Boiling in a Horizontal Evaporator Model for the Nuclear Industry

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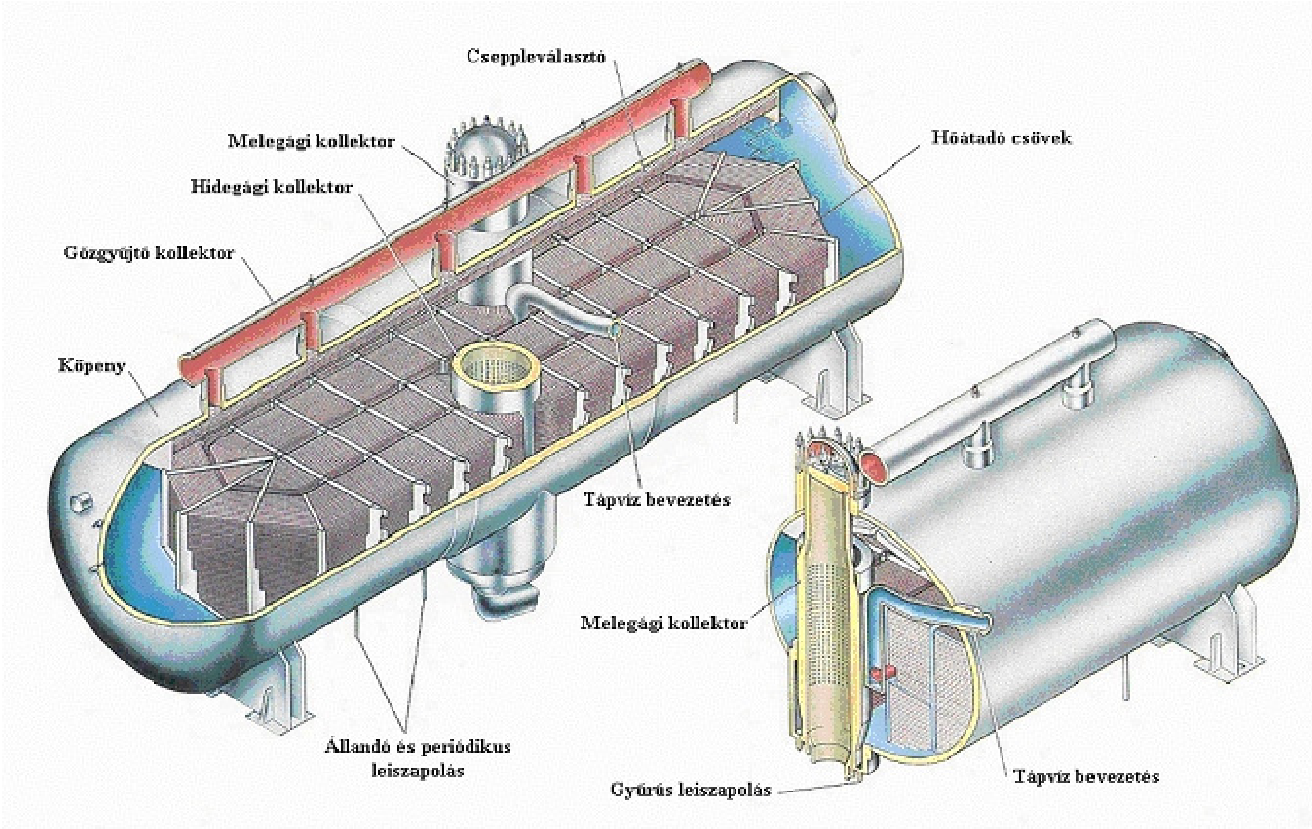
Outline

- Russian designed 440 MW PWR's are in service in 5 EU countries
- Horizontal evaporators:
  - mainly empirical construction,
  - lack of powerful models
- CFD.HU Ltd performed a CFD analysis for the Paks nuclear plant using ANSYS-FLUENT

