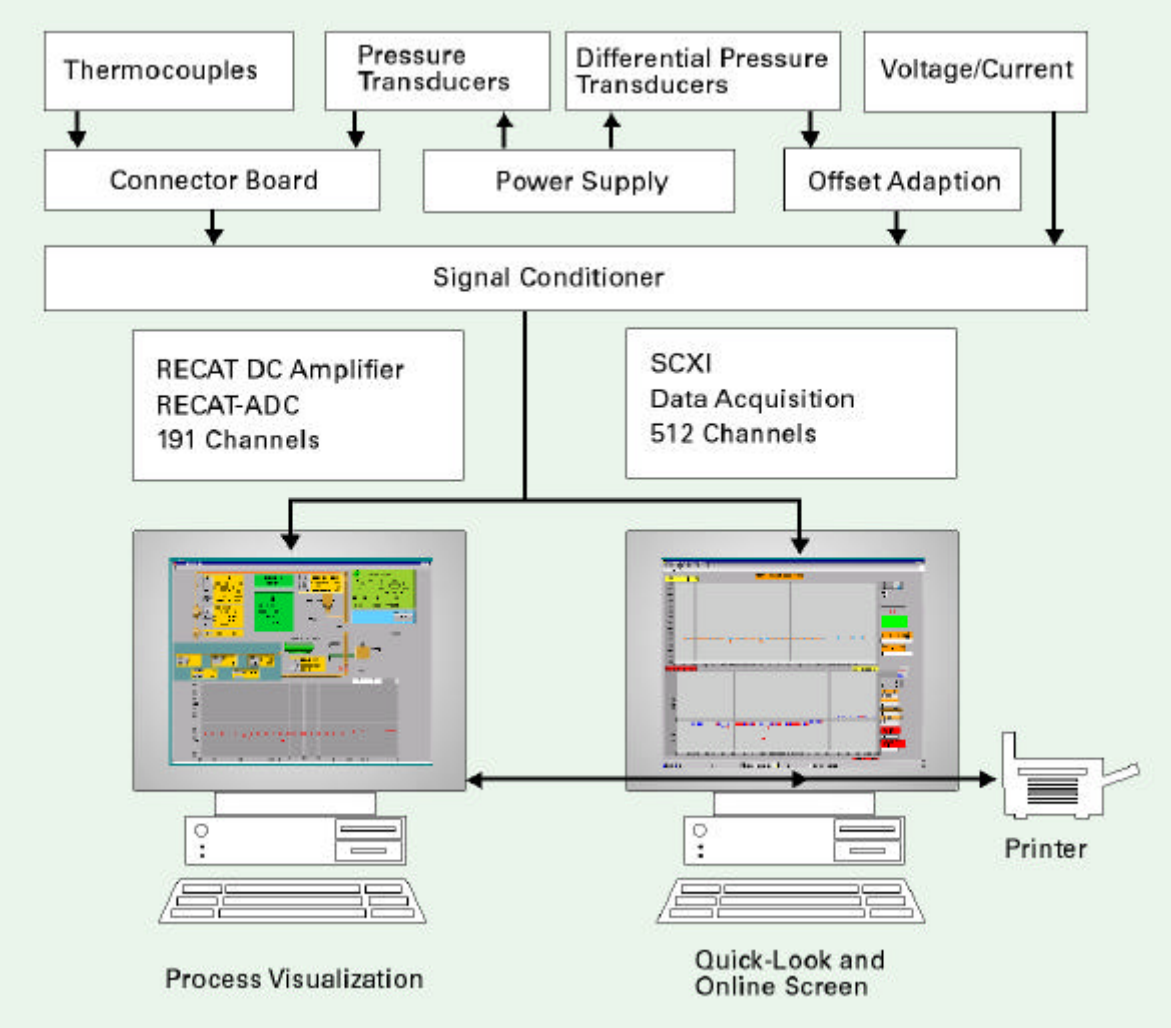


Technical data:

System pressure	330 bar
Temperature	600 °C
Mass flow	28 kg/s
Heat capacity	2000 kW

FRAMATOME ANP

Data acquisition and processing

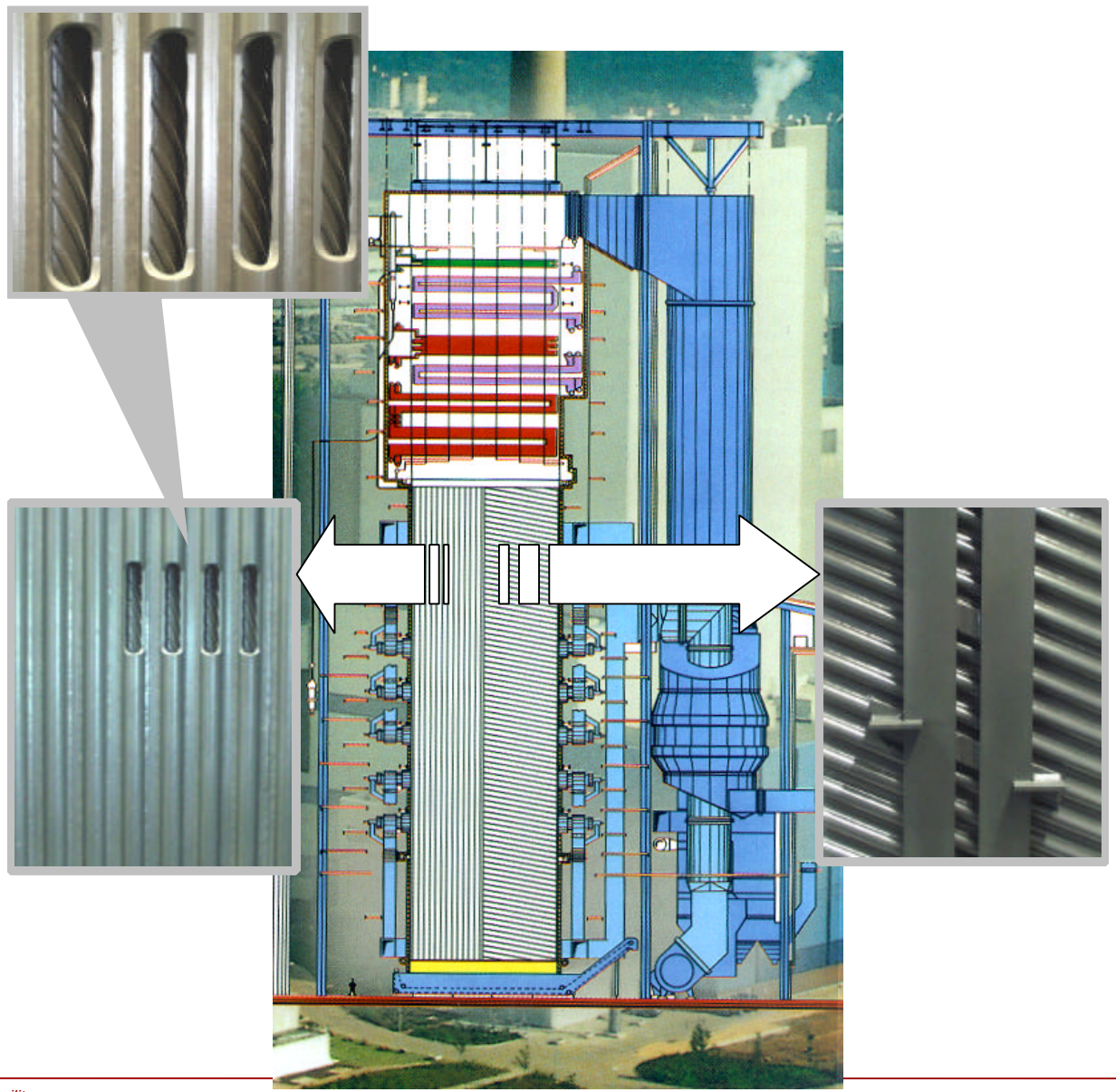


FRAMATOME ANP

More than 25 years of experiences

Topic of Investigation	Special Test Features
Fossil-Fired Power Generation	
• Heat transfer and pressure loss in tubes for BENSON and drum boilers	Pressures from 25 to 280 bar, steady-state and transient conditions
• Thermal stresses in membrane waterwalls of BENSON boilers	Transient conditions
• Cooldown of hot surfaces (Leidenfrost effect)	Pressures up to critical pressure (220 bar)
• Wet steam measuring system for improved feedwater control at BENSON boilers	Combination of venturi tube and gamma densitometer, pressures up to 220 bar
Nuclear Power Generation	
• GAP cooling between debris crust and reactor pressure vessel wall (TMI 2 accident)	Complex test setup; pressures up to 115 bar; gaps of 1 to 10 mm
• Heat transfer performance of a safety condenser for new pressurized water reactors	Complex test setup with elevations scaled 1:1; 600 kW/m^2, $\leq$ 40 kg/m^{2}s, $\leq$1.35 bar on secondary side
• Cladding tube temperatures in fuel assembly with various spacer grid designs	Testing of production-type components under realistic PWR conditions
• Influence of fouling on secondary-side heat transfer in a steam generator tube that has been in service	Testing under realistic conditions; comparisons with archived tube and chemically cleaned tube formerly in service
• Leakage rates from real cracks	Test object with real cracks (bending stress, fatigue); pressures up to 160 bar; 0 to 70 K subcooling
Power Plant concepts for Direct Solar Steam Generation	
• Heat transfer in absorber tubes - Forced-flow once-through concept - Injection concept - Recirculation concept	30-m-long test tube tube diameters of 50, 65 and 85 mm, pressures up to 100 bar
Thermally Enhanced Heavy Oil Recovery	
• Wet steam piping network	Diameters of 25 and 50 mm, up to 100 bar
• Robust measuring techniques for application in the field	Gamma densitometer, venturi and pitot tubes
Water Chemistry	
• Formation of protective magnetite layers	BENSON boiler conditions
• Behavior of protective layers in the event of thermal shocks	Transient conditions
• Material loss due to erosion corrosion	Conditions of fossil-fired boilers and nuclear plant secondary cycles
Other topics	
• Determination of material properties of components made of nickel alloys	Steam generator tubes made from Inconel 690, Incoloy 800, PWR conditions
• Performance tests for heat exchangers of rail vehicles	Traction motor heat exchanger for electric multiple unit trains

