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Simulation of Fatigue relevant thermal Loads of Components in Piping Networks

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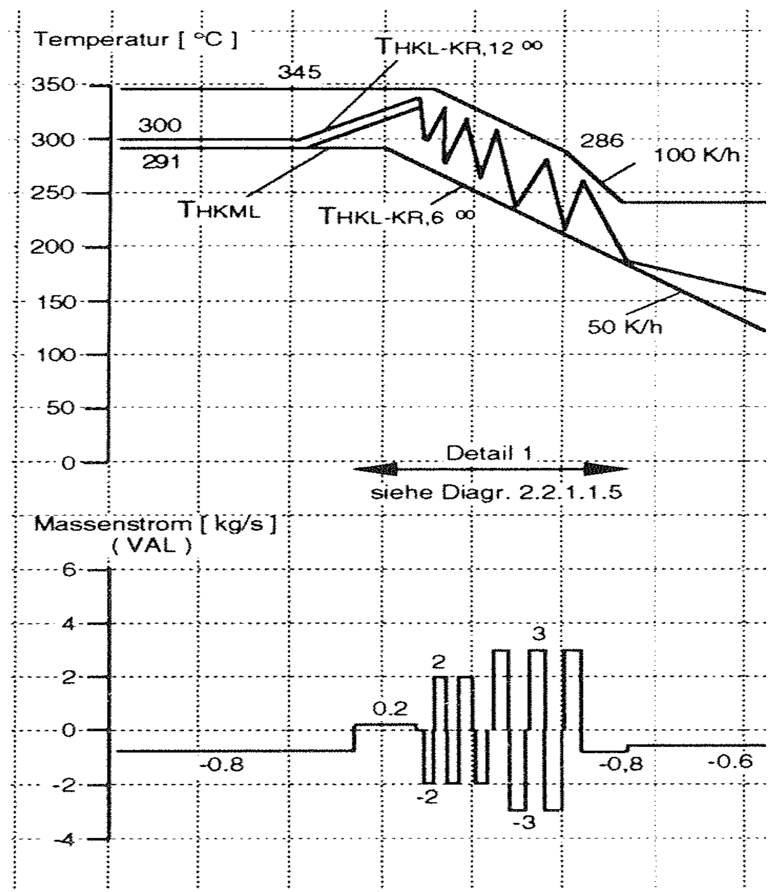
Thermal Loads in Pipes or Components

- **Problem: Thermal loads in pipes or components which cannot be measured directly by e.g. local temperature measurement**
- **Standard method: definition of conservative thermal transients. This leads to huge thermal loads.**
- **New method: A fluid and thermo dynamical calculation of the pipe or component leads to realistic temperature transients.**
- **Examples will be shown for the Regenerative Heat exchanger, the spray line and the pressurizer.**



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STADRU toolbox
System Design Lifecycle

STADRU tool box - Definition

► **STADRU**

tool box for thermal hydraulic calculations

provides the platform to solve system questions

closed loop concept for system design starting from the Basic Design over Detailed Design to the life time surveillance.

STADRU tool box

NPP system conditions

–> Design challenges

–> Code requirements

- single phase (Weak compressible)
  (e.g. oil, cooling medium, liquid H_2O, low ΔP air)
  - Steady state or slow transient
  - **T**hermal **T**ransient calculations including heat exchangers with huge temperature changes at tube or shell side
- Fully transient (compressible)
  - Gas (critical flow)
  - Liquid + gas (steam and inert gas in arbitrary concentrations)
  - Condensation/evaporation

    -fluide: e.g. H_2O, N_2, O_2, H_2, *He, Ar* or CO_2

STADRU toolbox meets these design challenges

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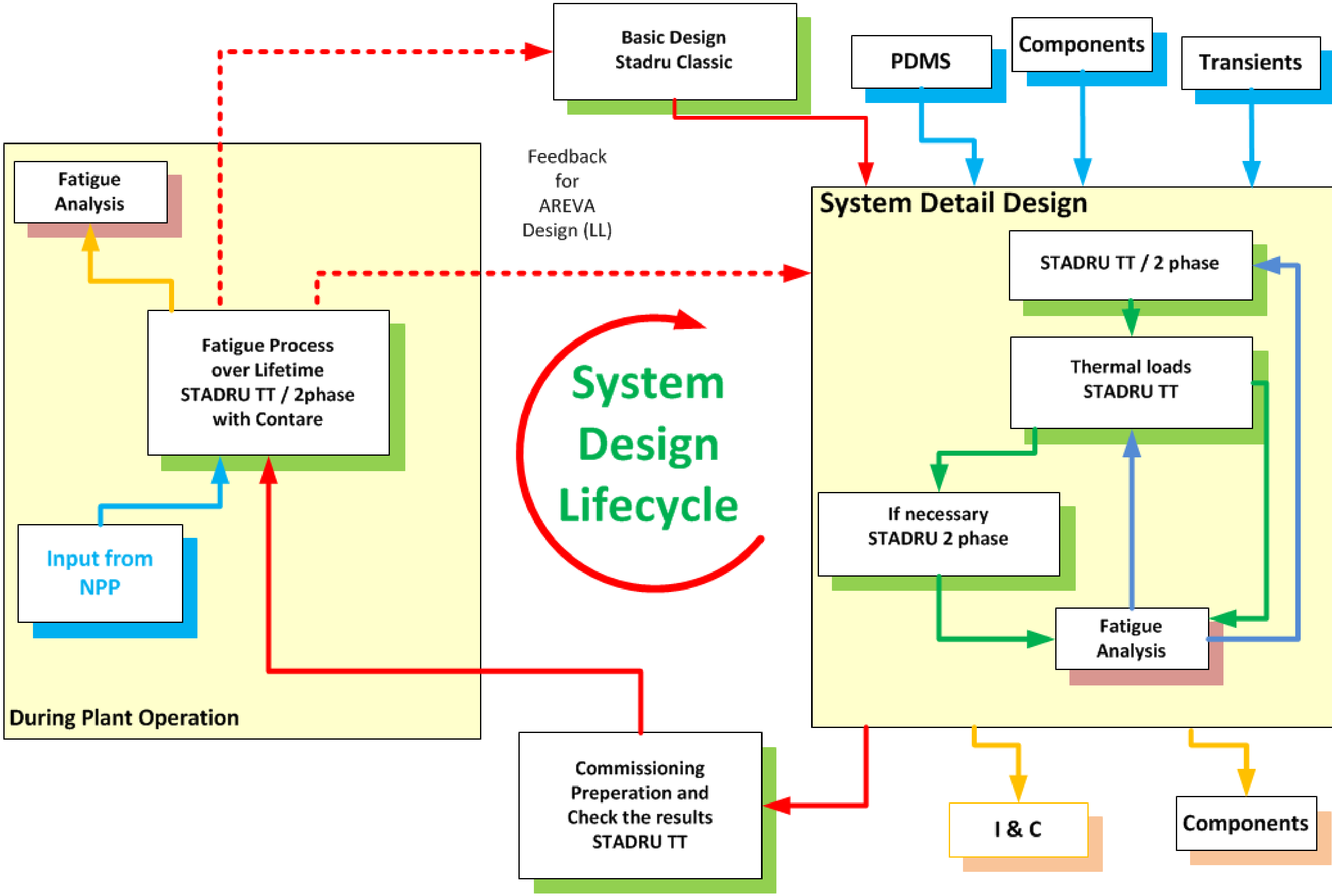
STADRU tool box
NPP system design lifecycle



System Design Lifecycle

STADRU tool box
NPP system design lifecycle

Closed loop concept for system design

- Basic and detail system design
- Examination of all system functions
- Definition of thermal loads
- Fatigue relevant loads to I&C and components
- Definition of all system operational modes
- Pre system testing based on commissioning needs
- Commissioning surveillance
- Life time surveillance of the systems

STADRU tool box
Deployment examples of the last few years

KONVOI design and commissioning	Cooling chain, cooling towers, CVCS, RHRS, SIS, Sealwater, Safety valve design, PZR Spray
Atucha (D2O)	Cooling chain, CVCS, RHRS, SIS, Sealwater, Safety valve design, Refueling machine
BIBLIS	Thermal loads for the CVCS (Life time cycle)
EPR	Thermal loads for the CVCS and design of the coolers
ATMEA	Thermal loads for different system parts
Gundremmingen	Reactor trip system of the BWR, Water system with gas energy supply (Accumulator tank system)
FRM 2 Munich	He systems
Beznau,	Gas/Water protection system for a water tank
Gösgen	Cooling system for fuel storage pool
Trillo	CVCS design, Back flushing of the sump grids
WWER plants	Cooling chain

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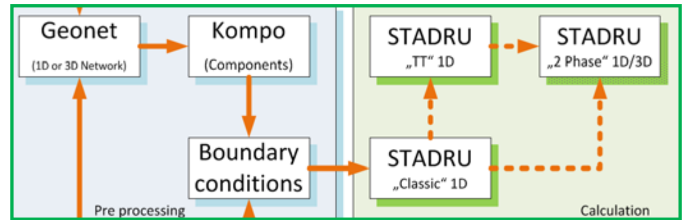
System
Design
Lifecycle

STADRU tool box
Program structure



GEONET: Generation of piping networks

KOMPO: Reproduction of components

STADRU Classic: Steady state or slow transient calculations of single phasic piping networks for system design.