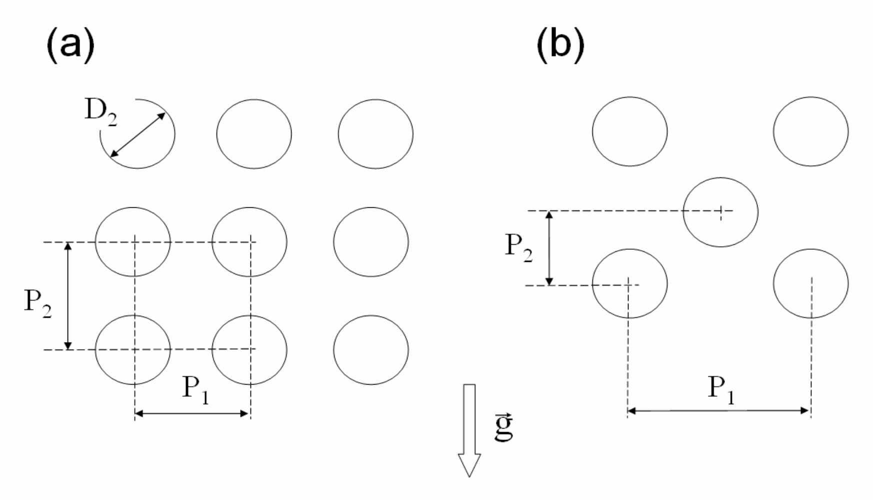
The Anatomy of the Evaporator



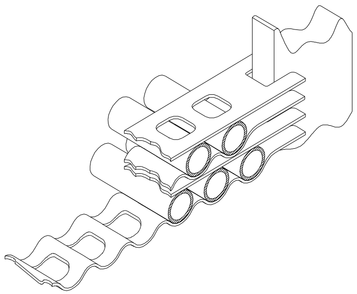
Primary loop:	1416 kg/s	123 bar	296/265 ℃
Secondary loop:	125 kg/s	46 bar	223/258 ℃

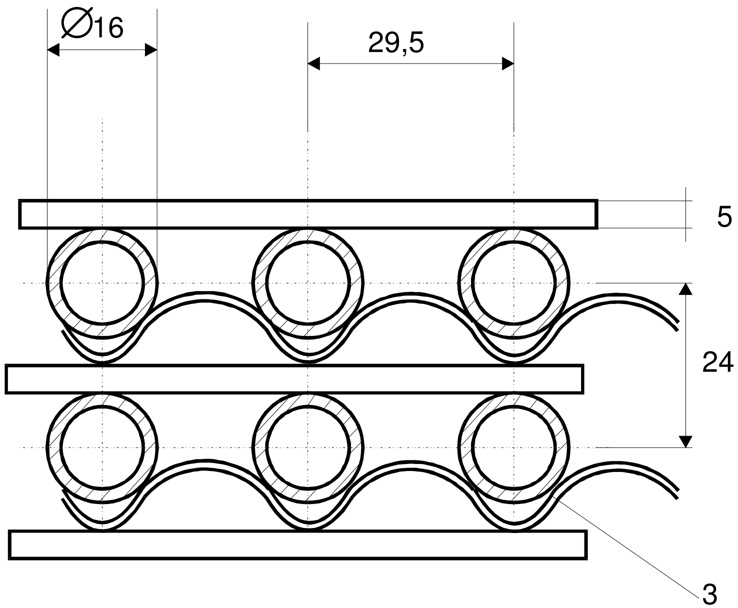
The Tube Bundle

- 5536 tubes
- 16 mm diameter
- 1.4 mm wall thickness
- 9 m average length (50 km total)
- U shaped, horizontal
- varying arrangement:

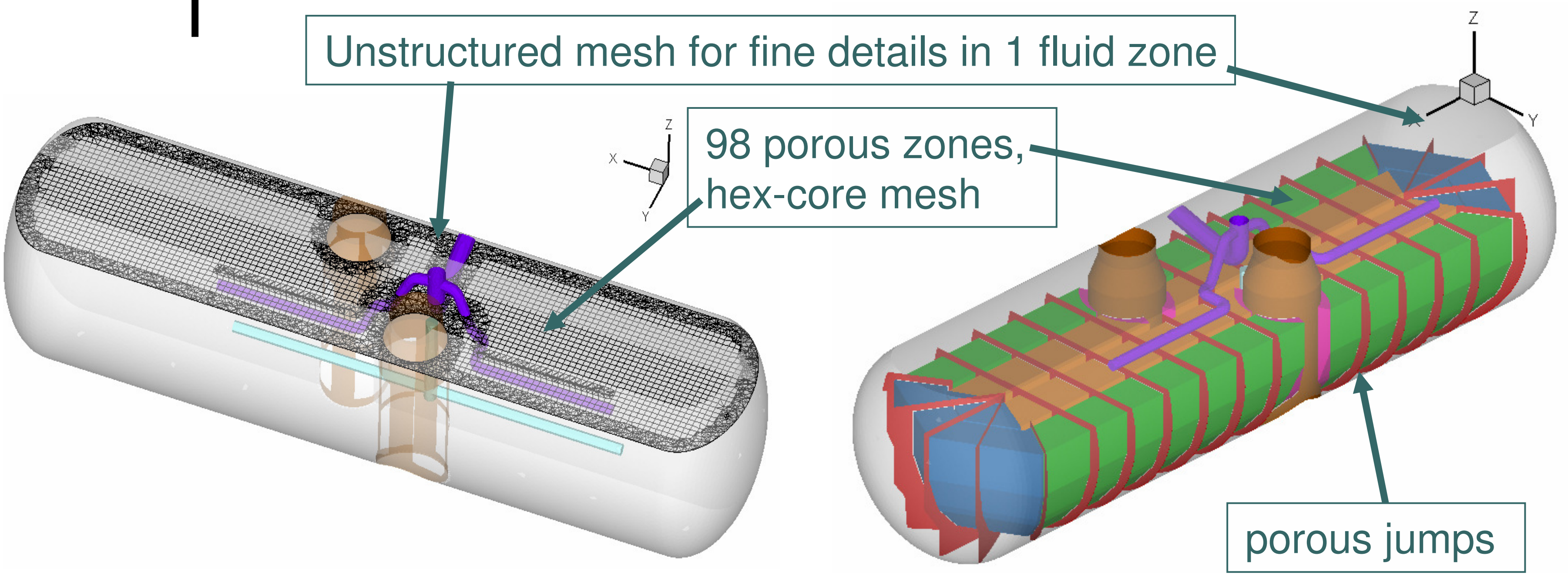


The Tube Supports





The Geometrical Model



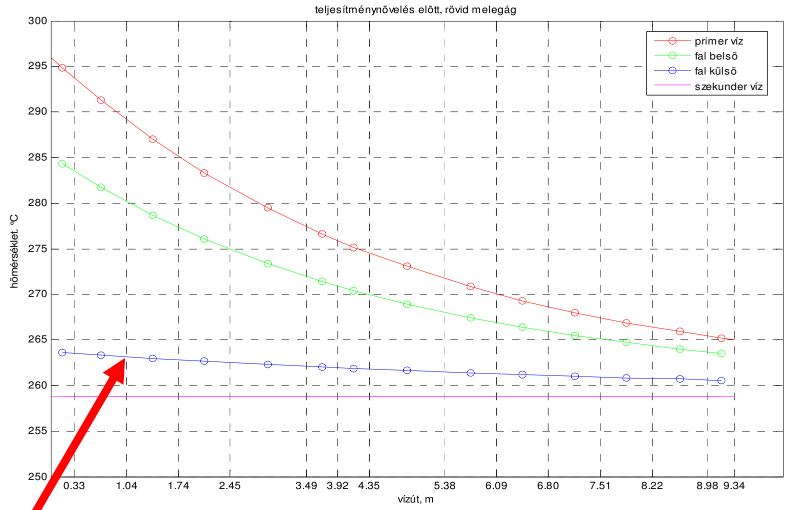
- Fine 3D model: 1.2 M cells, 3-7 cm details
- Rough 3D model: 0.5 M cells (fast initial transients)
- Micromodels (tube bundle and support, gaps)

The Physical Model

- Heat exchange model
- Model for pre-heating and two-way phase transition
- Model for the mechanical interaction of liquid and steam phases (advection of bubbles and droplets, free)
- Boundary conditions and source terms
- Level control model etc.

Heat Exchange

- Hydraulic model for the 5536 parallel pipes: individual mass flow rates
- For each pipe: 1D heat transfer model along the pipe



RESULTING

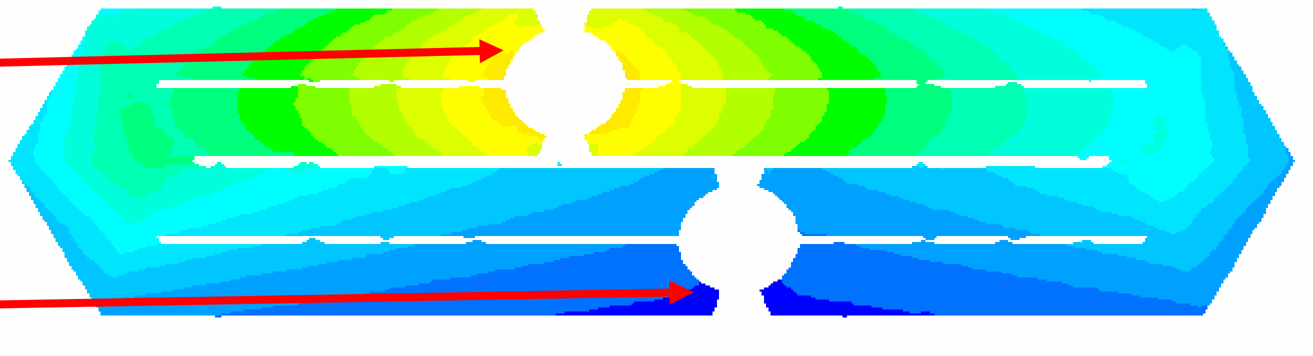
1. wall heat flux and superheat, T(x)-T*
2. highly inhomogeneous heat source density

- Hot side:

150 MW/m³

- Cold side:

1 MW/m³



Phase Transition and Energy Transport

•Modelled as a 3-phase mixture model:

phase 1	saturated vapour	23.2 kg/m³	531 K
phase 2	saturated liquid	785 kg/m³	531 K
phase 3	feed water	838 kg/m³	496 K