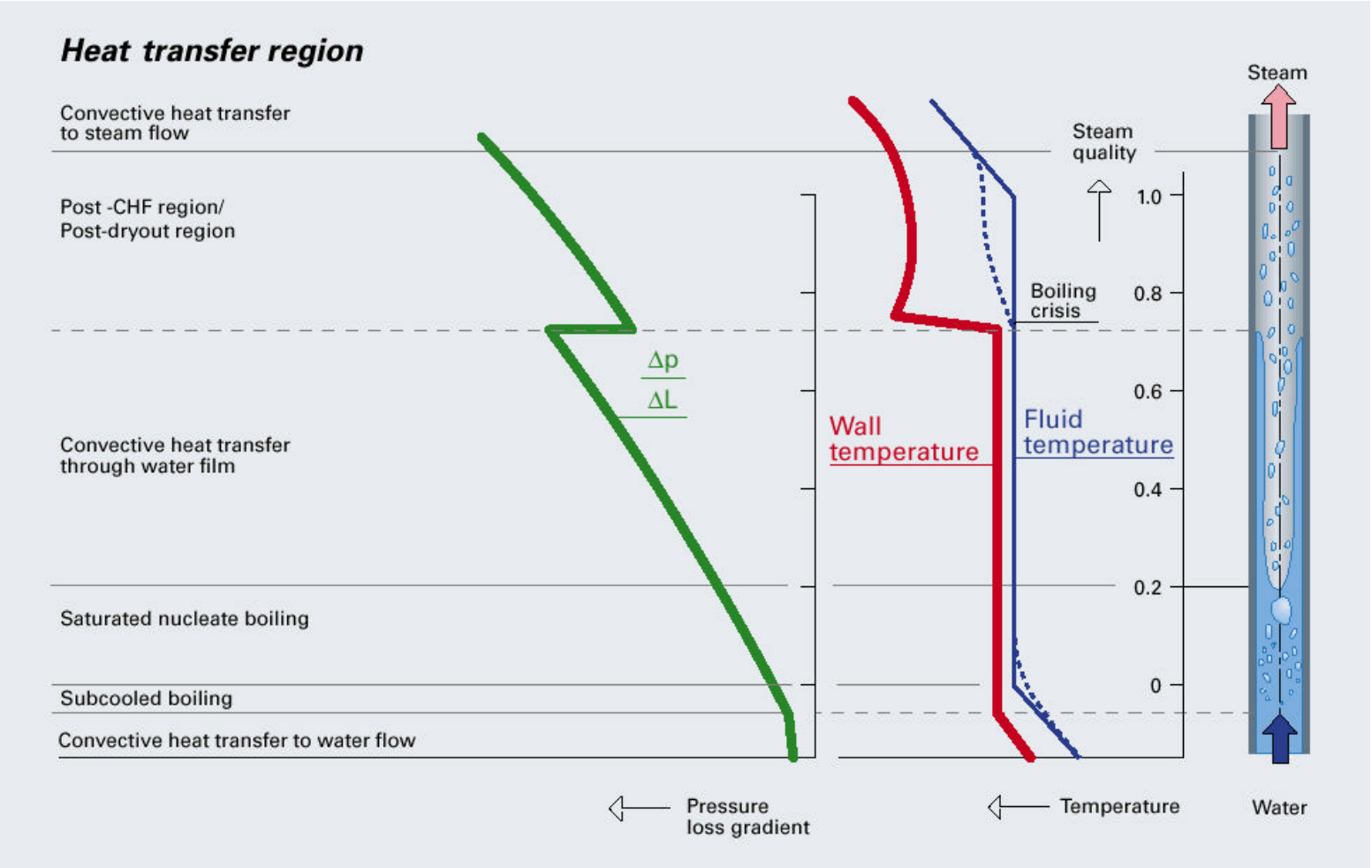
Typical BENSON Steam Generator



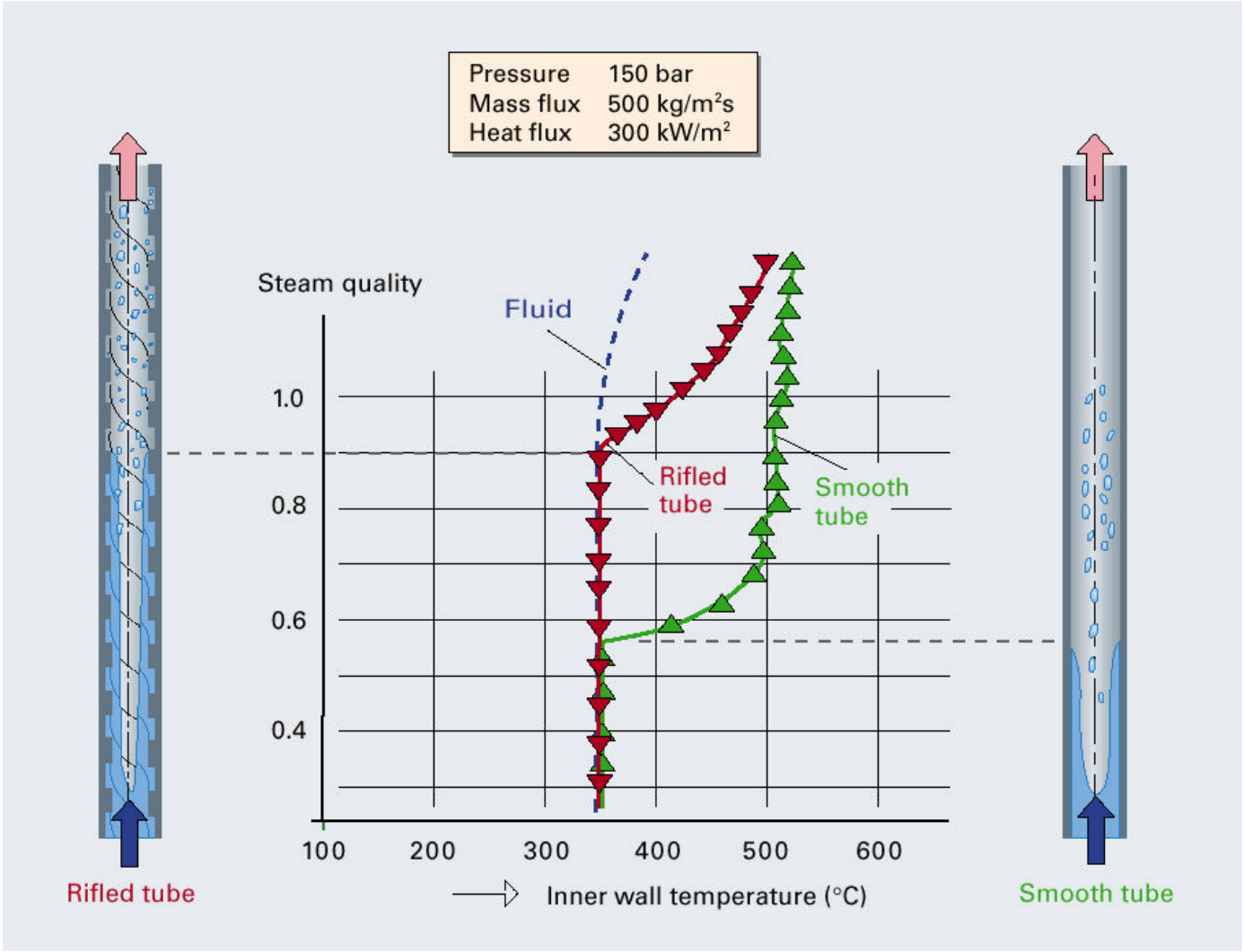
Furnace Walls of Vertical Rifled Tubing

Furnace Walls of Spiral-Wound Smooth Tubing

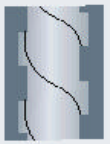
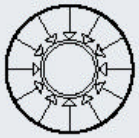
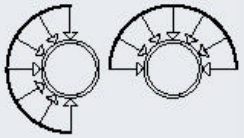
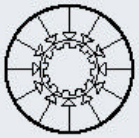
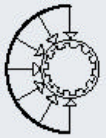
Wall temperature and pressure loss in a uniformly heated, vertical, smooth boiler tube



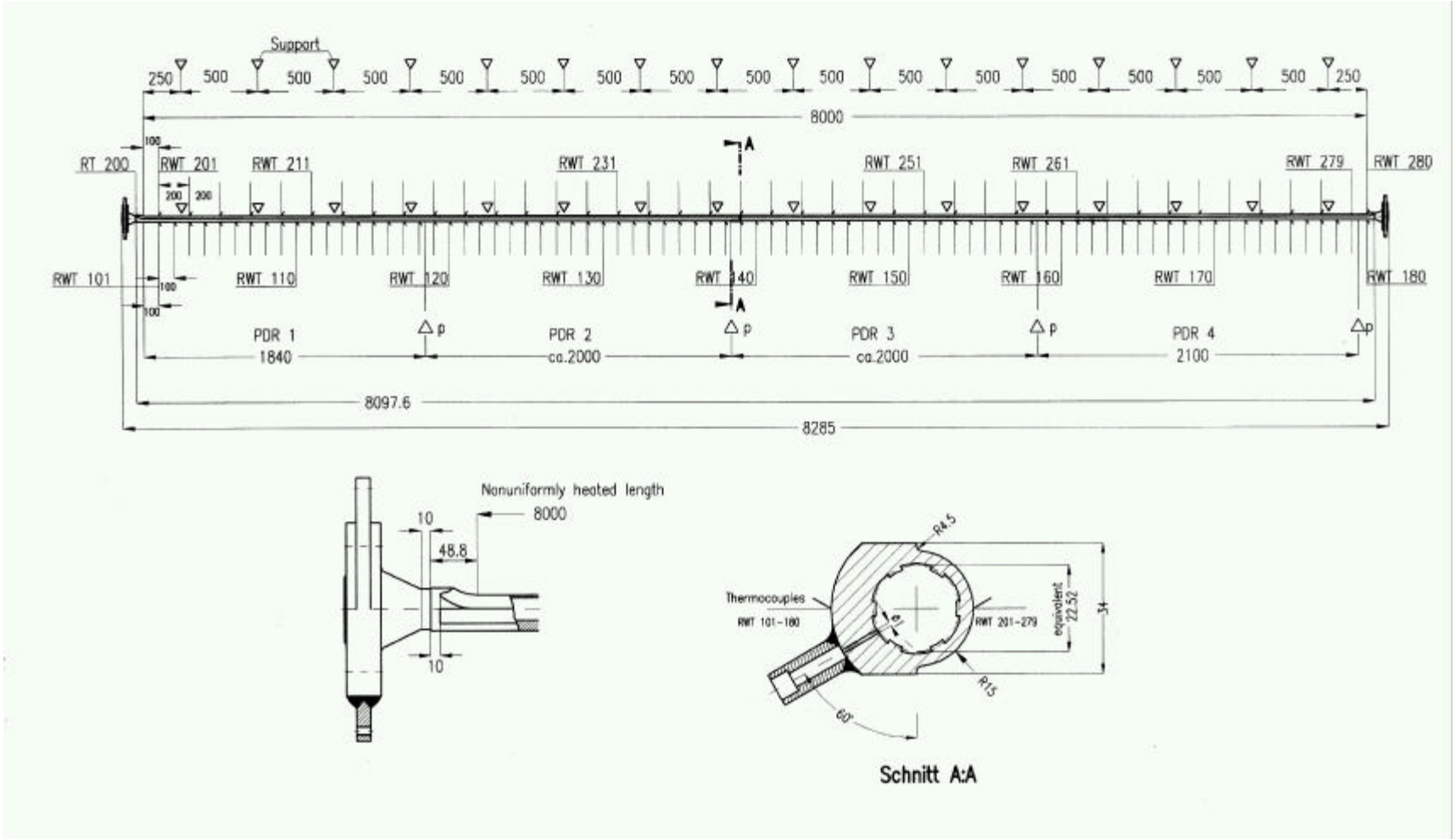
Wall Temperatures in Smooth and Rifled Boiler Tube



Overview of heat transfer tests for BENSON steam generator tubes

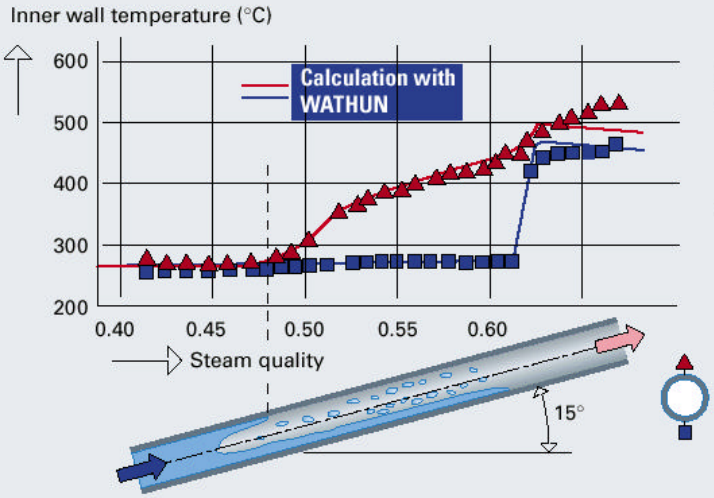
Tube Geometry					
Number of measurements		> 100.000		> 160.000	
Heating		 uniform	 one-side	 uniform	 one-side
Tube orientation	vertical				
	inclined				
	horizontal				
Test parameter		Pressure $25 \le p \le 280$ bar Mass flux $100 \le \dot{m} \le 2500$ kg/m²s Heat flux $0 \le \dot{q} \le 950$ kW/m² Tube inner diameter $8 \le d \le 50$ mm			