STADRU TT: Thermal Transient calculations of single phasic piping networks which includes the behavior of the pipe walls and the insolation as well as the time dependent behavior of heat exchangers.

STADRU 2-Phase: Time dependent thermal hydraulical calculation with change phase in 1-D networks or 3-D volumes

Graphical Post Processing: Tools for the different visualization of calculations

All parts of the tool box communicate via interface files and use collective libraries.

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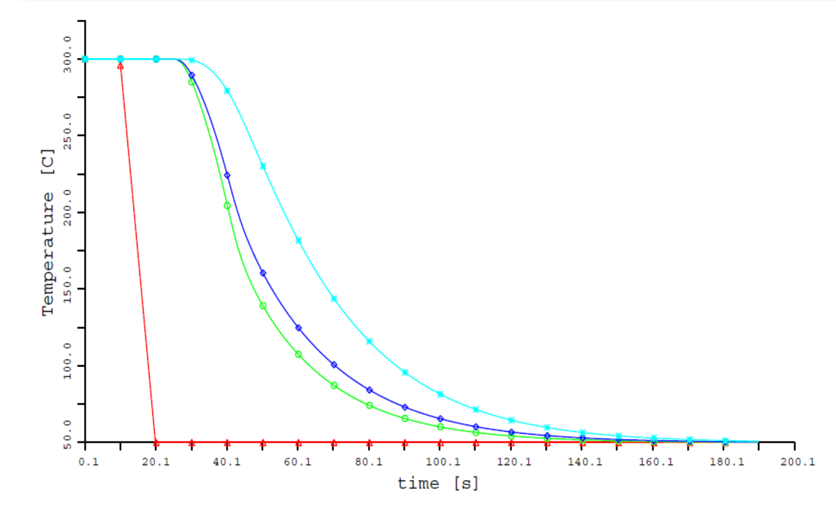
STADRU TT



Temperature transients in a piping system with a heat exchanger

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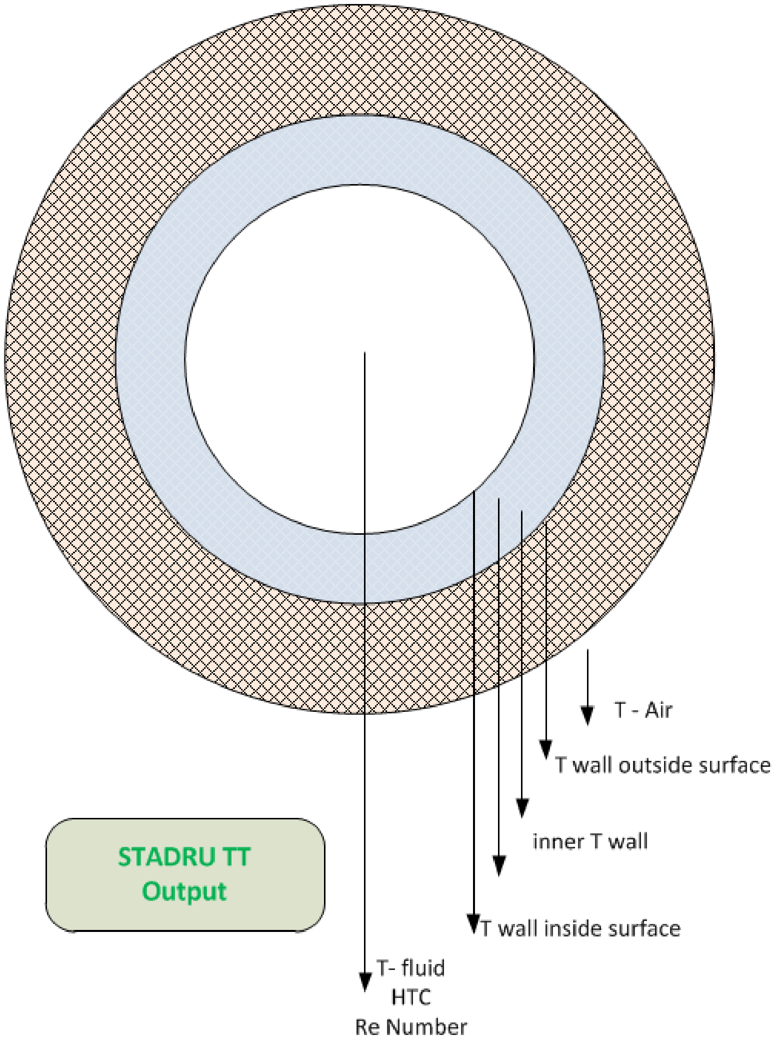
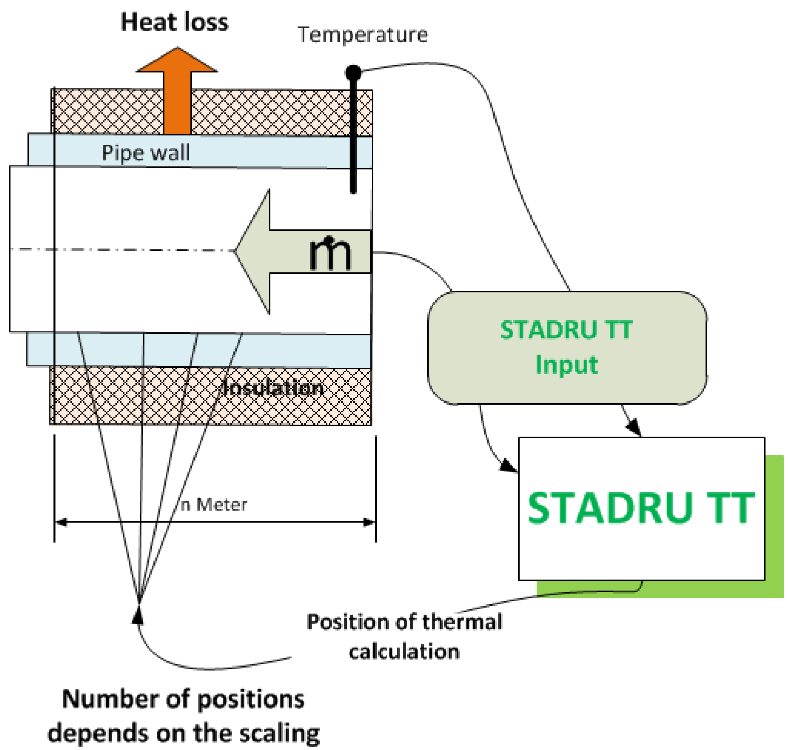
STADRU tool box
STADRU TT





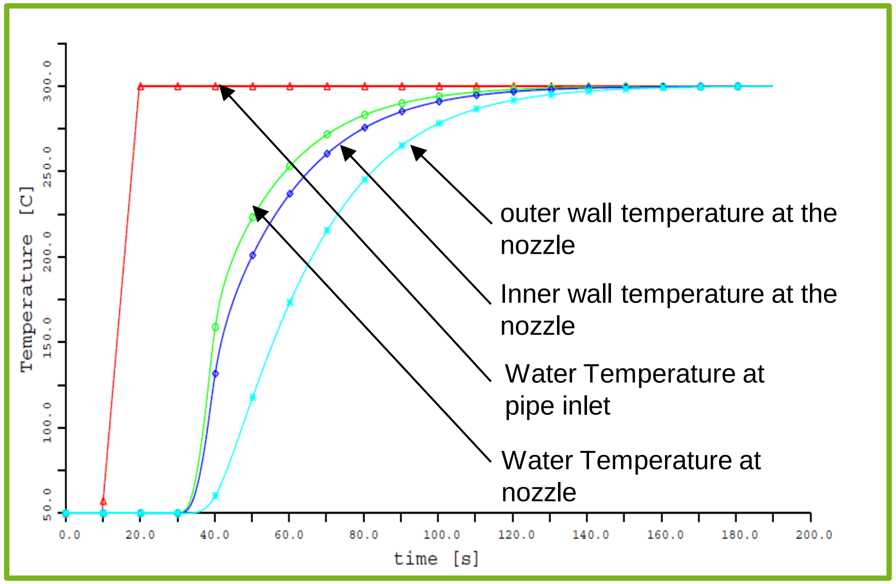
Following essentials for solving transient problems are considered by STADRU TT:

- radial and longitudinal mutual heat transfer
- heat storage within pipe wall
- heat loss through the insulation

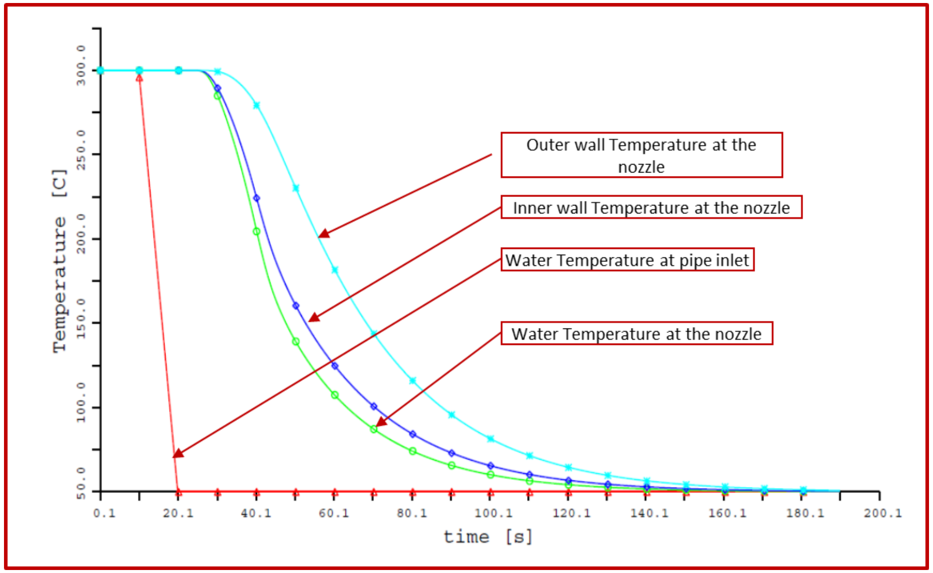
Pipe length 40 meter; mass flow 9 $\frac{kg}{s}$;

Temperature change in 10 seconds at the beginning of the pipe

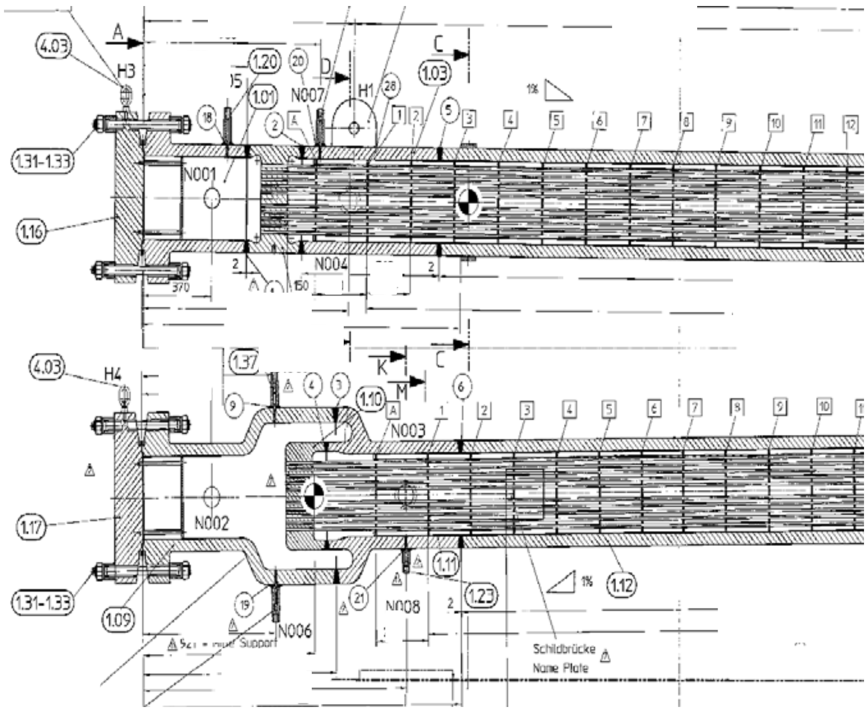
from 50°C to 300°C



from 300°C to 50°C



STADRU tool box – STADRU TT
Detailed model of complex REKU HX

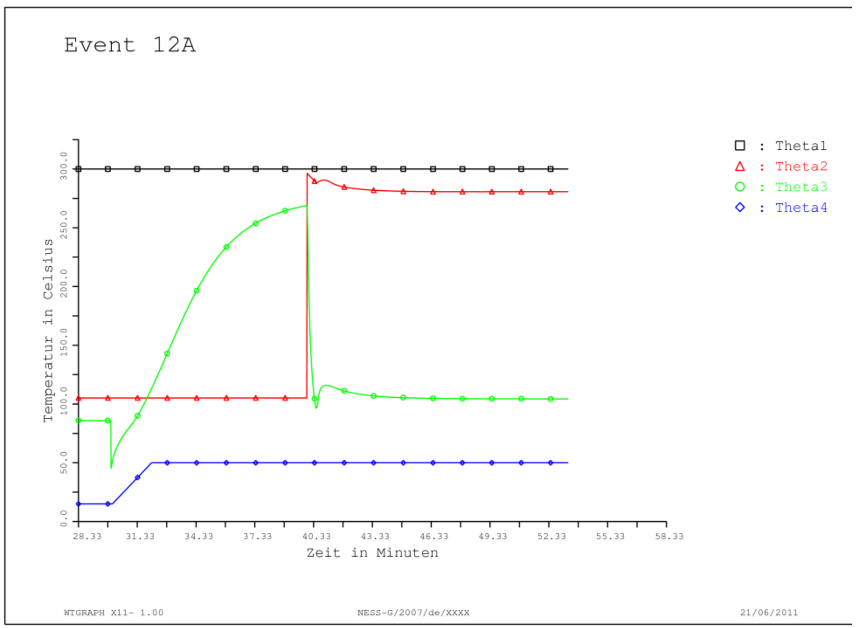


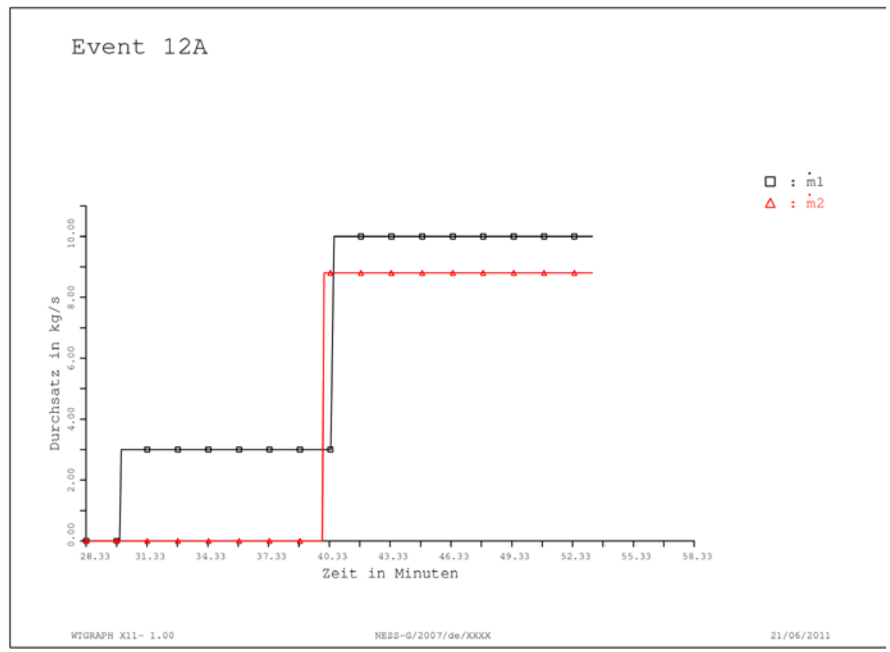
STADRU TT contains a multi-cell model of REKU HX with a set of coupled differential equations

A single cell model is not capable to describe/simulate such a complex HX with high $\Delta\vartheta$ (as for high $\Delta\vartheta$ the fluid properties can undergo a change up to 30 % and result into even higher thermal hydraulic consequences for component).