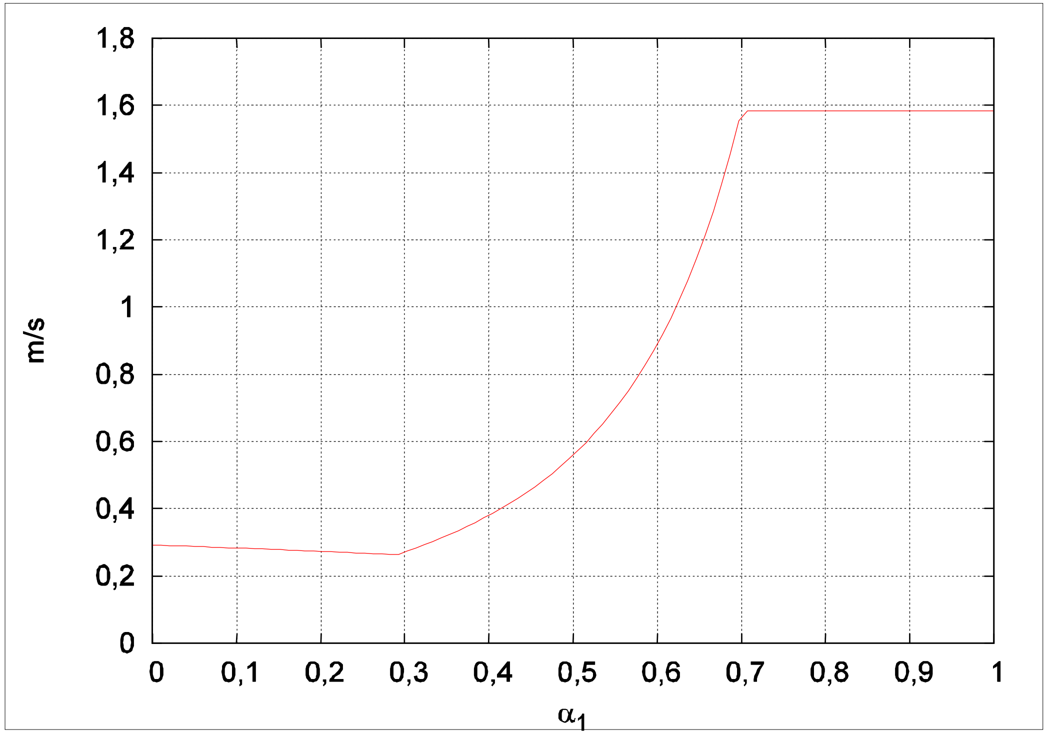
•Phase transition controlled by heat source and formation enthalpy balance (using UDF)

•Composition determines density and enthalpy:

- •no need for energy equation (fast),
- •provides buoyancy for momentum transport

Relative Motion of Phases

- Inhomogenous mixture model requires constitutive equation



- Semi-empirical correlation with steam volume fracton in similar systems (kettle reboilers)

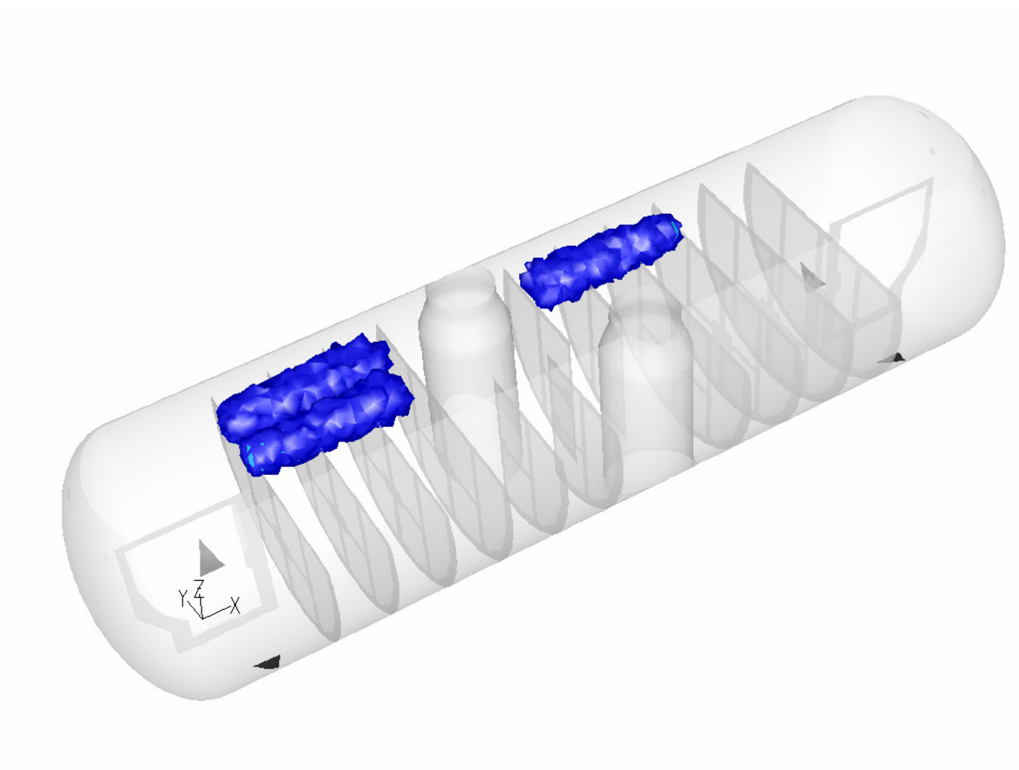
  [Stosic, Stevanovic (2002), Pezo et. al. (2006)]

- Adapted to match geometrical and thermophysical boundary conditions

Boundary Conditions and Source Terms

Feedwater intake:

- Inhomogenous source terms



Tube bundles:

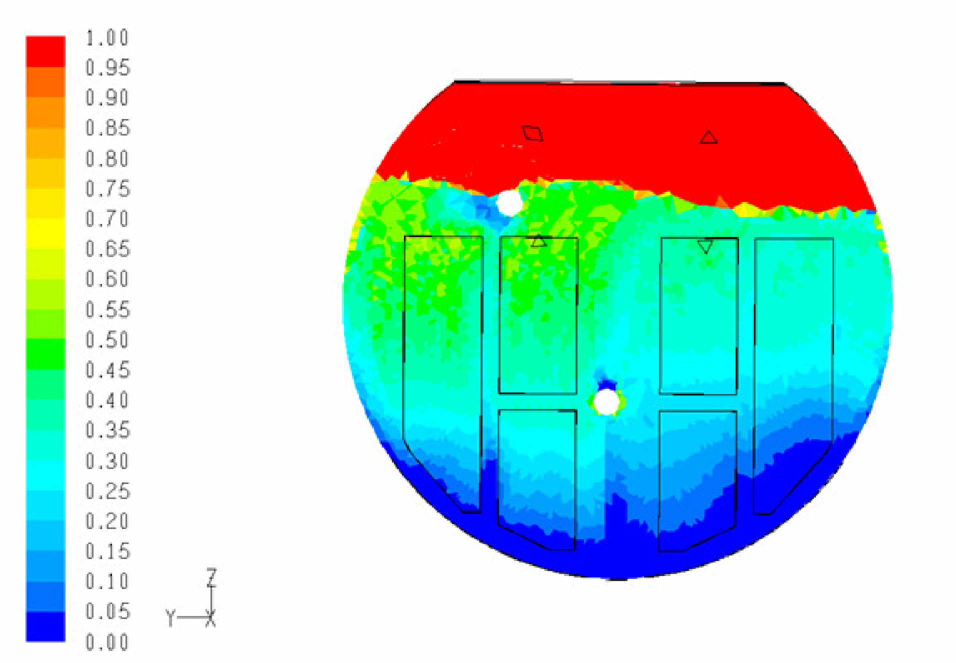
98 porous zones,

- steam concentration-dependent,
- anizotropic and
- inhomogenous

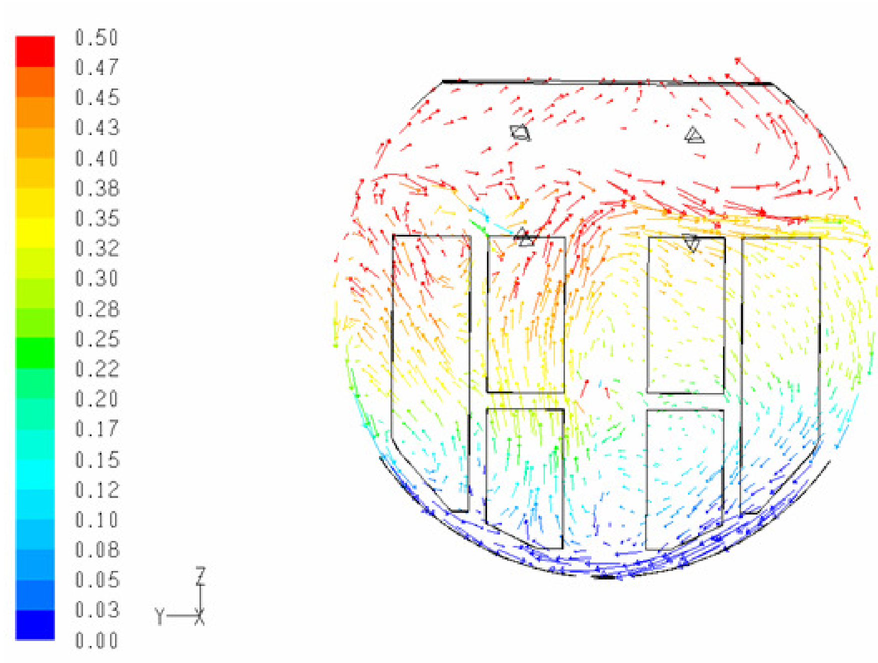
hydraulic resistance