Typical test tube



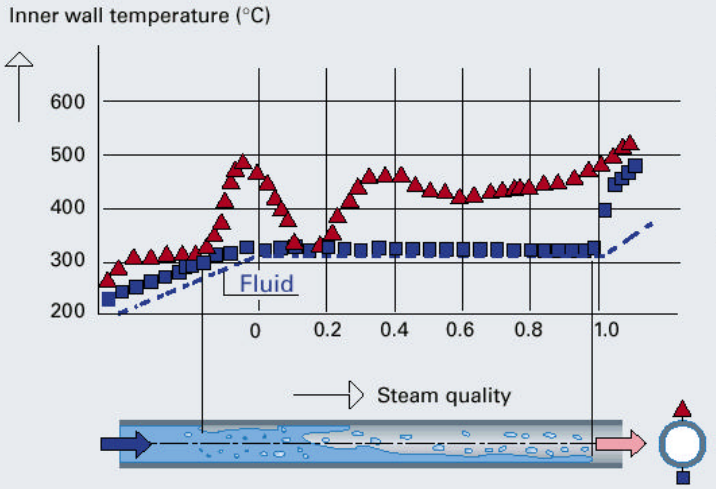
FRAMATOME ANP

Effect of gravity on heat transfer in inclined and horizontal smooth tubes



Inclined tube

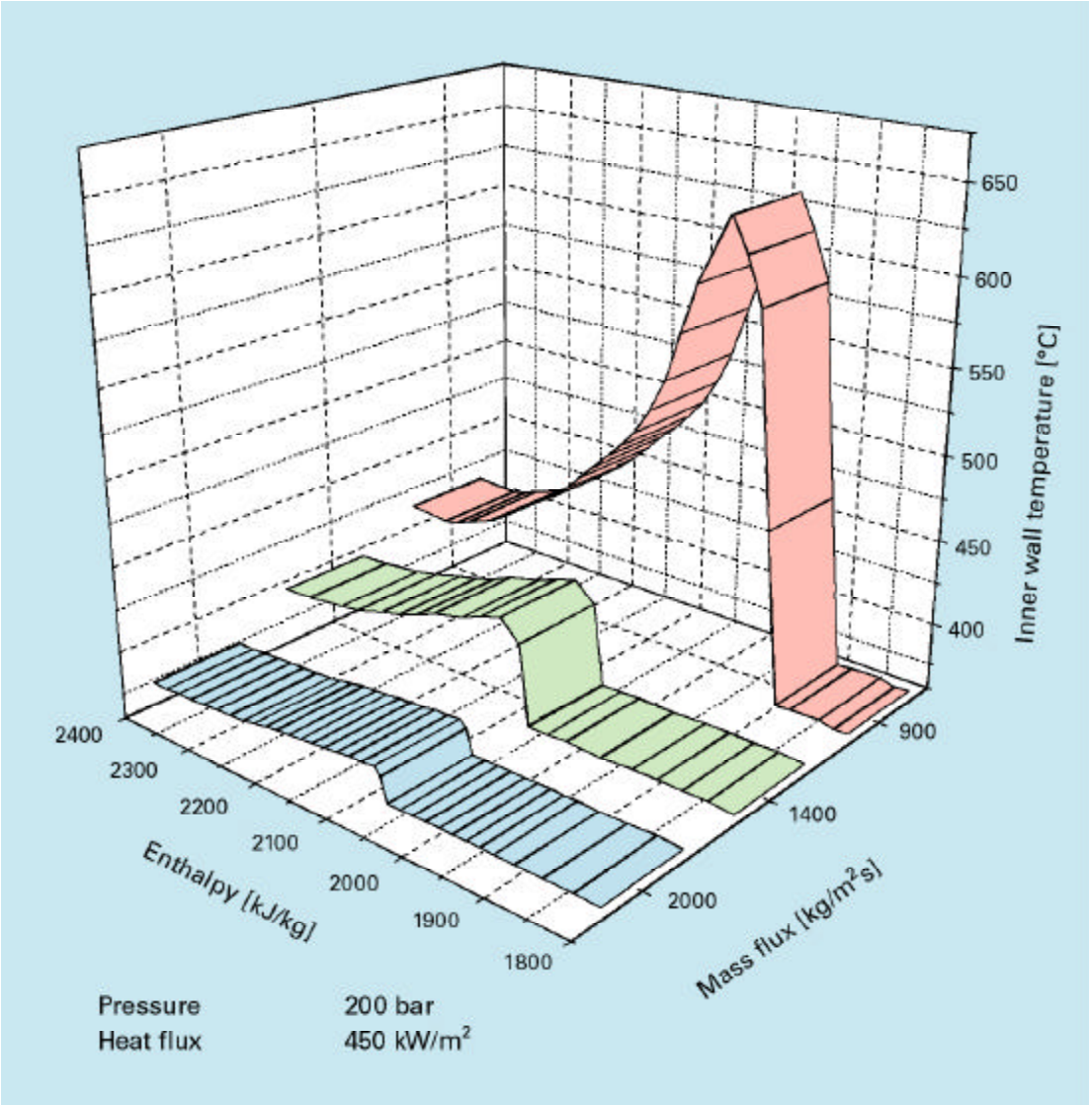
Pressure	50	bar
Mass flux	1000	kg/m²s
Heat flux	400	kW/m²
Tube inner diameter	24.3	mm



Horizontal tube

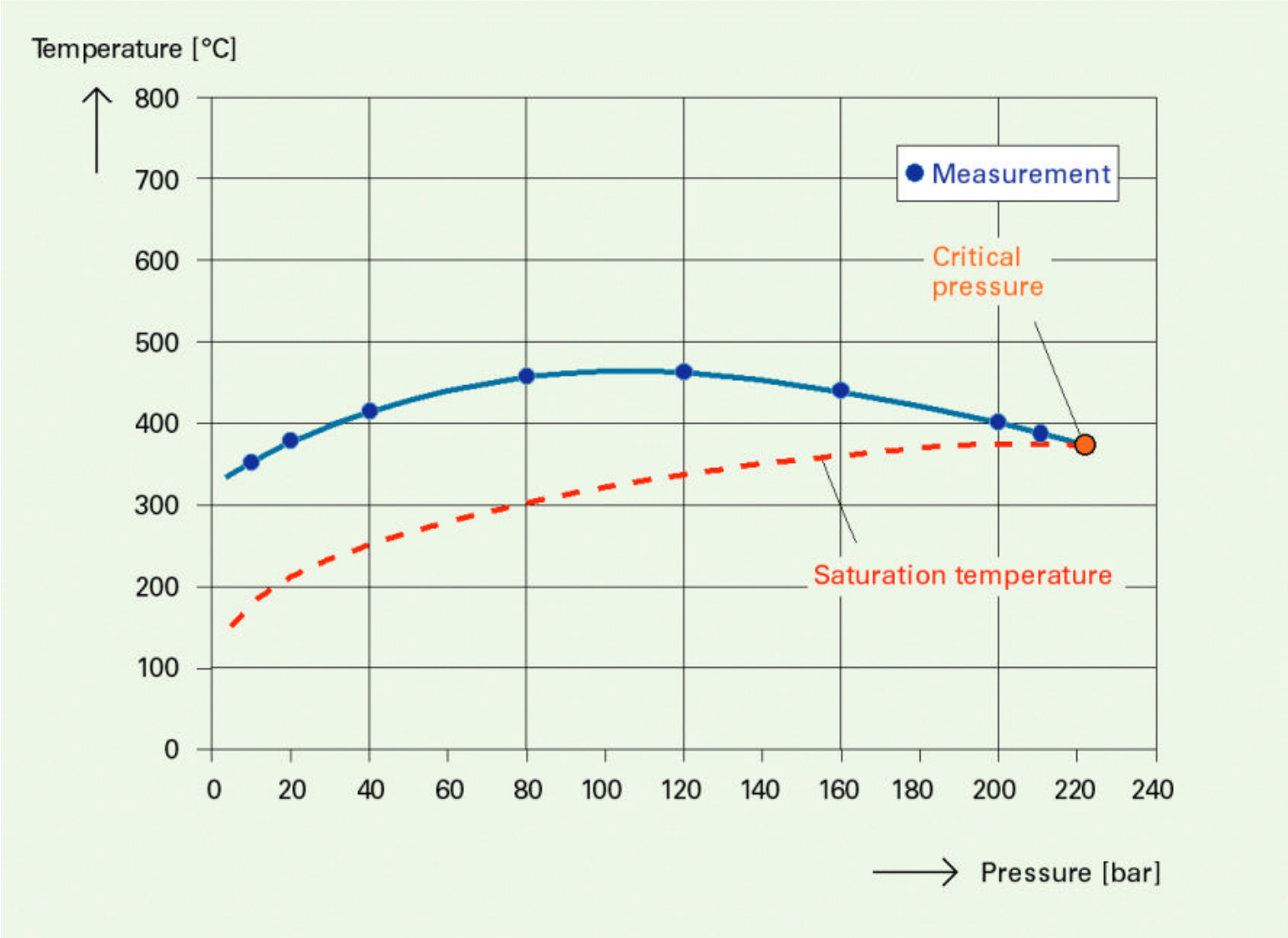
Pressure	100	bar
Mass flux	500	kg/m²s
Heat flux	300	kW/m²
Tube inner diameter	24.3	mm