STADRU tool box – STADRU TT
Layout transient

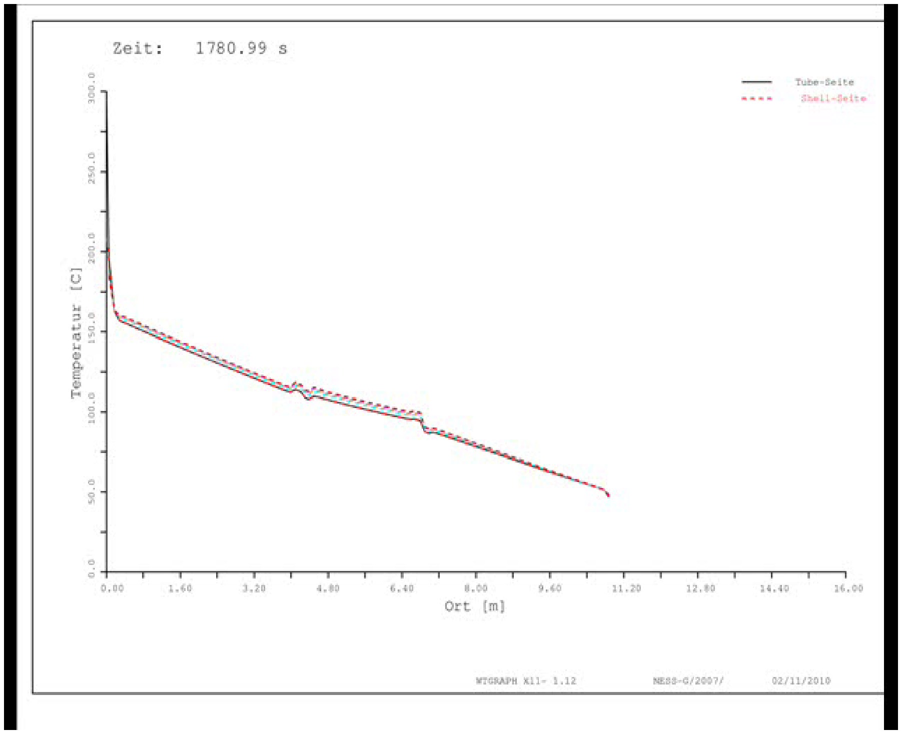
Temperature and massflow over the time at heat-exchanger





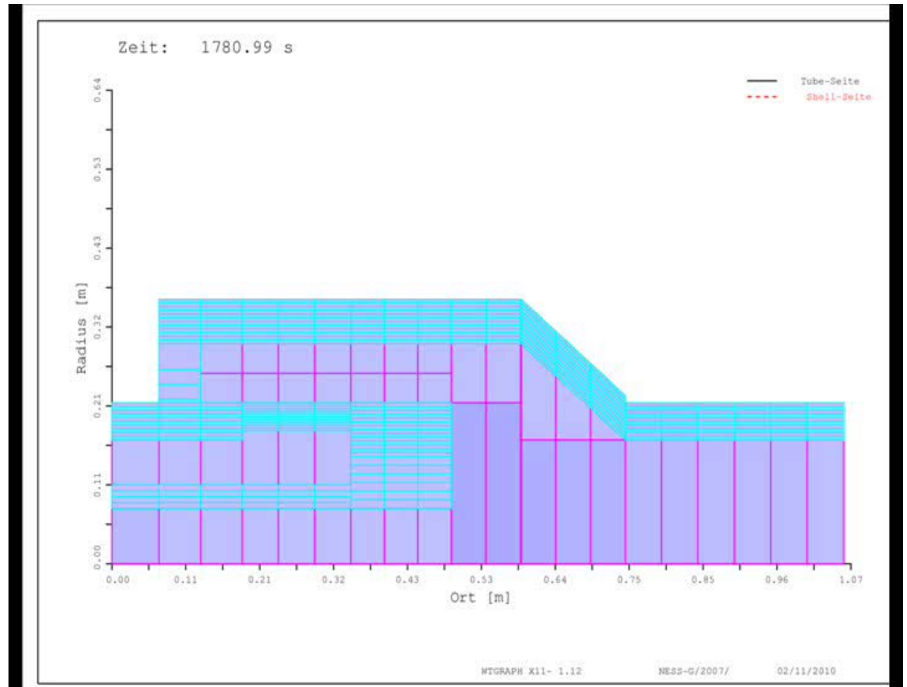
STADRU tool box – STADRU TT
Detailed model of complex REKU HX

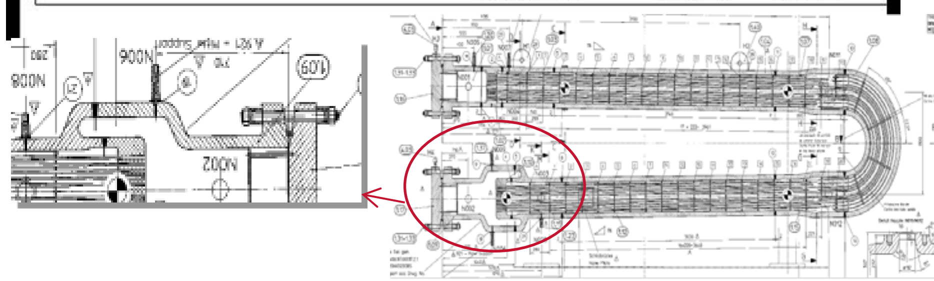
Temperature over the length of the heat-exchanger