Cross-Sectional Flow Field

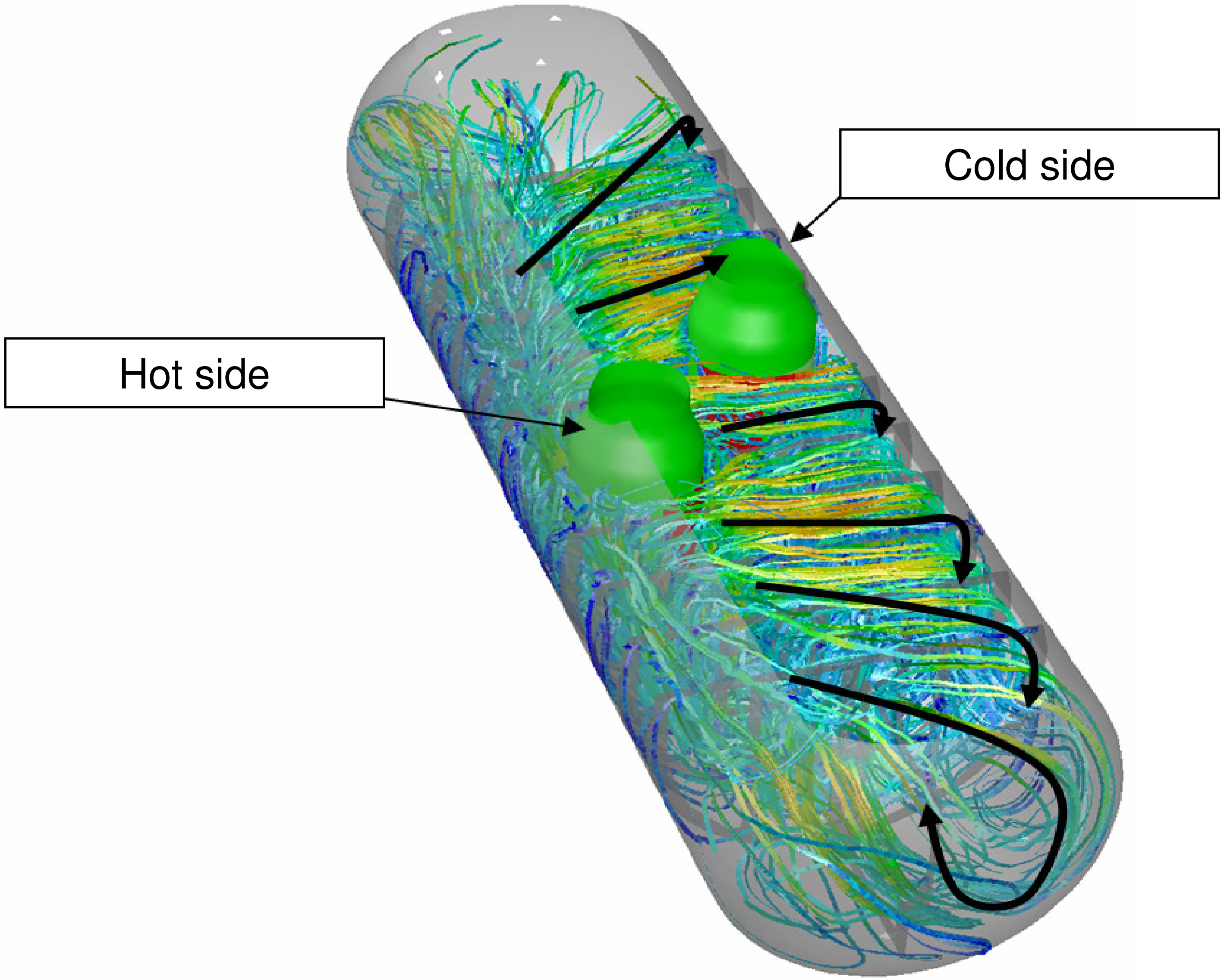
Steam volume fraction



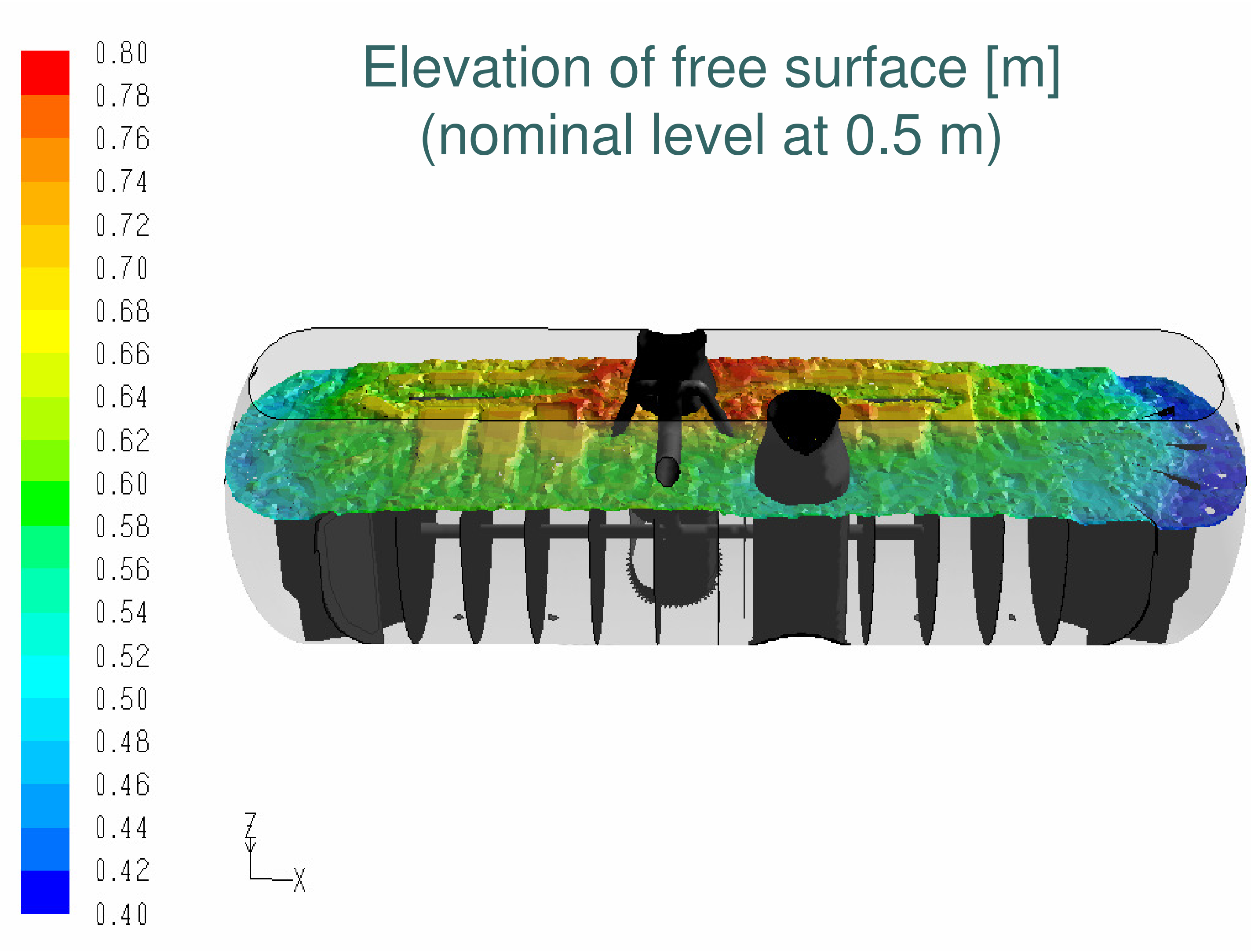
Velocity vector field
(colour: steam volume fracion)