Effect of the pressure

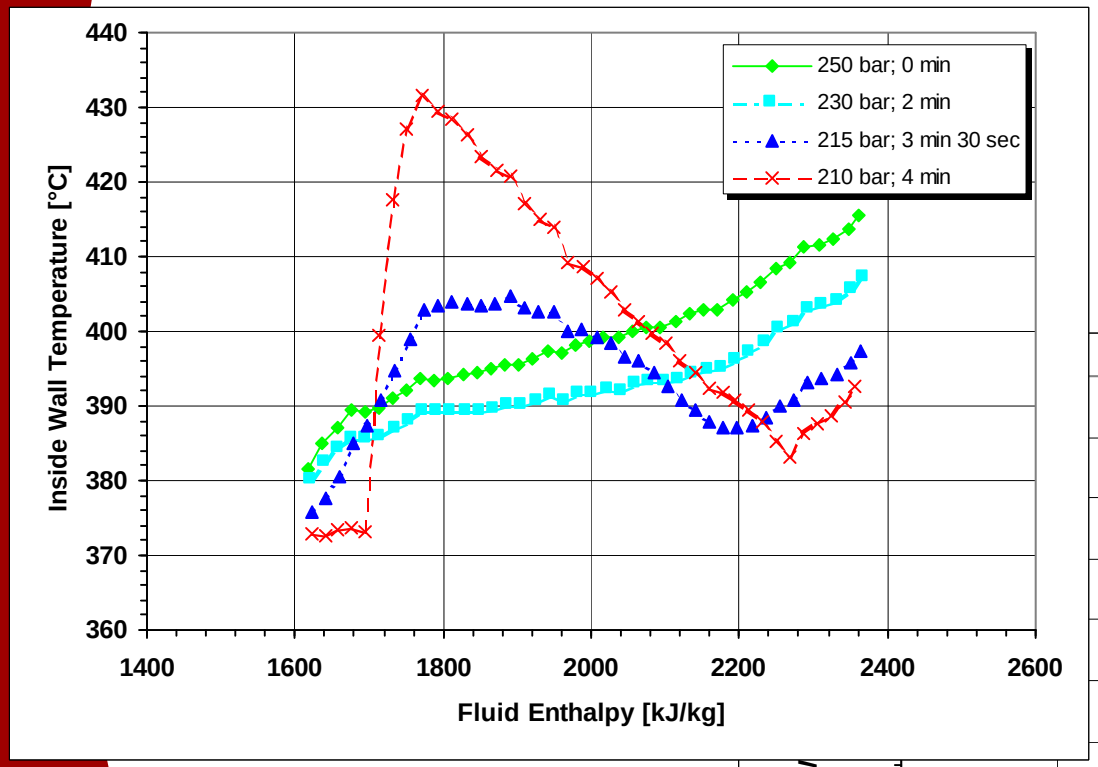


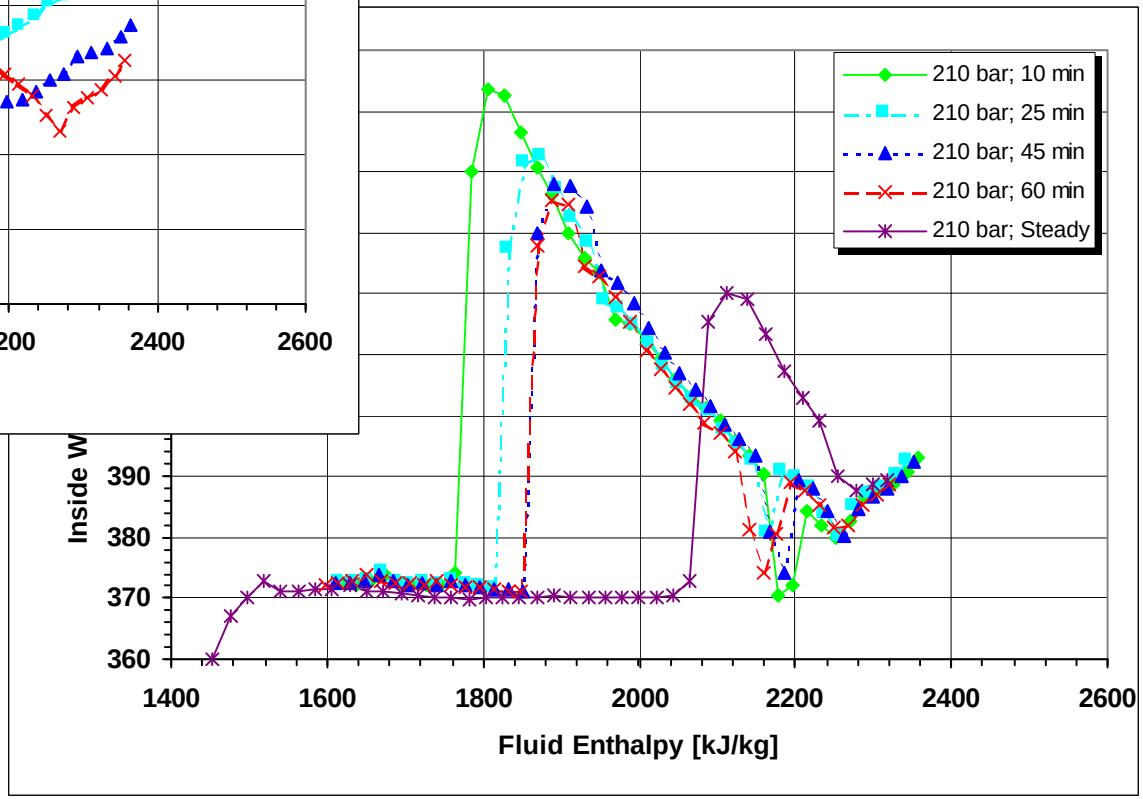
FRAMATOME ANP

Leidenfrost temperature for forced convection as a function of pressure

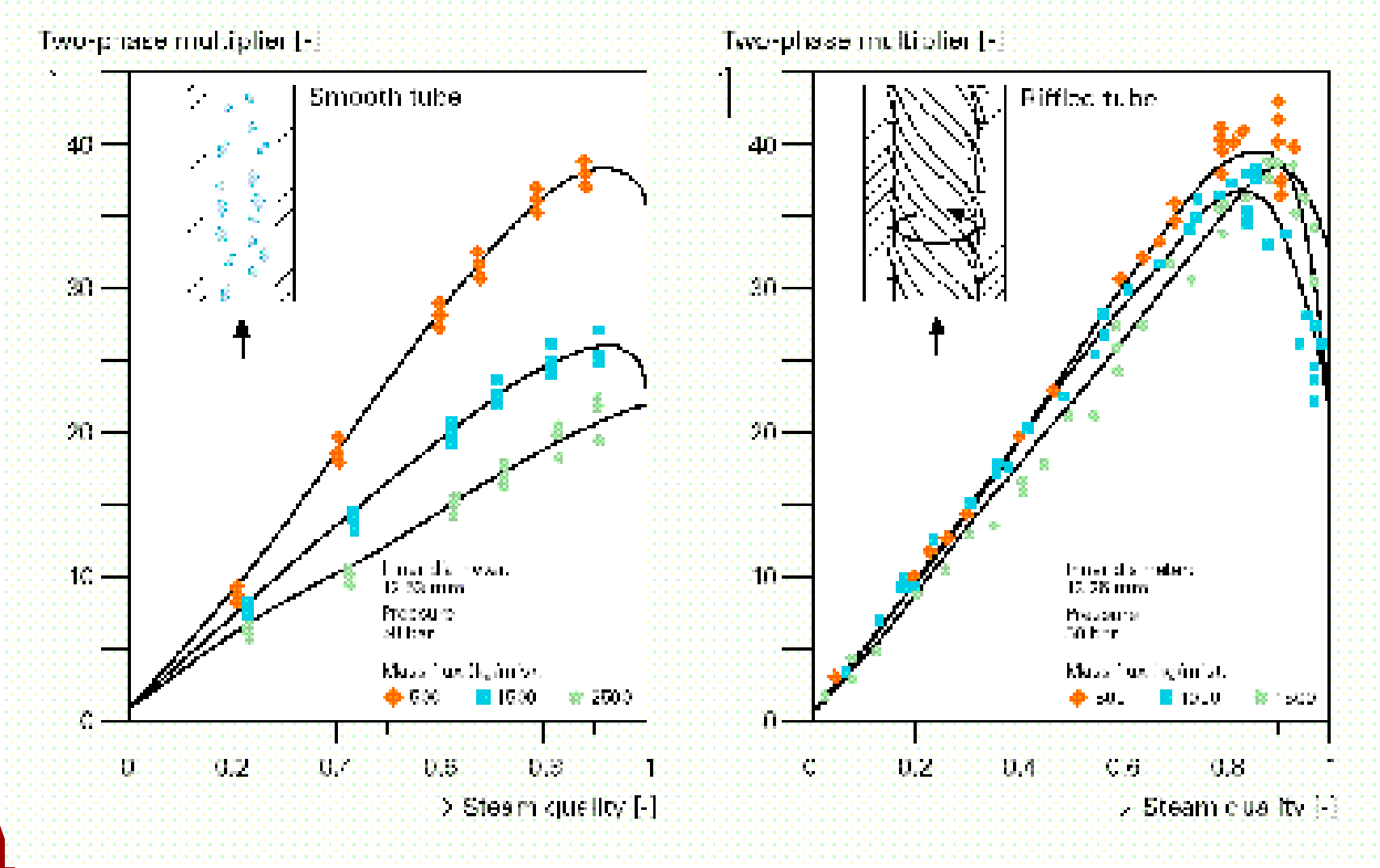


Transient tests
from super- to sub-critical conditions

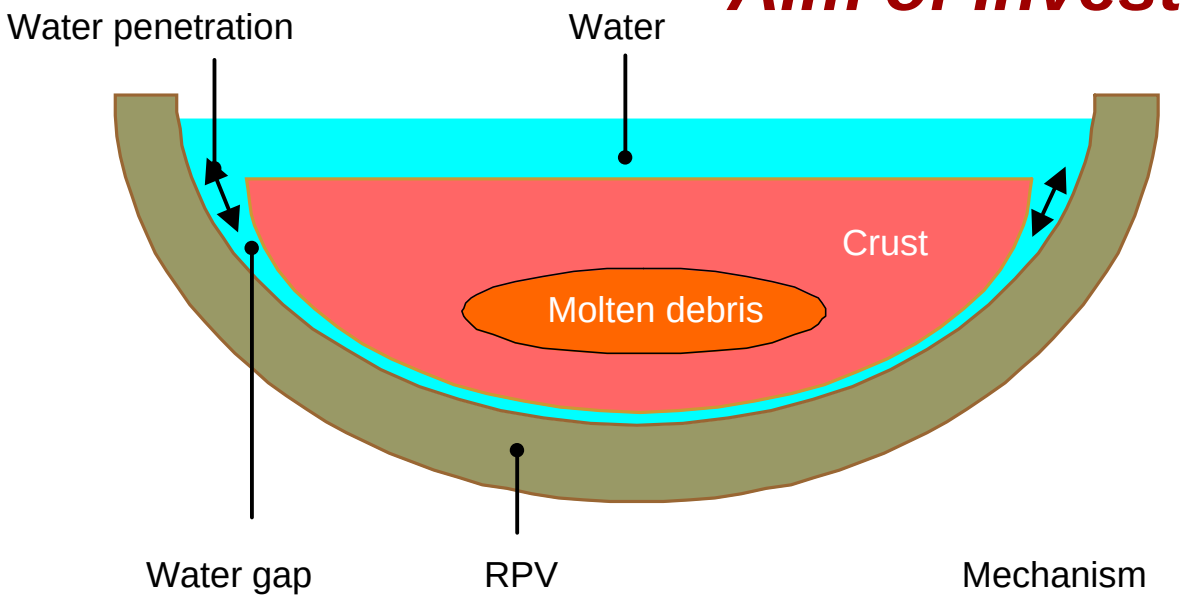




Two-phase flow multiplieres for smooth and rifled tubes



Gap Cooling Process ; TMI-2 Aim of Investigation



Predition of today's codes:

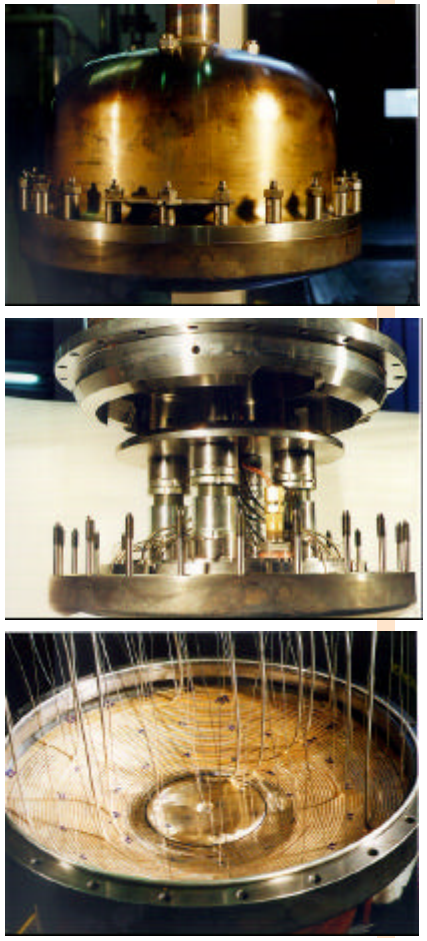
RPV failure due to high material temperatures

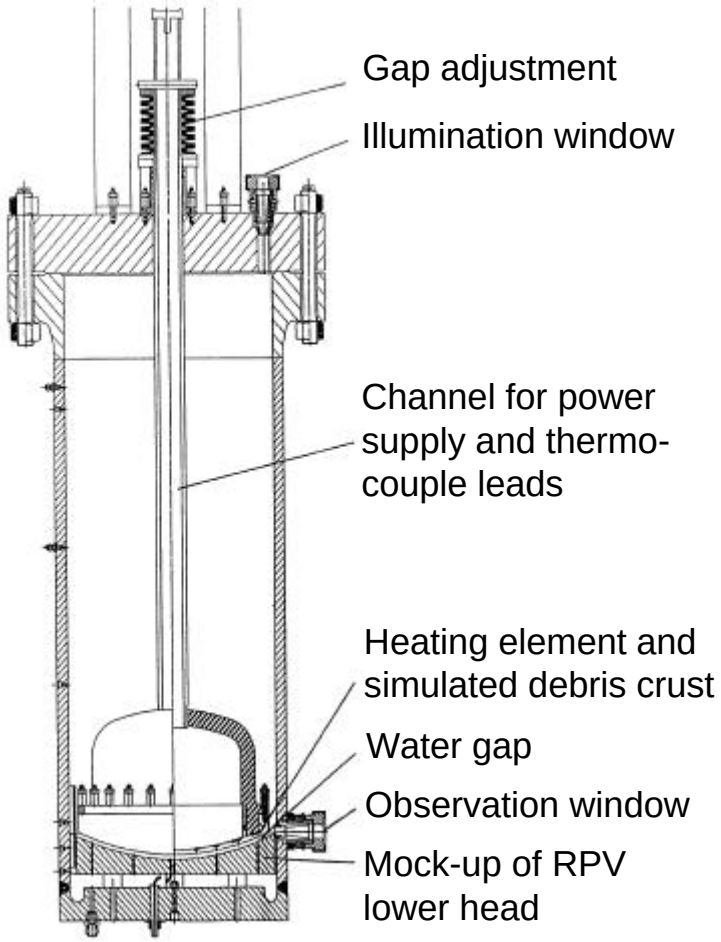
TMI-2 Accident:

No RPV failure due to sufficient cooling of the relocated debris

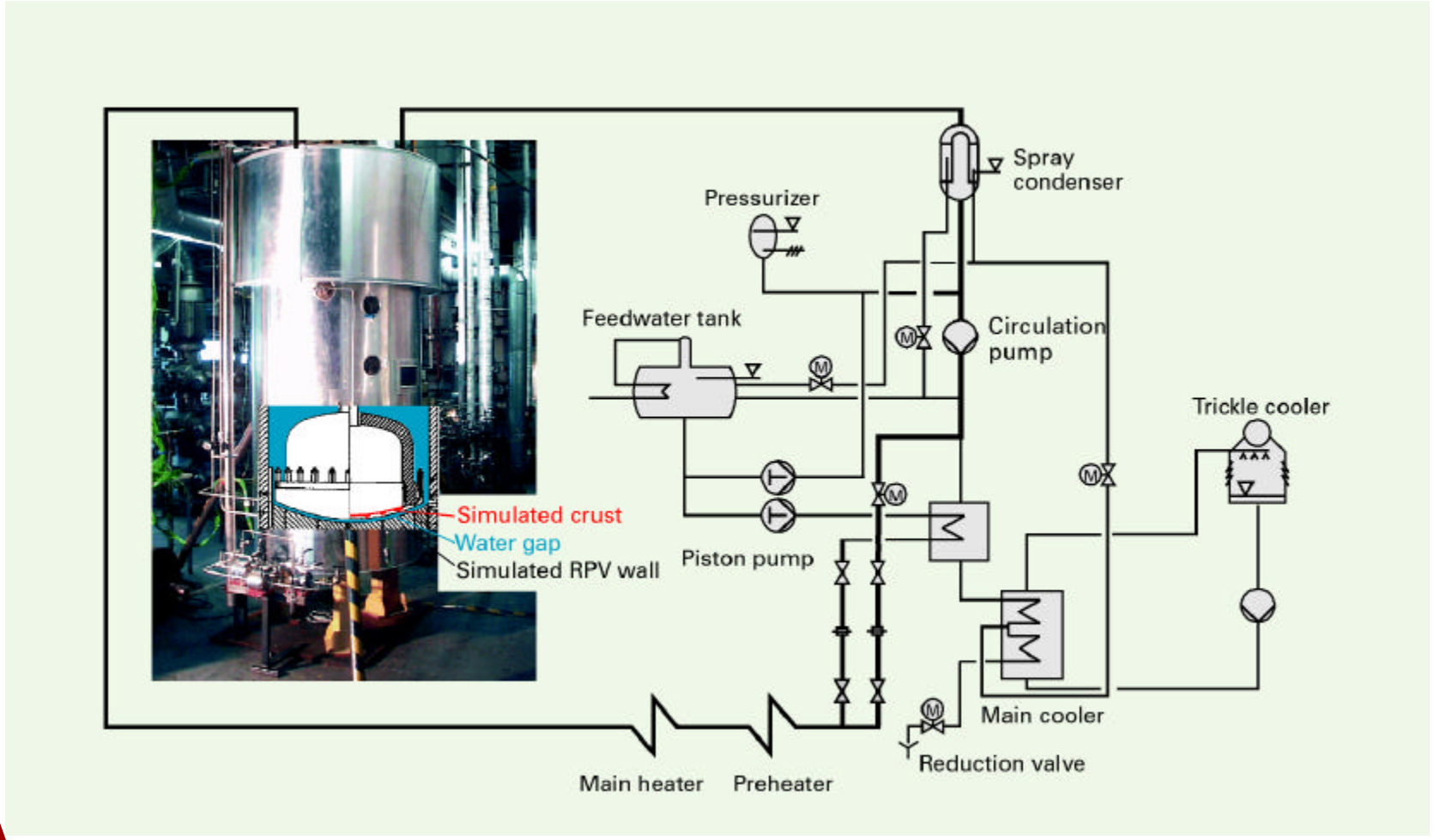
- Simulation of the accident taking into accout a gap cooling mechanism related to the water availability in the lower plenum
- Investigation of conditions which are conductive to efficient steam/water cooling (geysering etc.) crucial for RPV integrity

Gap Cooling Process ; TMI-2 Test Apparatus



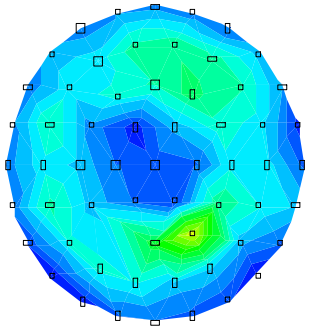


Gap Cooling Process ; TMI-2
Test Apparatus intgrated in the BENSON Facility

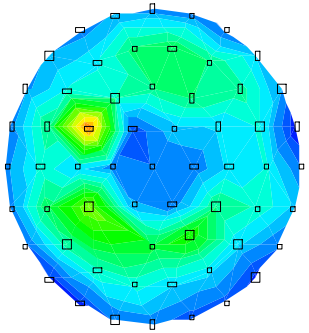


Gap Cooling Process ; TMI-2
Time Sequence During the Transition to Boiling Crisis

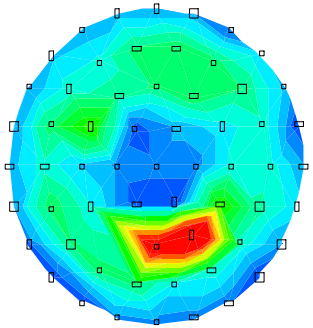
Time: 4:49:57 pm
Heat flux: 434.6 kW/m^2



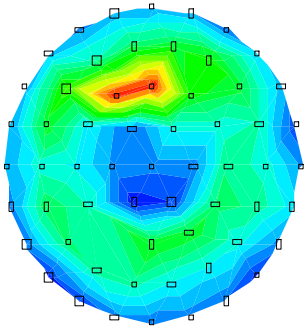
4:50:40 pm
449.9 kW/m^2



4:51:59 pm
473.7 kW/m^2



4:52:10 pm
474.0 kW/m^2

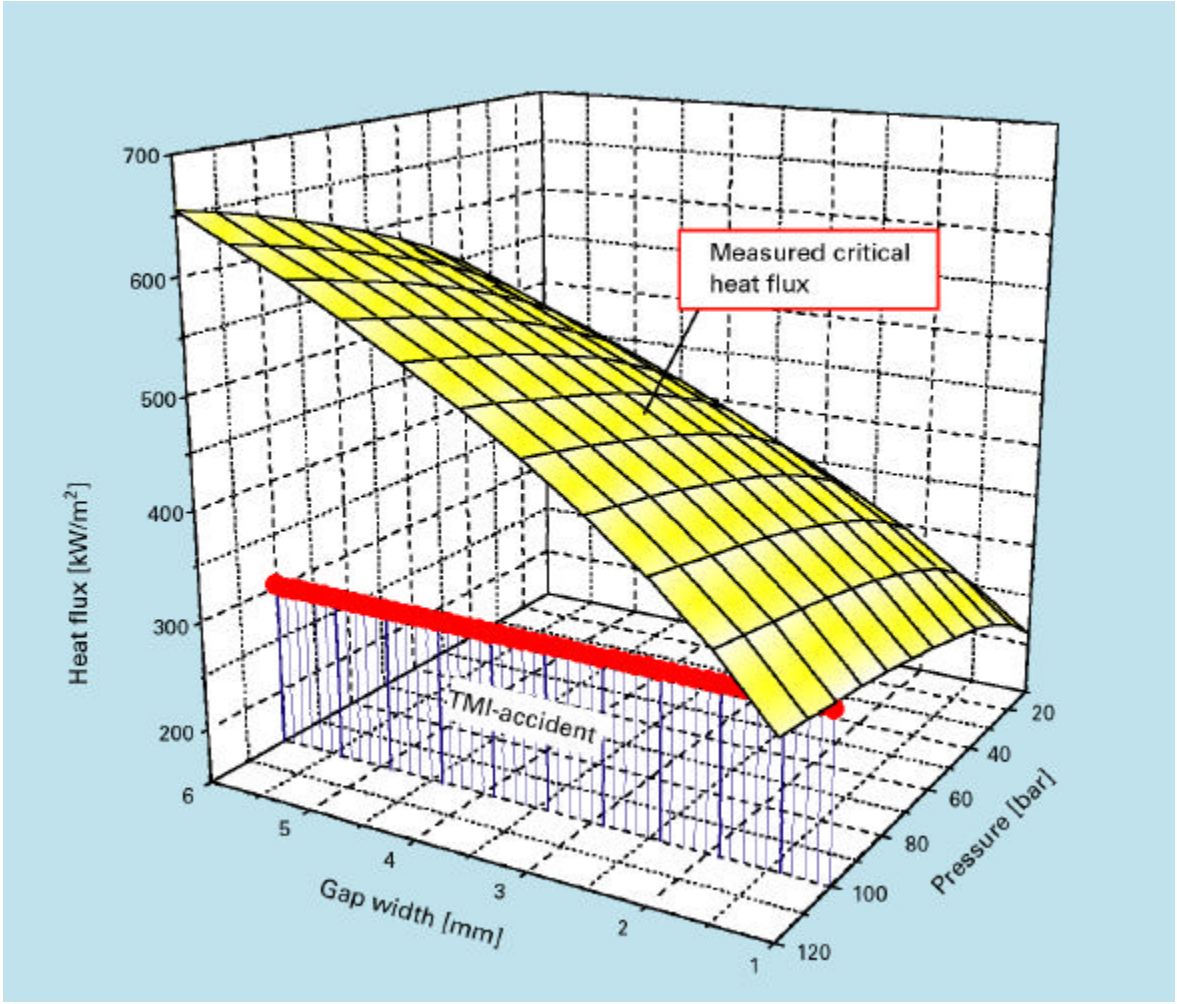


Temperature [°C]