Start

Temperature over the outlet-chamber of the heat-exchanger





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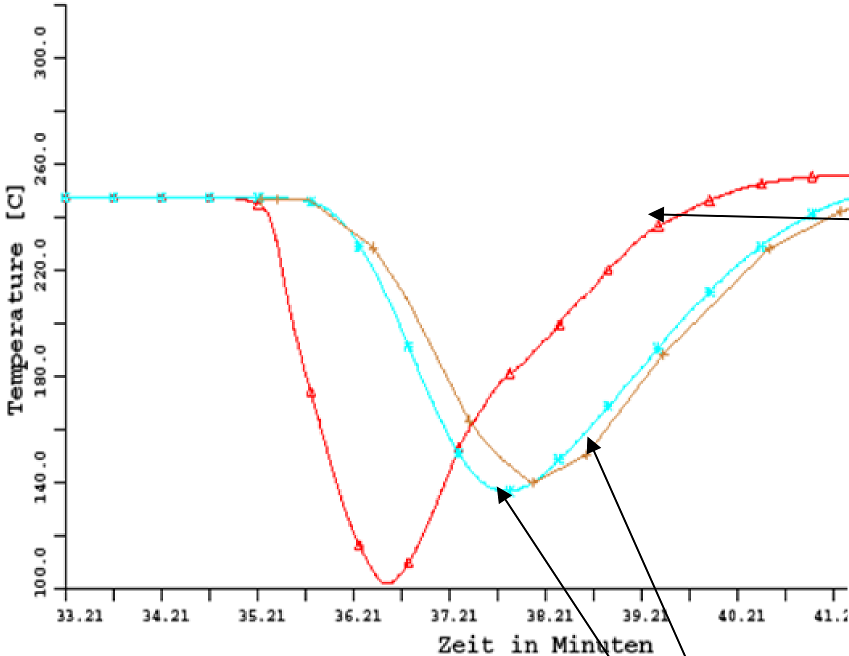
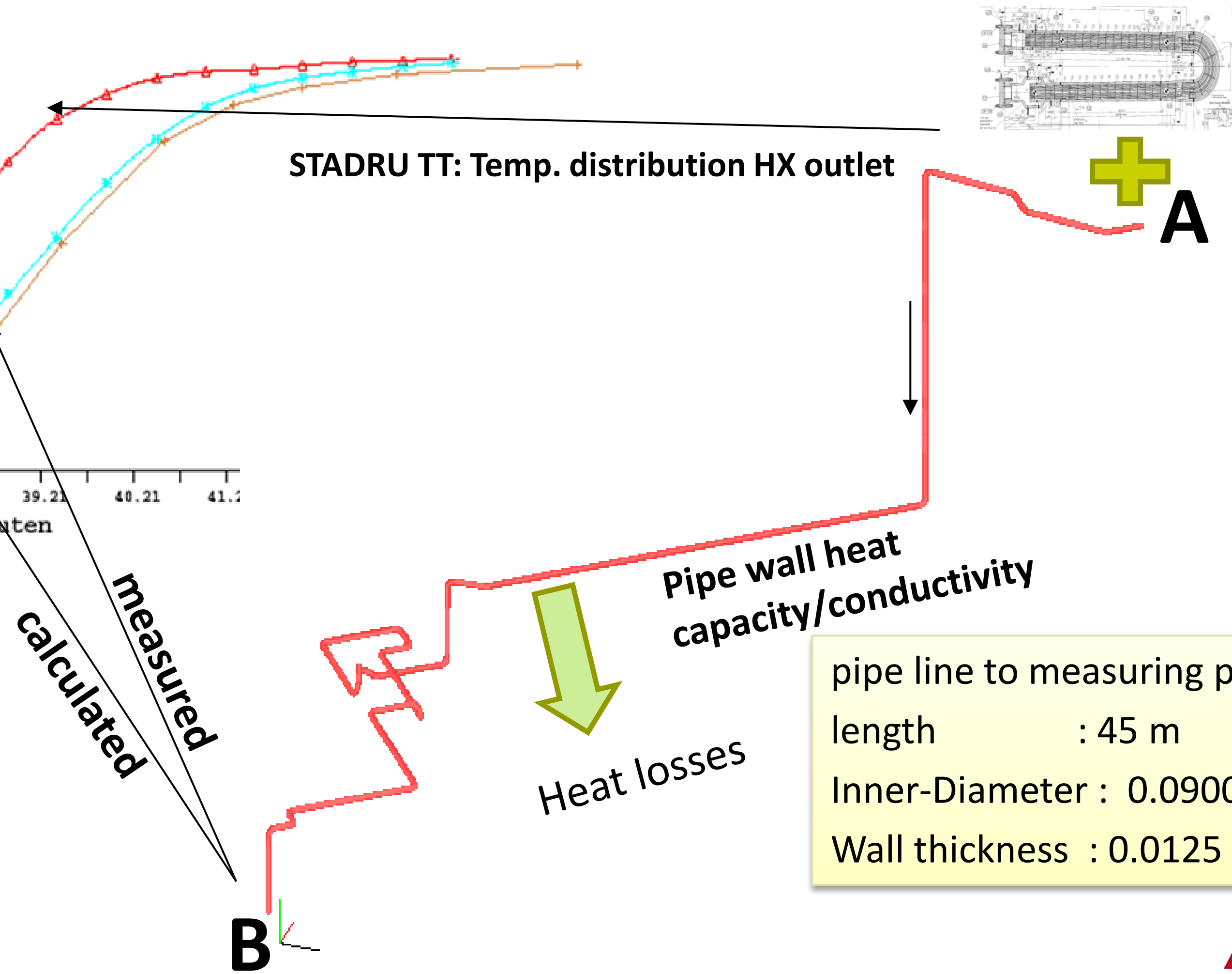
STADRU tool box – STADRU TT





STADRU TT: Influence of pipe length, heat capacity and heat loss + fully transient calculation of multi-cell REKU HX of the load transient.

pipe line to measuring point	
length	: 45 m
Inner-Diameter	: 0.0900 m
Wall thickness	: 0.0125 m

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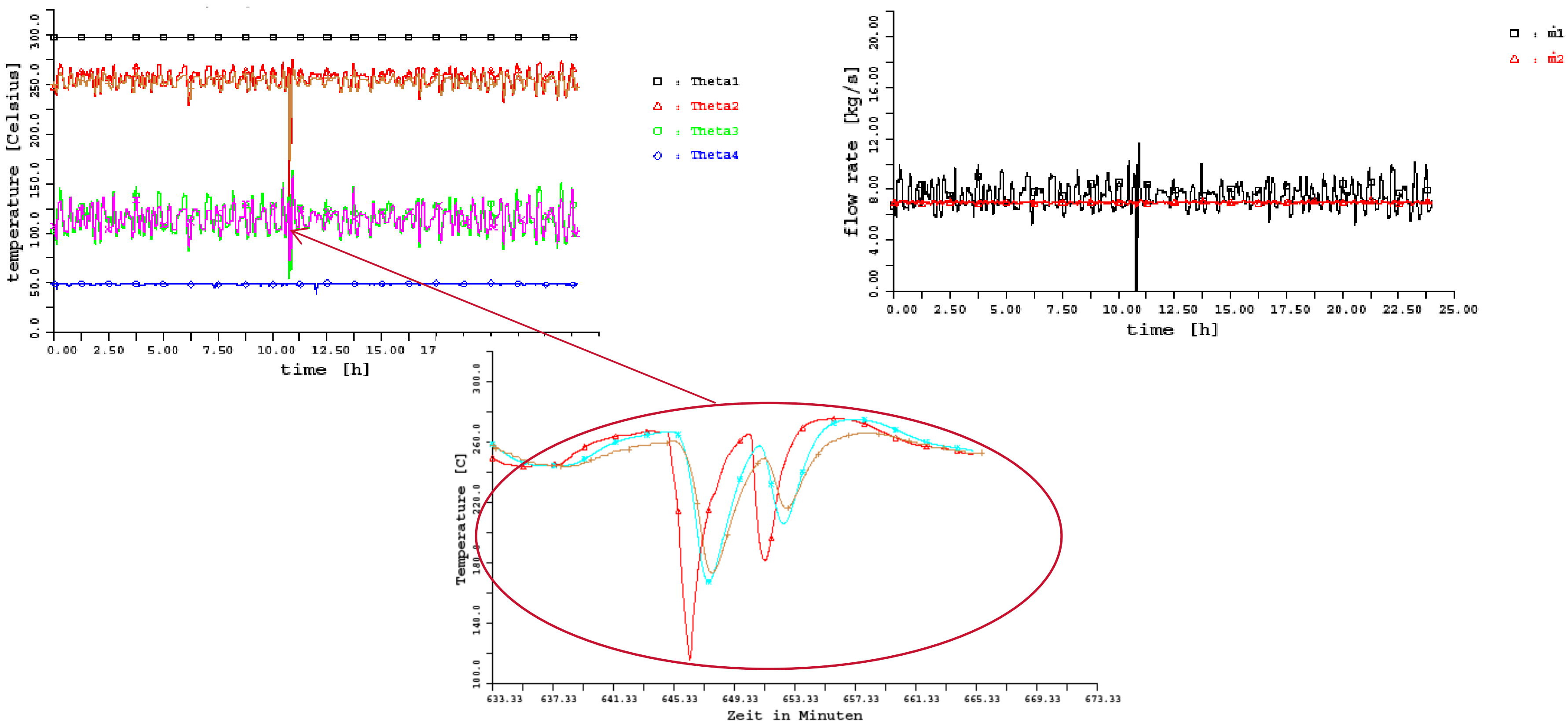
STADRU tool box – STADRU TT
Analysis of a day

Space of calculation time: 1 Day ~ 86400sec

Temperature and massflow over the time at the heat-exchanger



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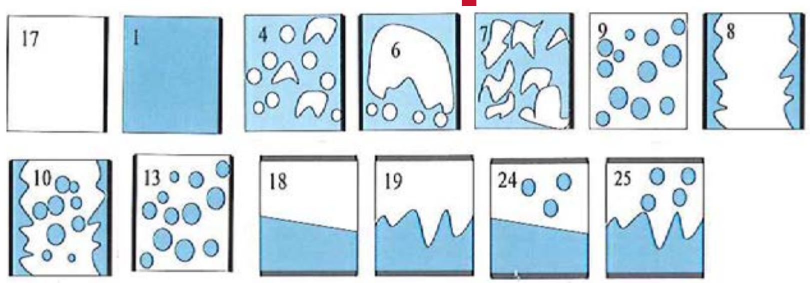
STADRU tool box – STADRU TT Advantages