Overall Flow Pattern

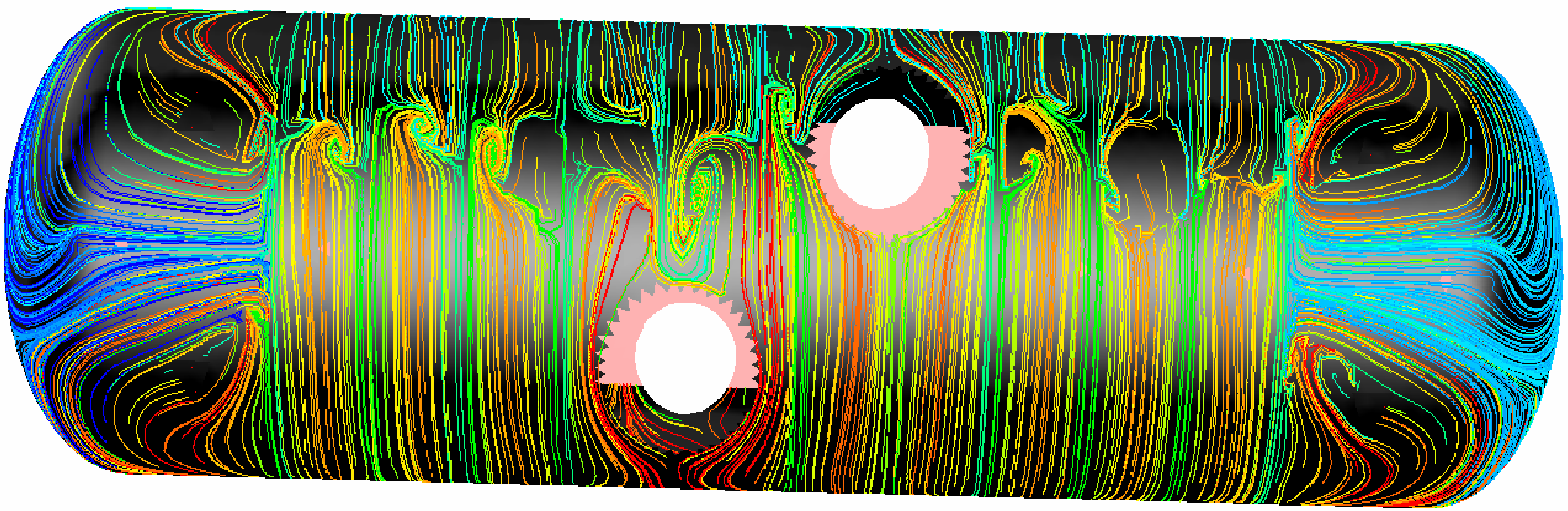


The Free Surface

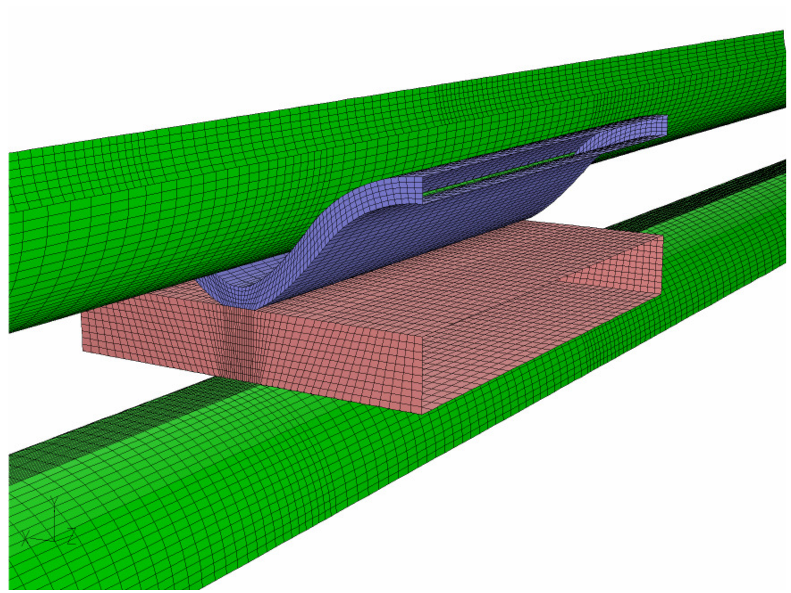


Flow Structure on the Bottom of Container

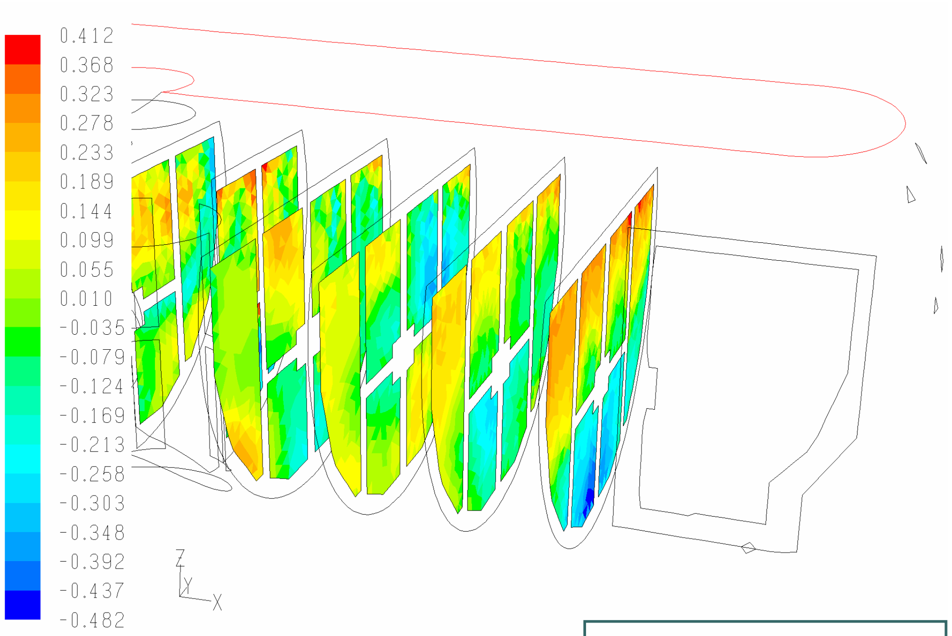
Saddle points and stems of separation vortices
(Correlate with location of sediment deposition)



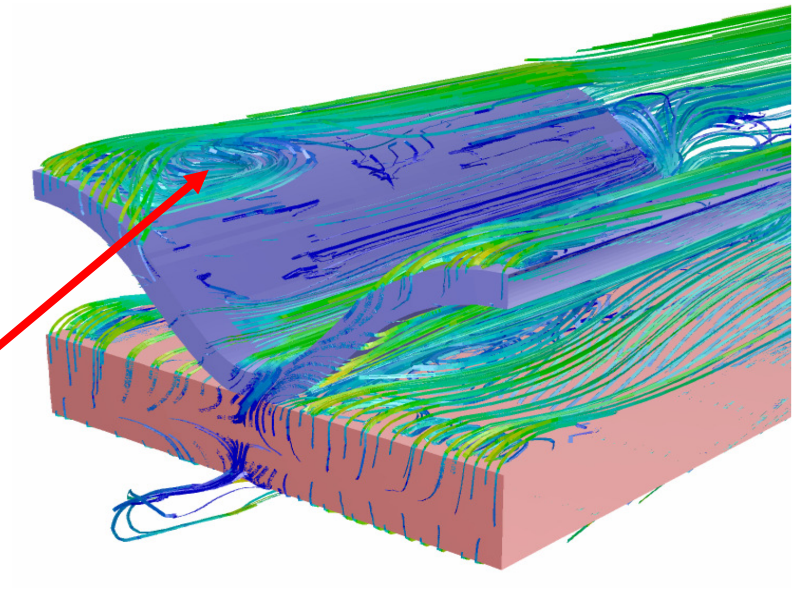
Flow Through Tube Supports



Transverse velocity [m/s]



Separated flow



Summary of Model Abilities

- Distributed parameter model of the unit
- Provides complete flow and other fields
- Allows:
  - studying effects of variation in geometry and operating state,
  - Lagrangian tracking of particle transport and modelling sedimentation,
  - analysis effects of closing individual tubes,
  - analysis of transient states, abnormal and accident situations