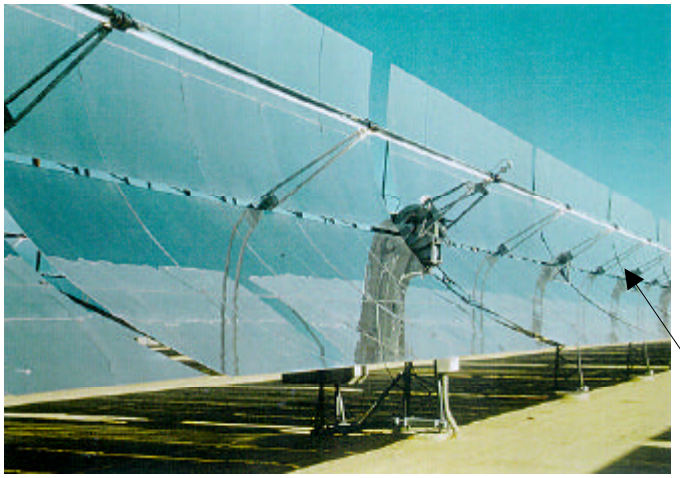
Time sequence

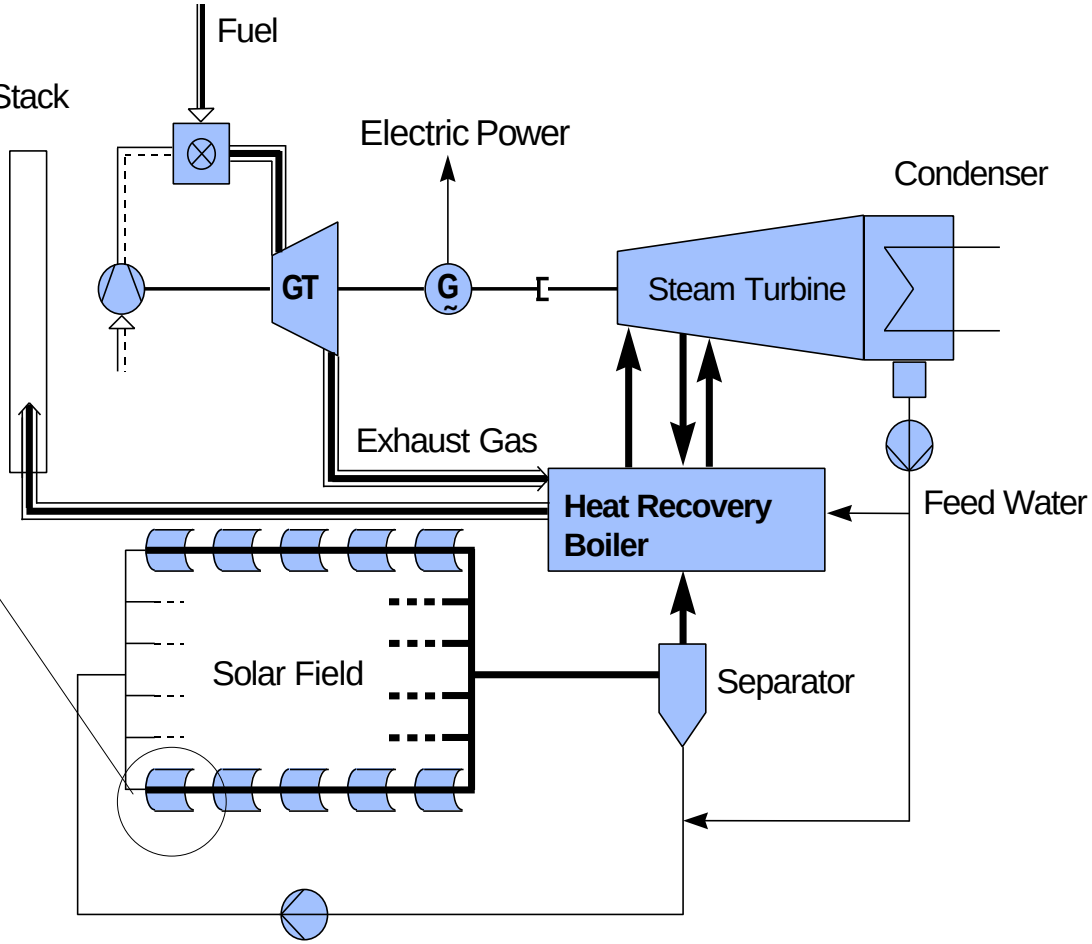
Gap width:	5.0	mm
Water submersion:	1.3	m
Pressure:	10	bar
Subcooling:	0.0	K

Critical heat flux in a gap versus decay heat TMI-2

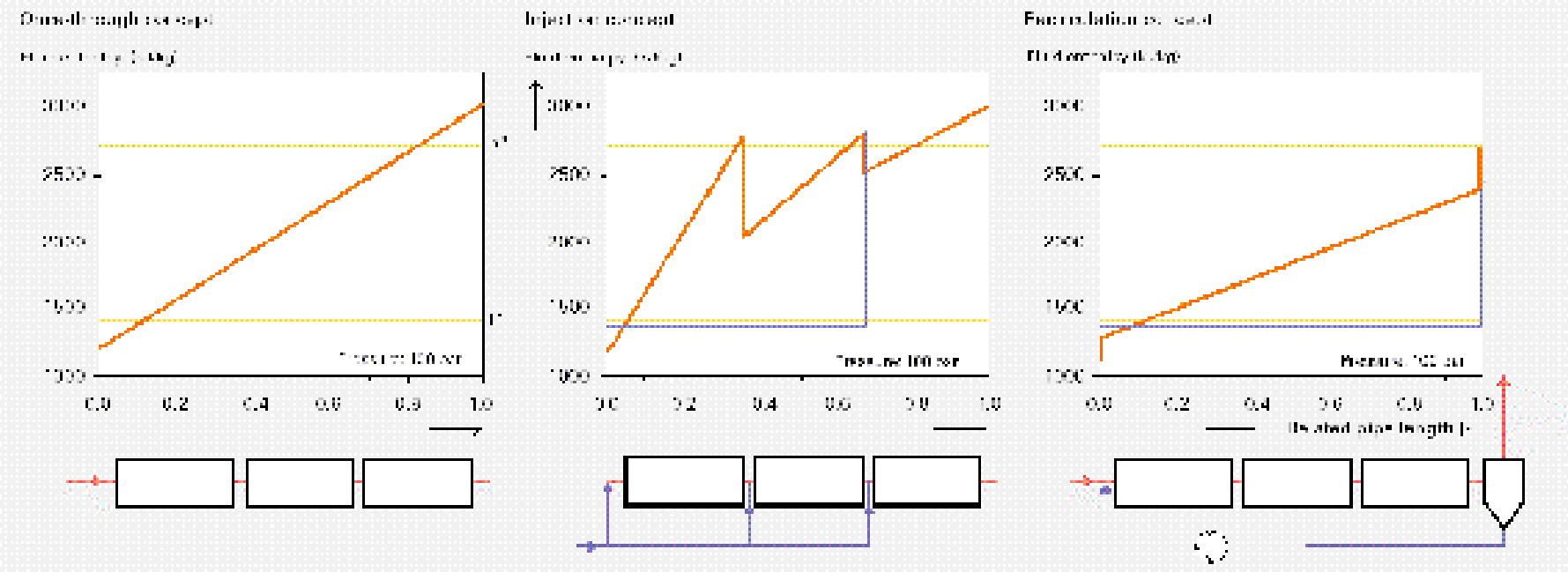


Heat Transfer Behavior in Absorber Tubes of Solar Power Plants with Direct Steam Generation



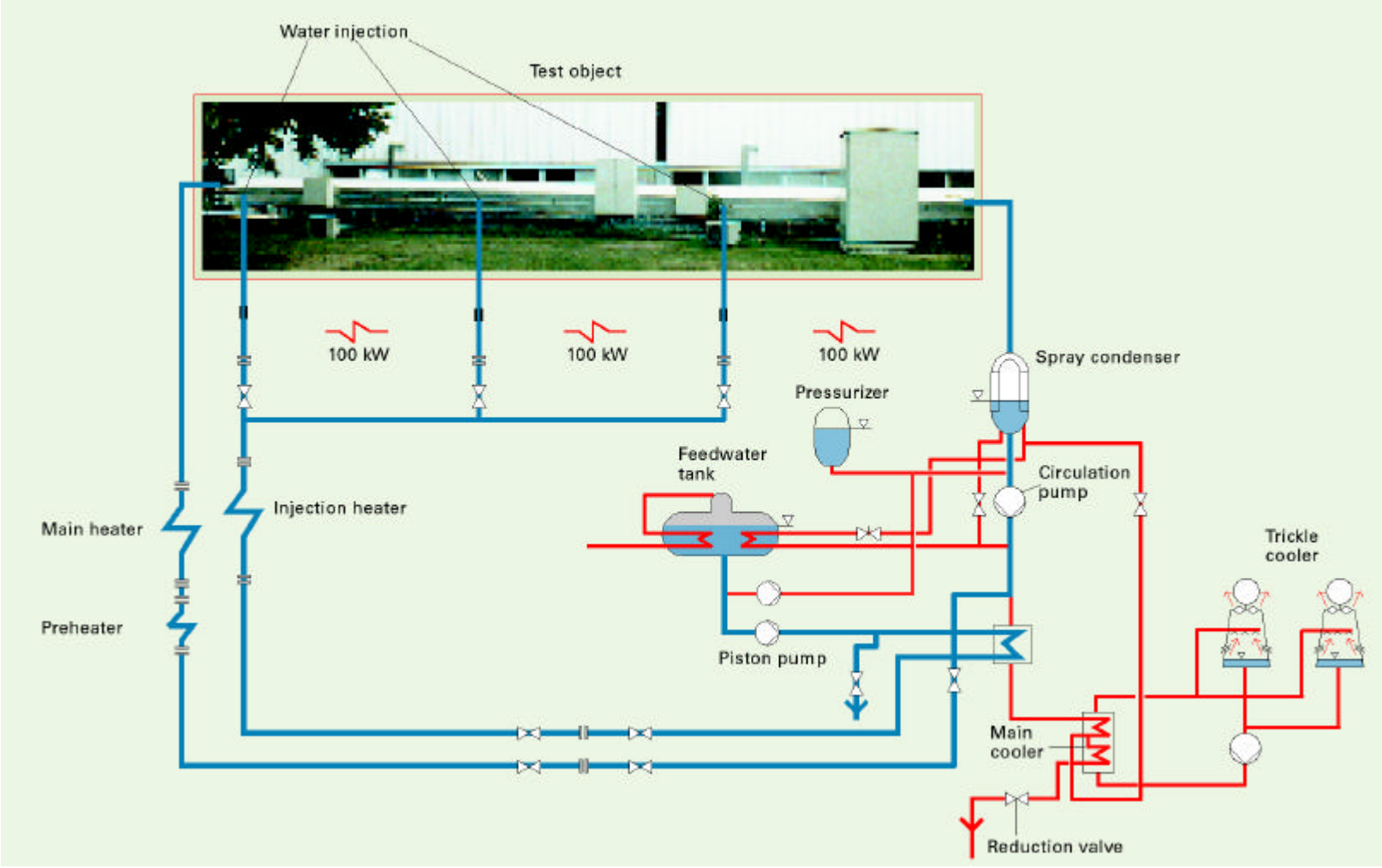


Solar field concepts



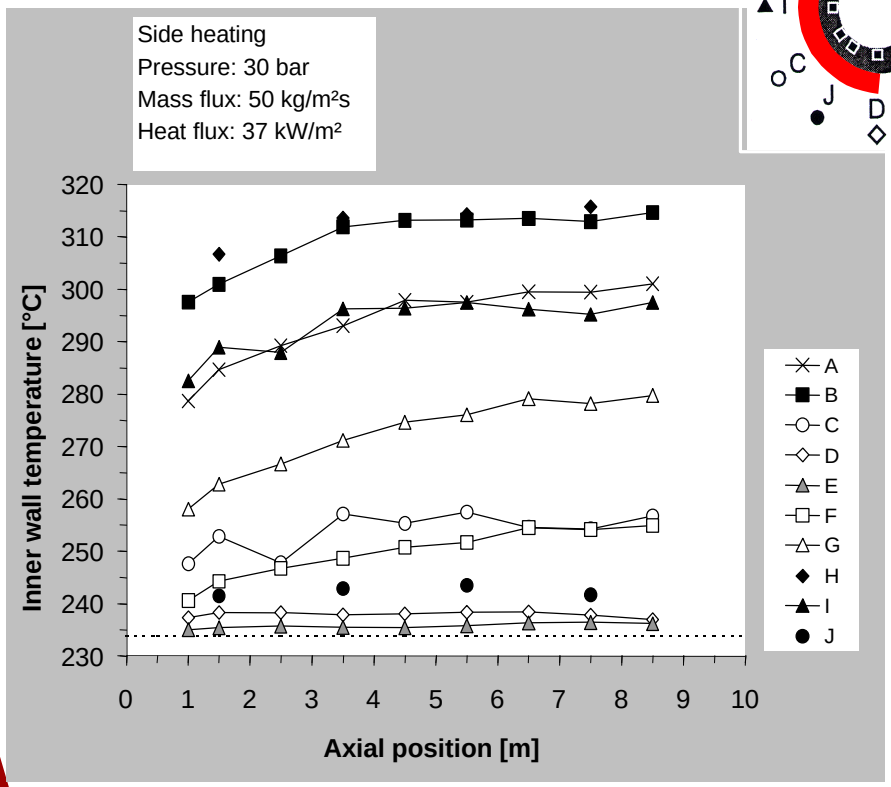
FRAMATOME ANP

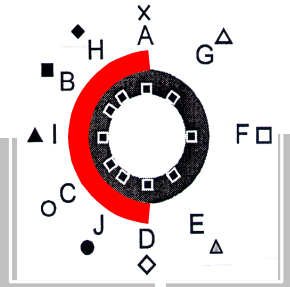
Test-setup


Water injection
Test object
100 kW
100 kW
100 kW
Spray condenser
Pressurizer
Feedwater tank
Circulation pump
Main heater
Injection heater
Trickle cooler
Preheater
Piston pump
Main cooler
Reduction valve