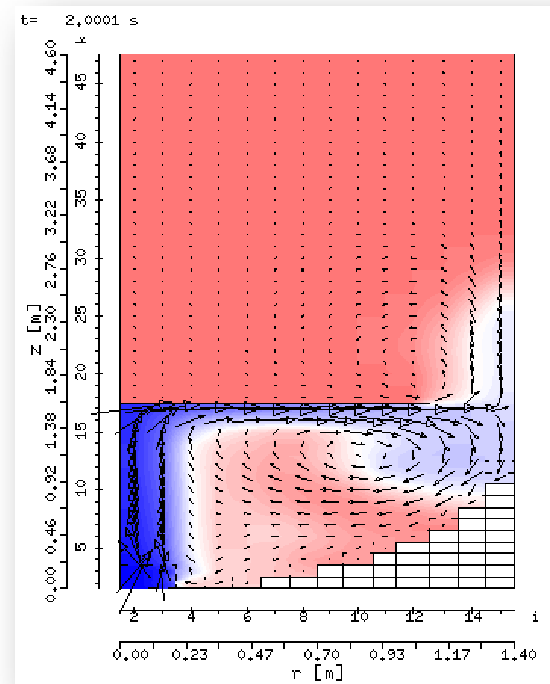
- The time dependent temperature at or in internal structures like tube plates or outlet chambers is calculated
- High resolution of the geometry
- The change of fouling over time can be calculated (fouling factor)
- Analysis and optimization of operational modes
- Direct transfer of the calculated temperature profiles to fatigue analysis
- The detailed time dependent calculation of temperatures leads to lower fatigue loads (reduction factor between 2 and 15)

STADRU 2-phase



Time dependent thermal hydraulical calculation with change of phase in

- 1-D networks or
- 3-D volumes



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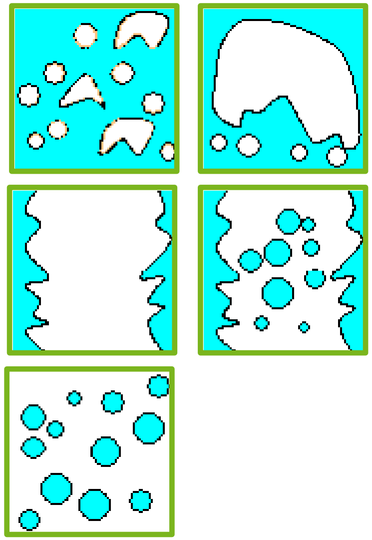
STADRU 2-Phase

- STADRU2-Phase solves the time dependent conservation equations for momentum, mass and energy (Navier-Stokes equations).
- The closure relations for computation of the drag forces as well as the mass, momentum and energy source terms are based on flow patterns characterizing the specific nature of the two phase flow like bubbly, slug or film flow.
- STADRU 2-Phases uses about 40 flow patterns to characterize the different flow situations; especially fragmentation or coalescence of droplets or bubbles.
- STADRU 2-Phase uses for each cell different velocities and temperatures for gas, liquid and droplets or bubbles, and is thus able to handle droplet entrainment or deposition in case of film flow or horizontal stratified flow.

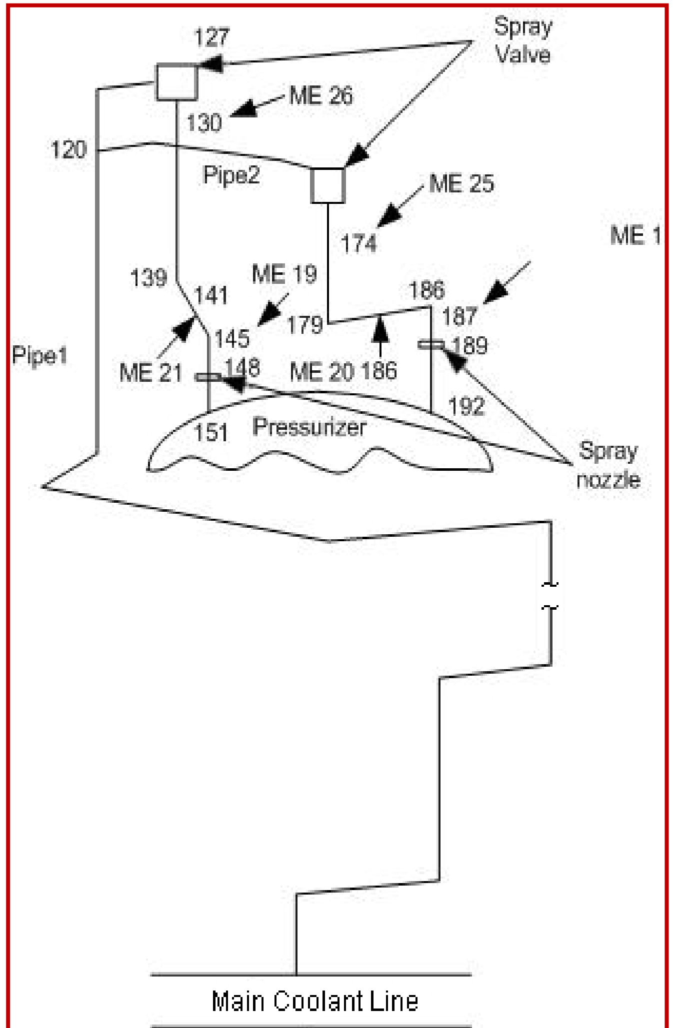


Pressurizer spray line for a German Nuclear power plant

- Change from permanent spraying to full spraying with respect to the
- Pressurizer
  - Pressure : 156 bar
  - Temperature : 345 °C
- Permanent spraying
  - Mass flow : 0.8 kg/s
  - Temperature : 300 °C
- Full spraying
  - Mass flow : 12 kg/s
  - Valve opening : 1 s

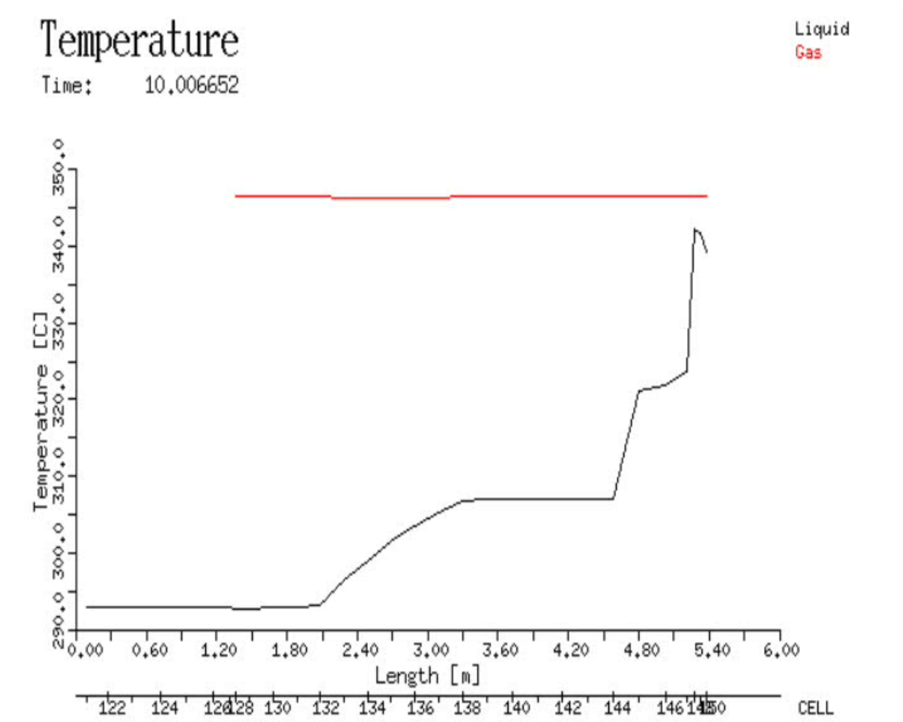
Background:

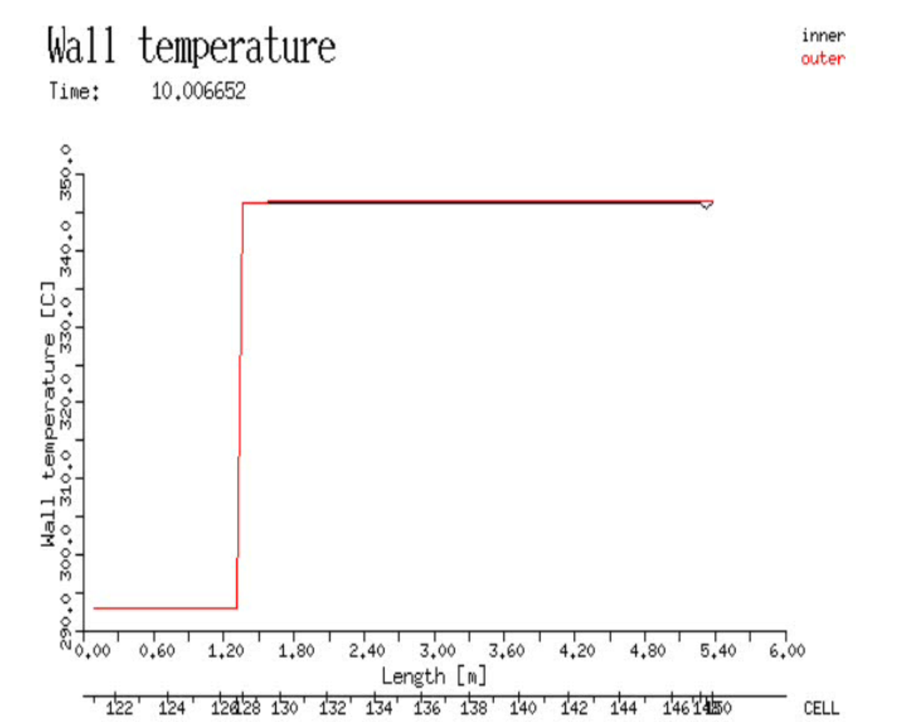
- The permanent spray is very small and does not fill the pipe.
- During spraying, there is a change from steam to water and back at spray valve close.
- The calculation was made for determination of the thermal loads at the spray nozzle.



STADRU 2-Phase
Opening of the Spray Valve

Fluid and wall temperature over the length of the spray line





Spray valve **Horizontal Part** **Spray nozzle** **Spray valve** **Horizontal Part** **Spray nozzle**

Start

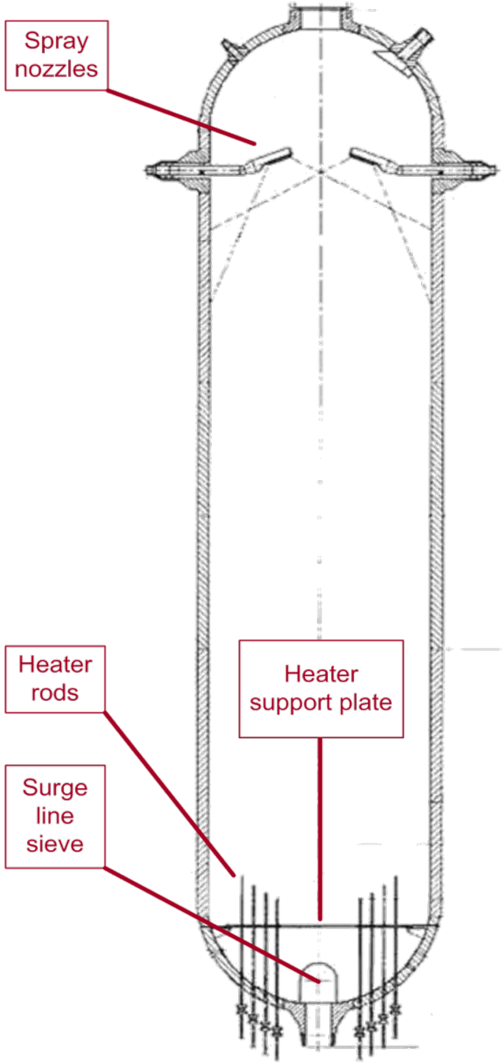
STADRU 2-Phase
Benefit of the 1D Calculation

- **Temperatures, velocities and void fraction of the fluid at every position between the spray valve and the spray nozzle**
- **Mean wall temperatures at every position between the spray valve and the spray nozzle**
- **Optimization of the system with different boundary conditions**
- **Realistic temperature transients for thermal loads**

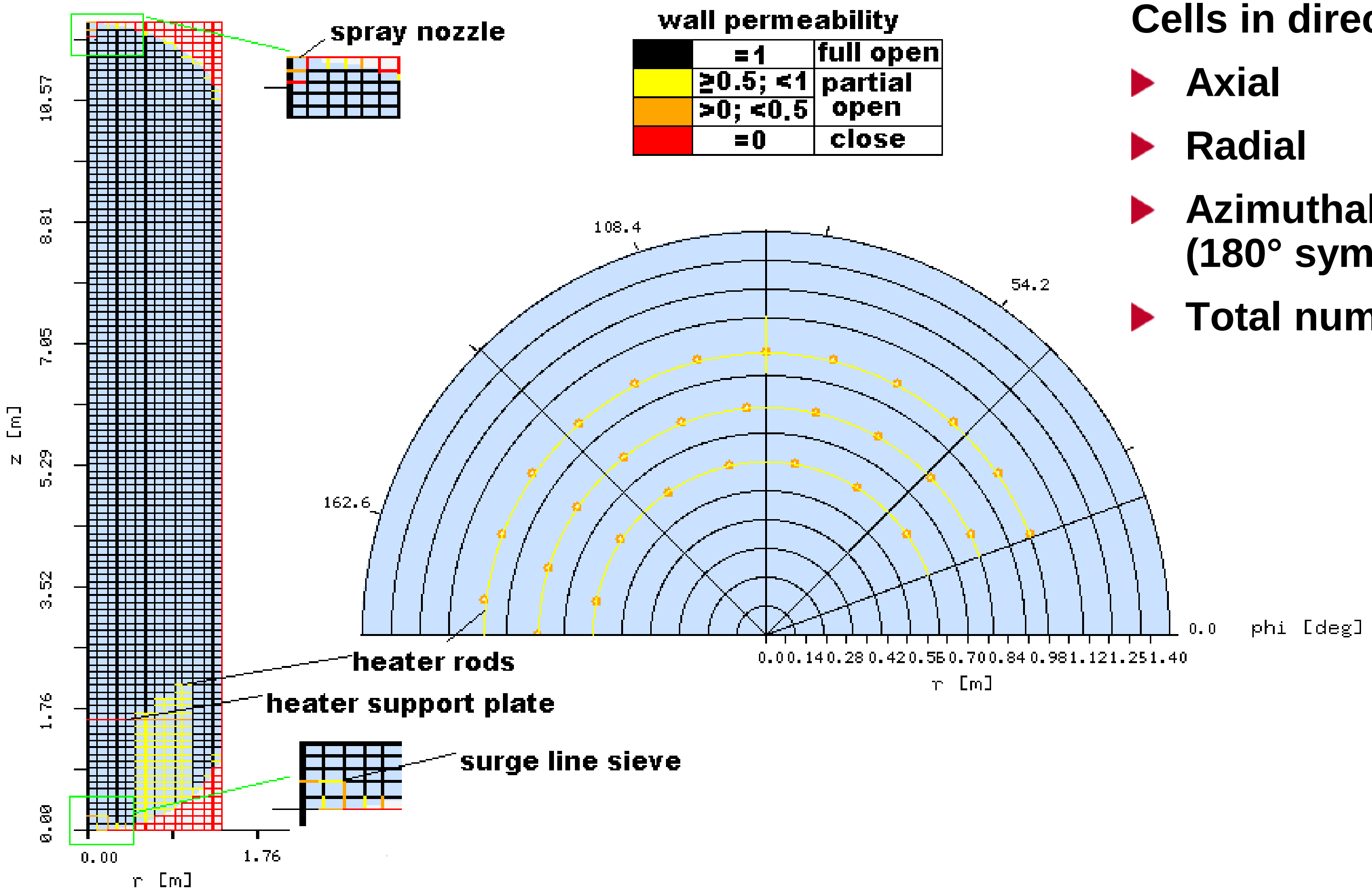
STADRU 2-Phase
3D Simulation: Pressurizer

- Simulation of the thermal loads in the pressurizer which is described by a 3D model

- Height: 11.7 m
- Diameter: 2.8 m
- Volume: ~ 75 m³
- Max. heating power: 2 MW
- Surge line diameter: 0.350 m



STADRU 2-Phase
3D Geometry Model



wall permeability

black	=1	full open
yellow	≥0.5; <1	partial open
orange	>0; <0.5	
red	=0	close

Cells in direction:

- **Axial 117 x 0.1 m**
- **Radial 14 x 0.1 m**
- **Azimuthal 3 x π/4 + 2 x π/8 (180° symmetry)**
- **Total number of cells: 8190**