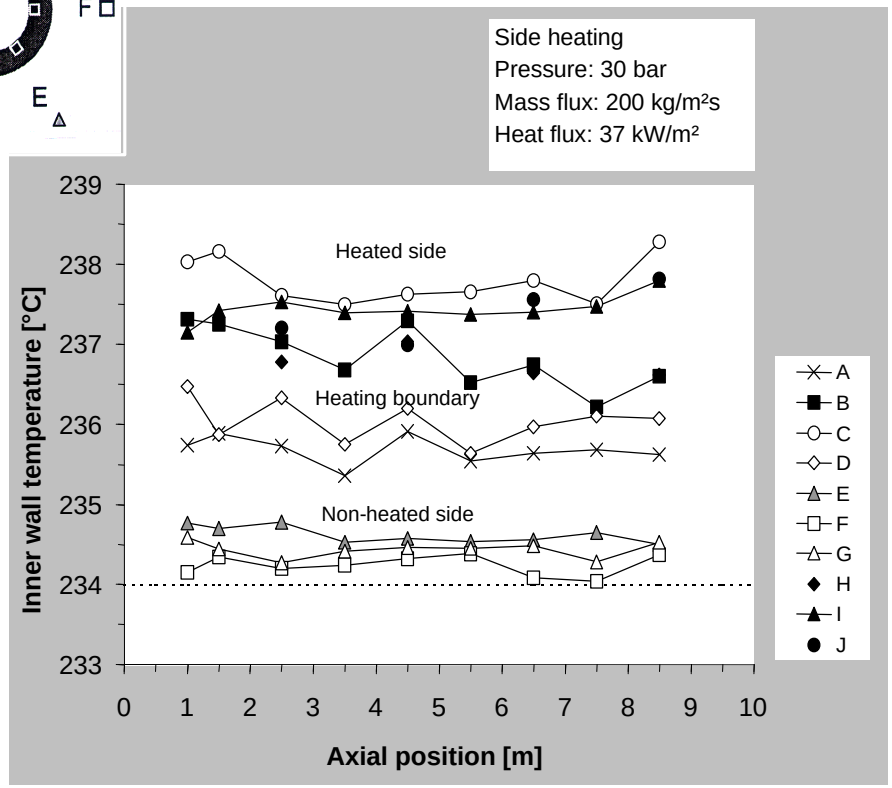
Wall Temperature Distribution as Function of Flow Pattern

Stratified Flow

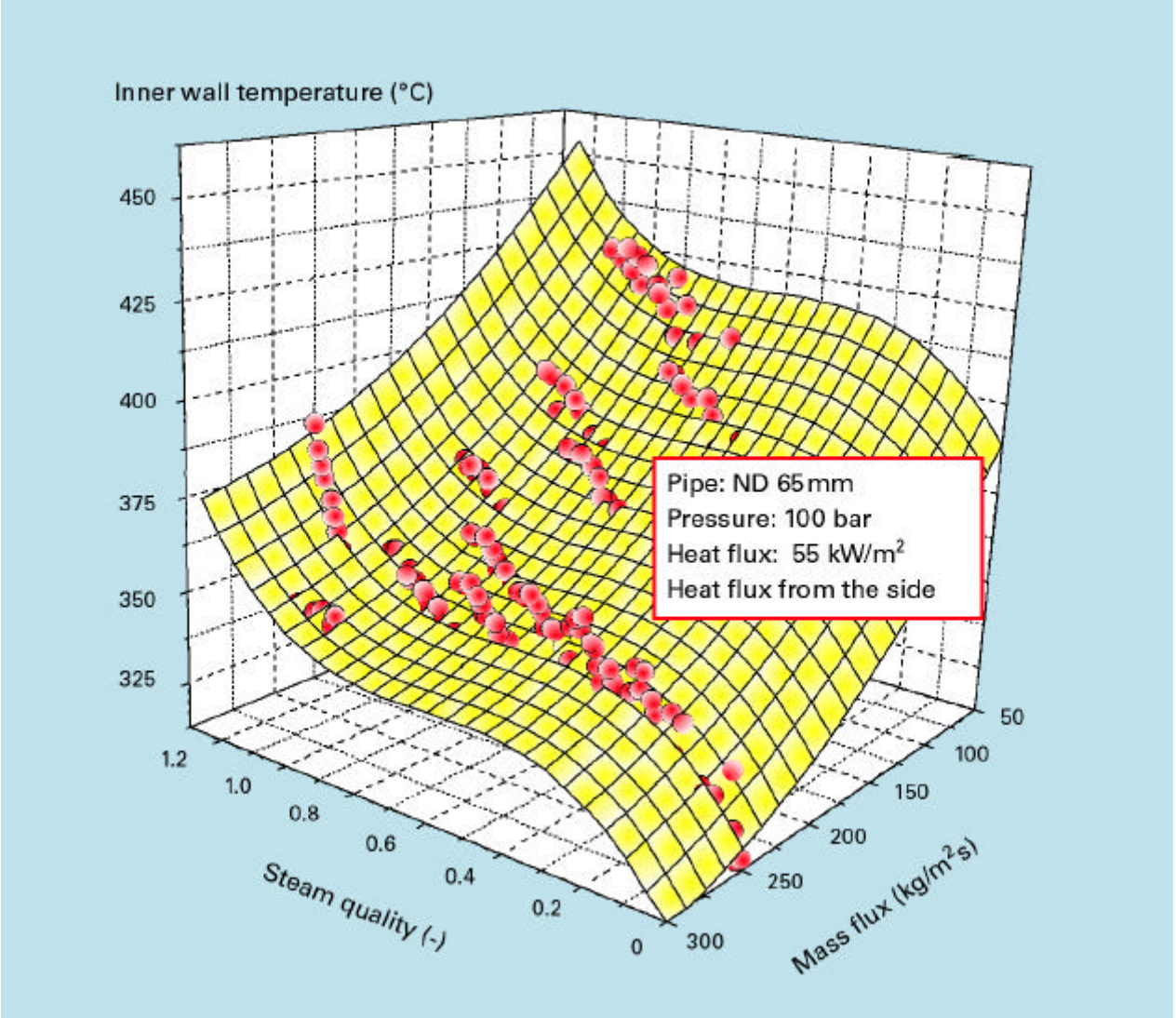




Annular Flow

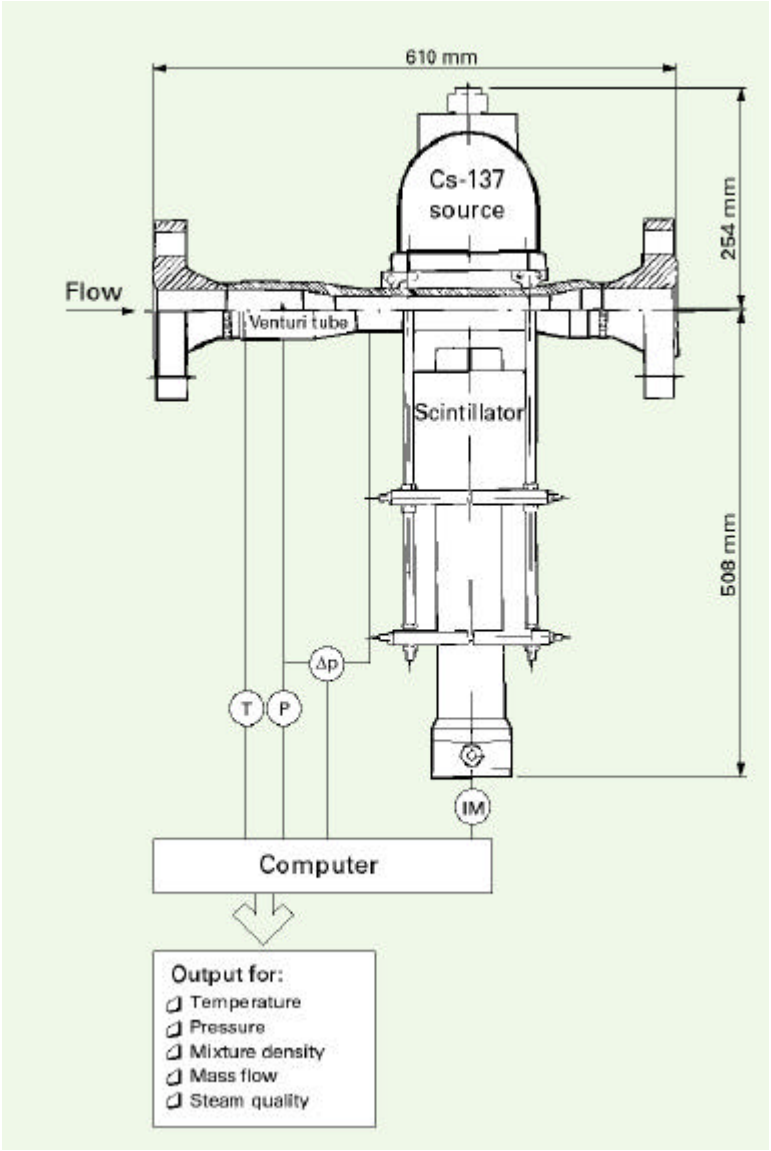


Inner wall temperatures parabolic tough like tubes

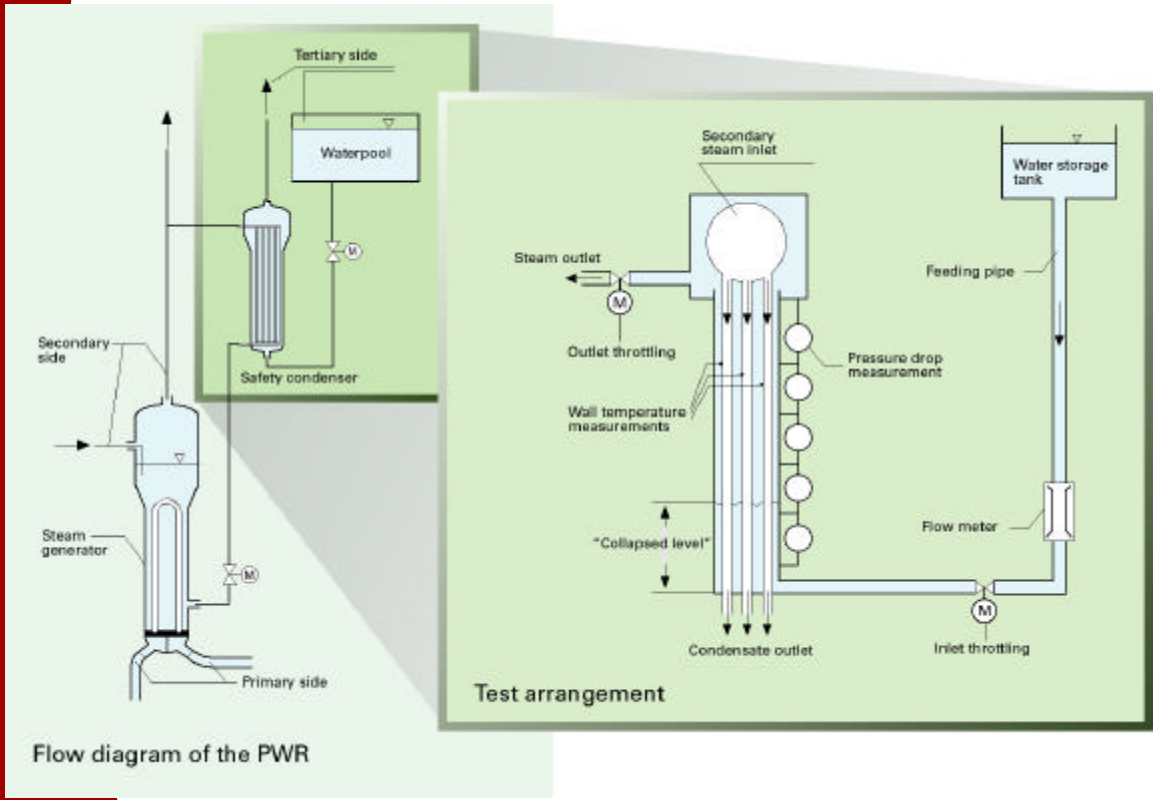


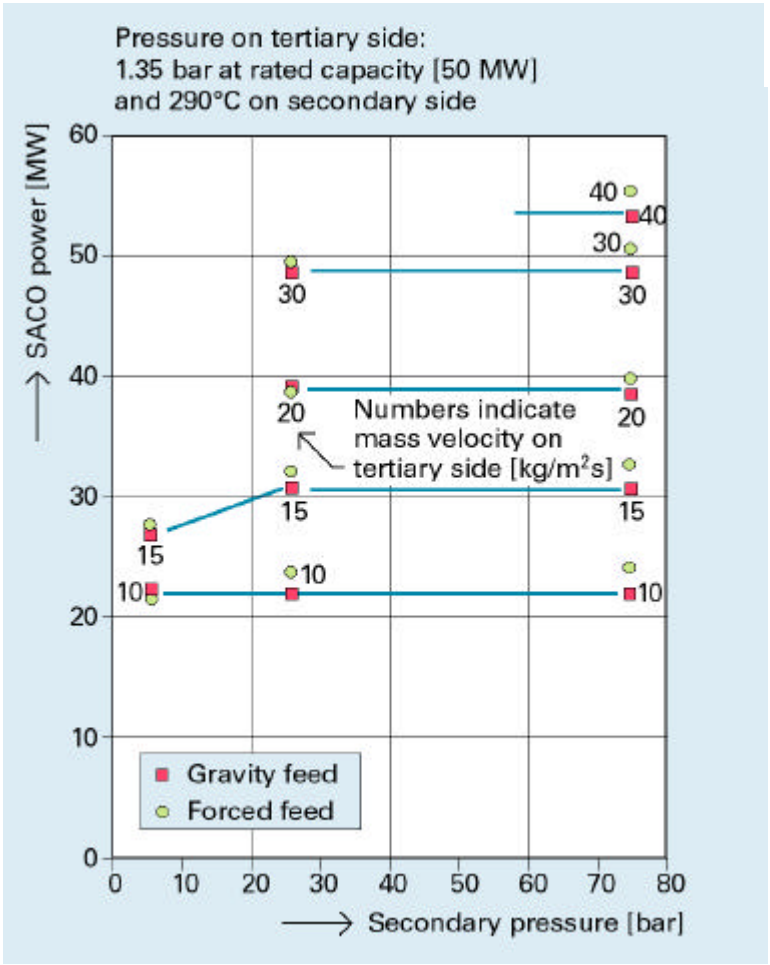
FRAMATOME ANP

Qualification of two phase flow measurement equipment



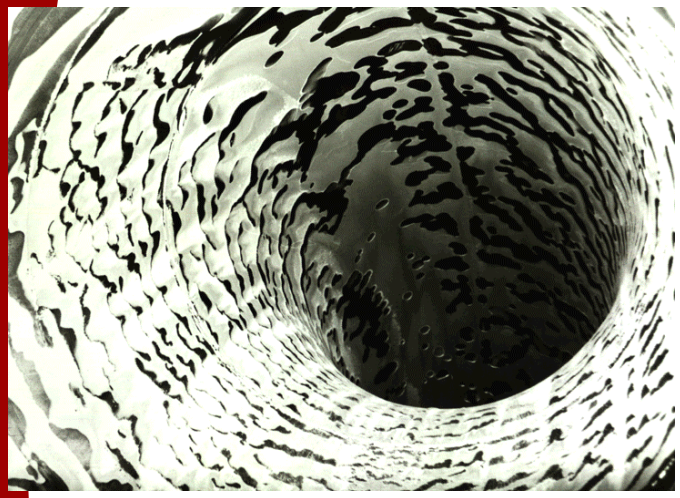
Safety condenser - flow investigations

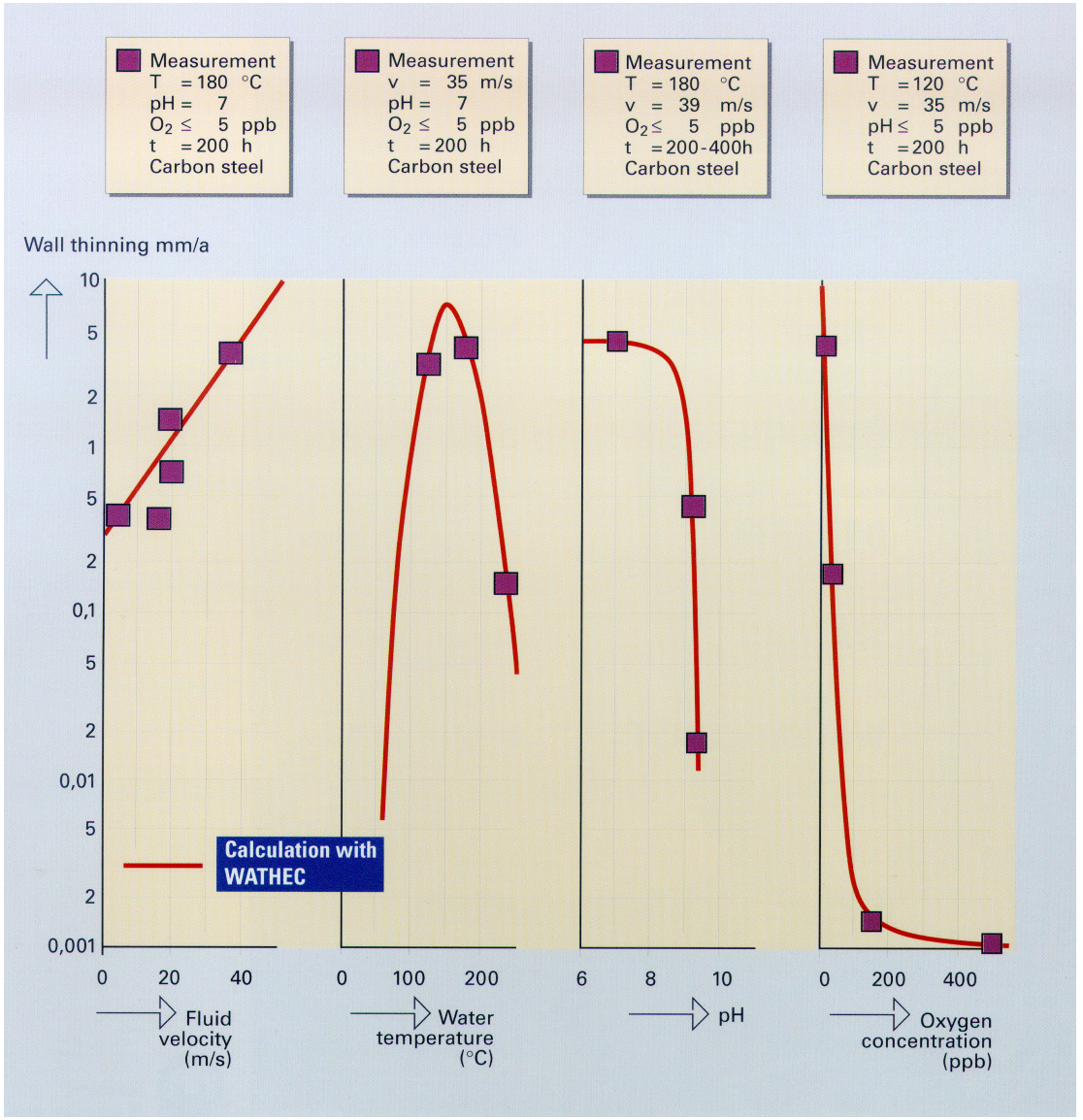




FRAMATOME ANP

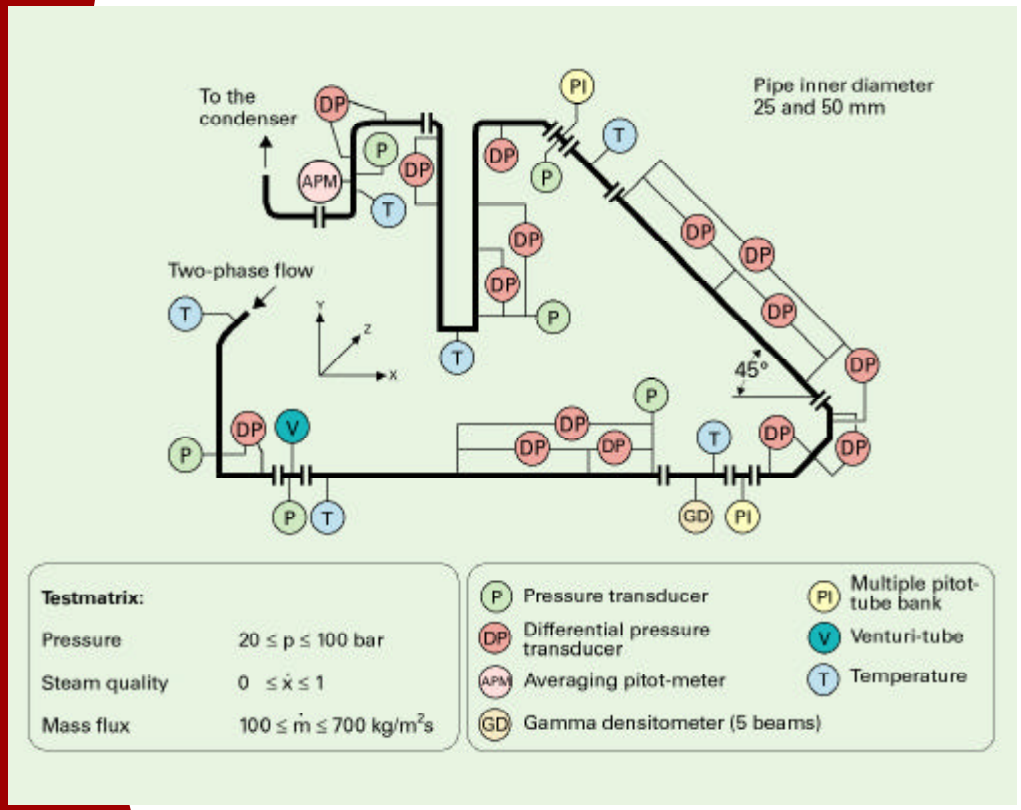
Wall thinning due to erosion corrosion

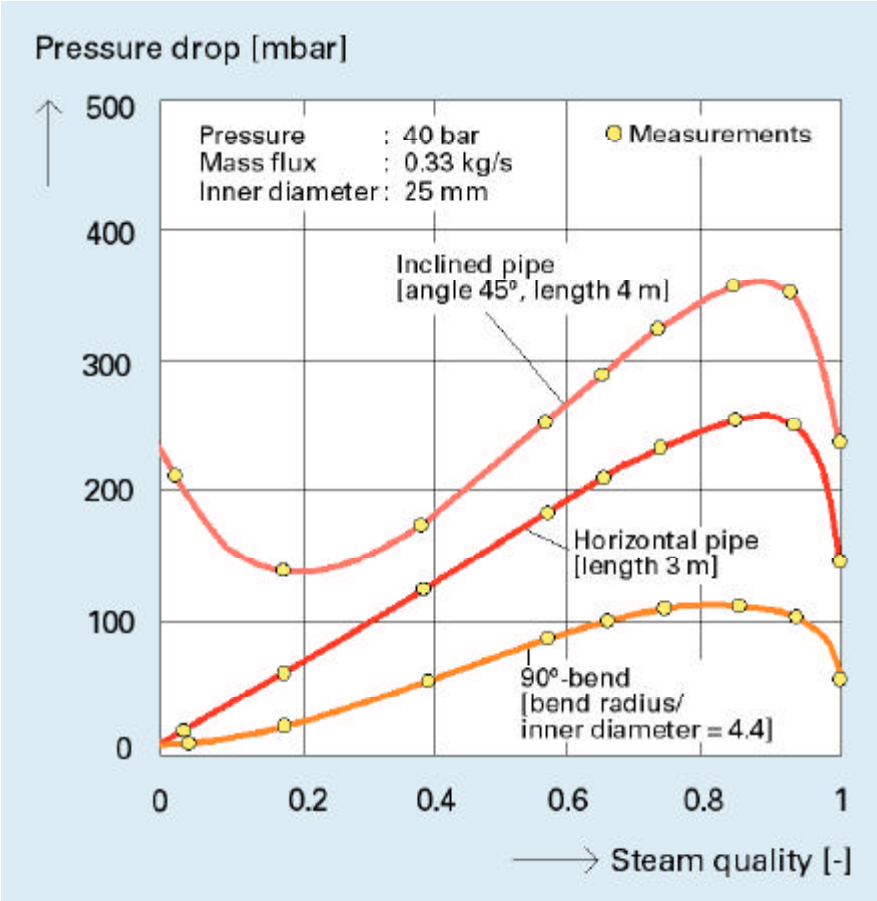




FRAMATOME ANP

Pressure drops in two-phase flow networks





FRAMATOME ANP