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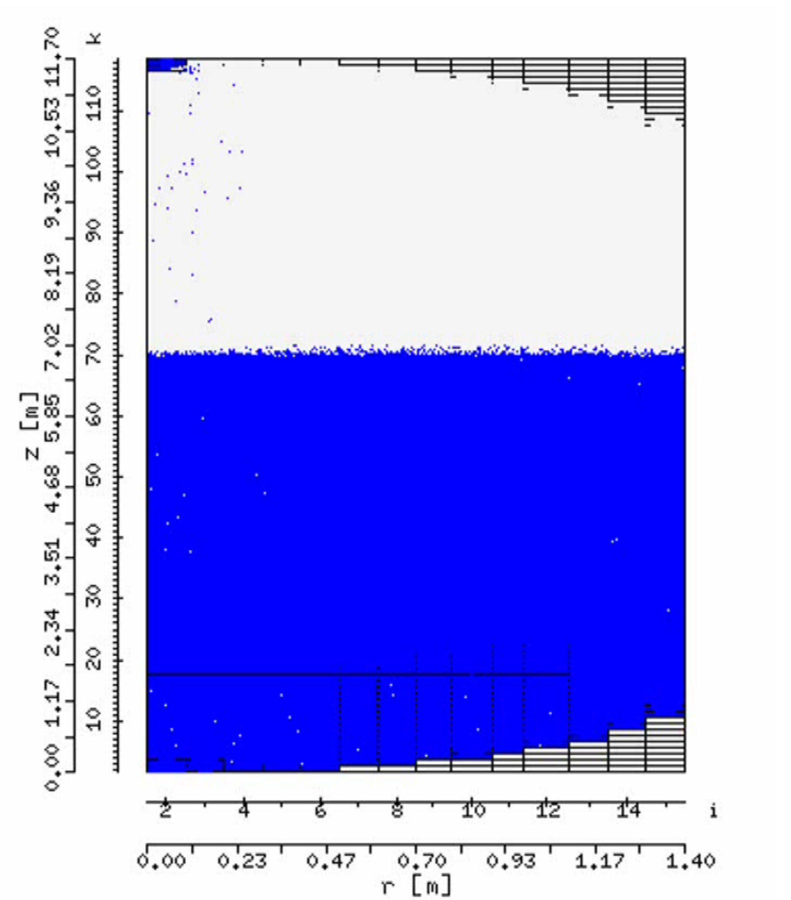
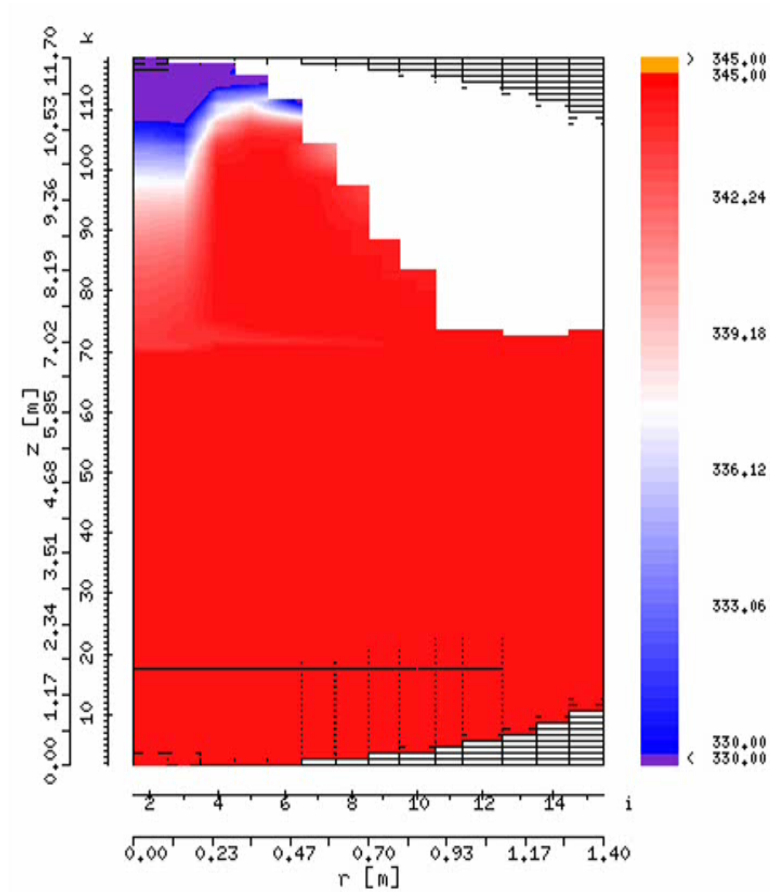
STADRU 2-Phase
3D Outsurge

Volume fraction of steam and liquid



Start

Liquid temperature



- **Pressure decrease in the surge line:**

  20 bar in 35 s

- **Permanent spray:**

  0.8 kg/s with 290 °C

- **Permanent heating with:**

  2 * 117 kW

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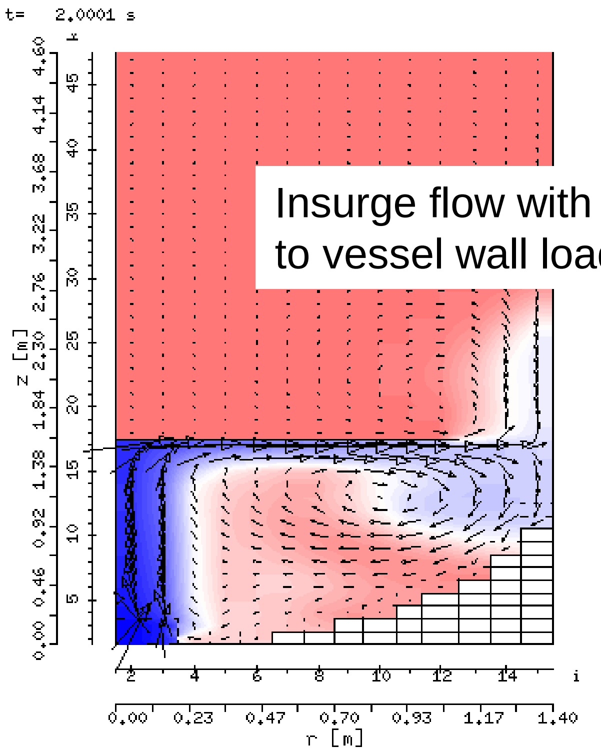
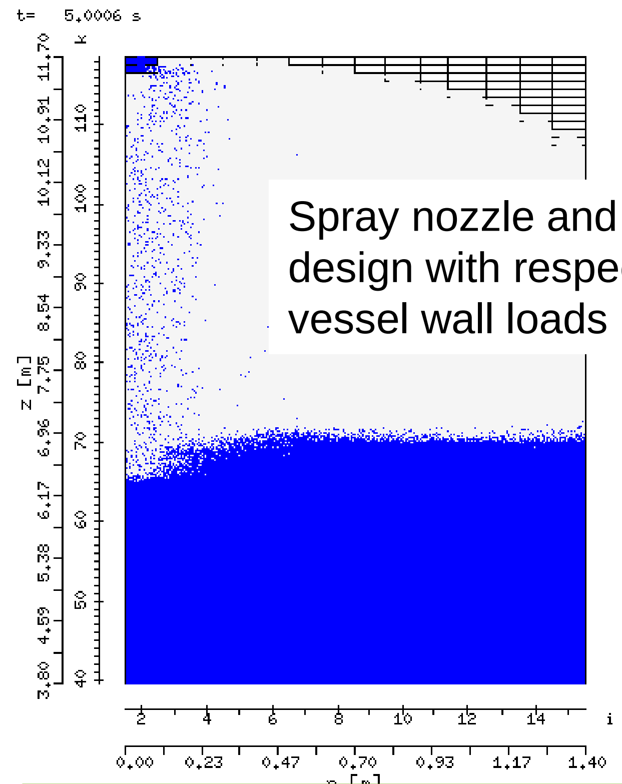
STADRU 2-Phase
3D Design studies for components





Study result:

The plate is blocking the flow. The insurge is directed to the vessel wall

> Thermal loads

Study result:

The spray flow does not reach the vessel wall under operational conditions

> No thermal loads

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STADRU 2-Phase
Benefit of the 3D Calculation

- **Analysis of temperature and velocity fields in the 3D volume**
- **Optimization of the system with different boundary conditions**
- **Temperatures, velocities and void fraction of the fluid at every position in the pressurizer**
- **Realistic temperature transients for thermal loads in the pressurizer and the adjoined systems**

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End of presentation: Simulation of Fatigue relevant thermal Loads of Components in Piping Networks

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