Validation of Multiphase Flow Modeling in ANSYS CFD

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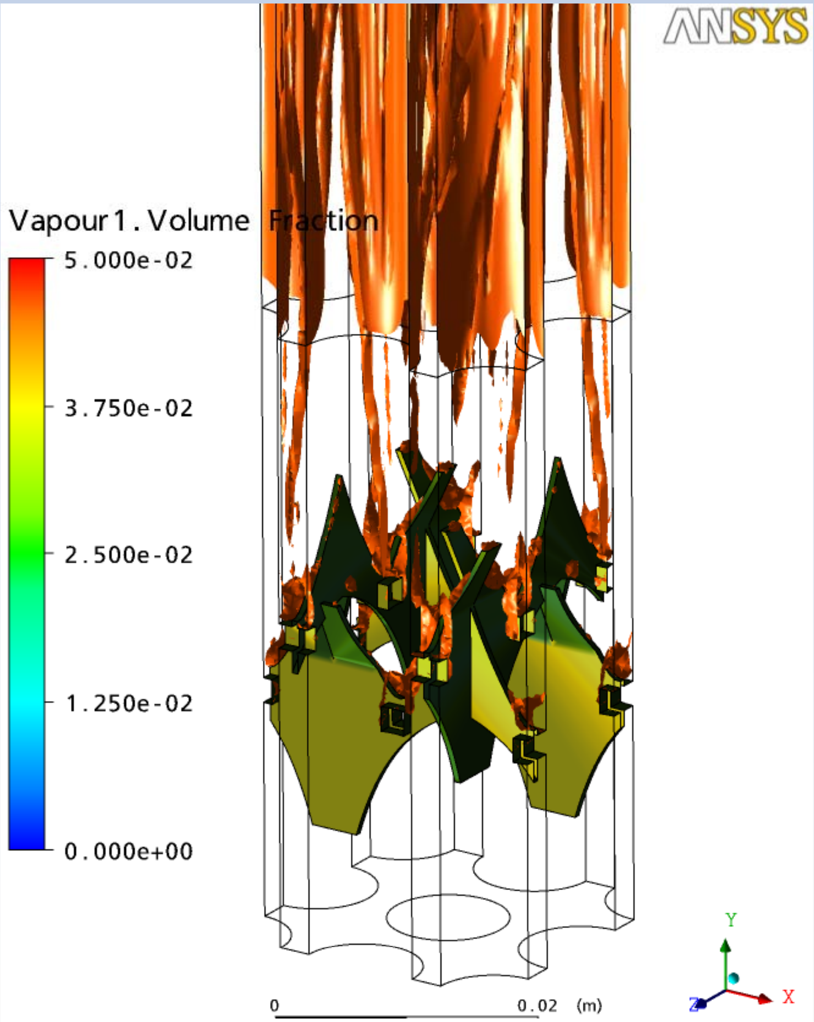
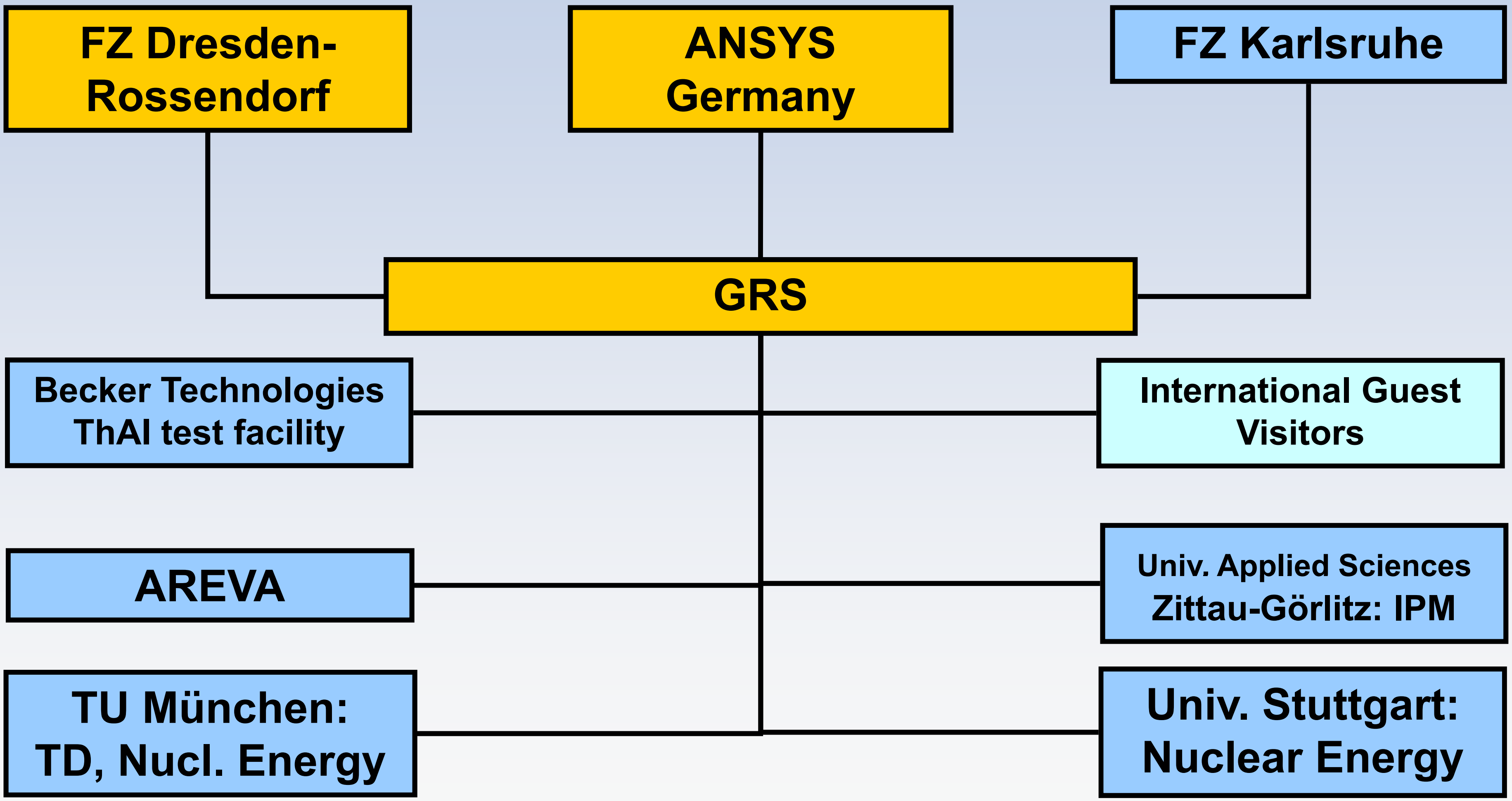
Outline

- Introduction
- MPF model validation for adiabatic air-water flows
- Polydisperse MPF model validation – MUSIG model
- Bartolomej testcase (PWR)
- Lee testcase (BWR)
- Wall boiling with conjugate heat transfer (CHT)
- Summary & Outlook

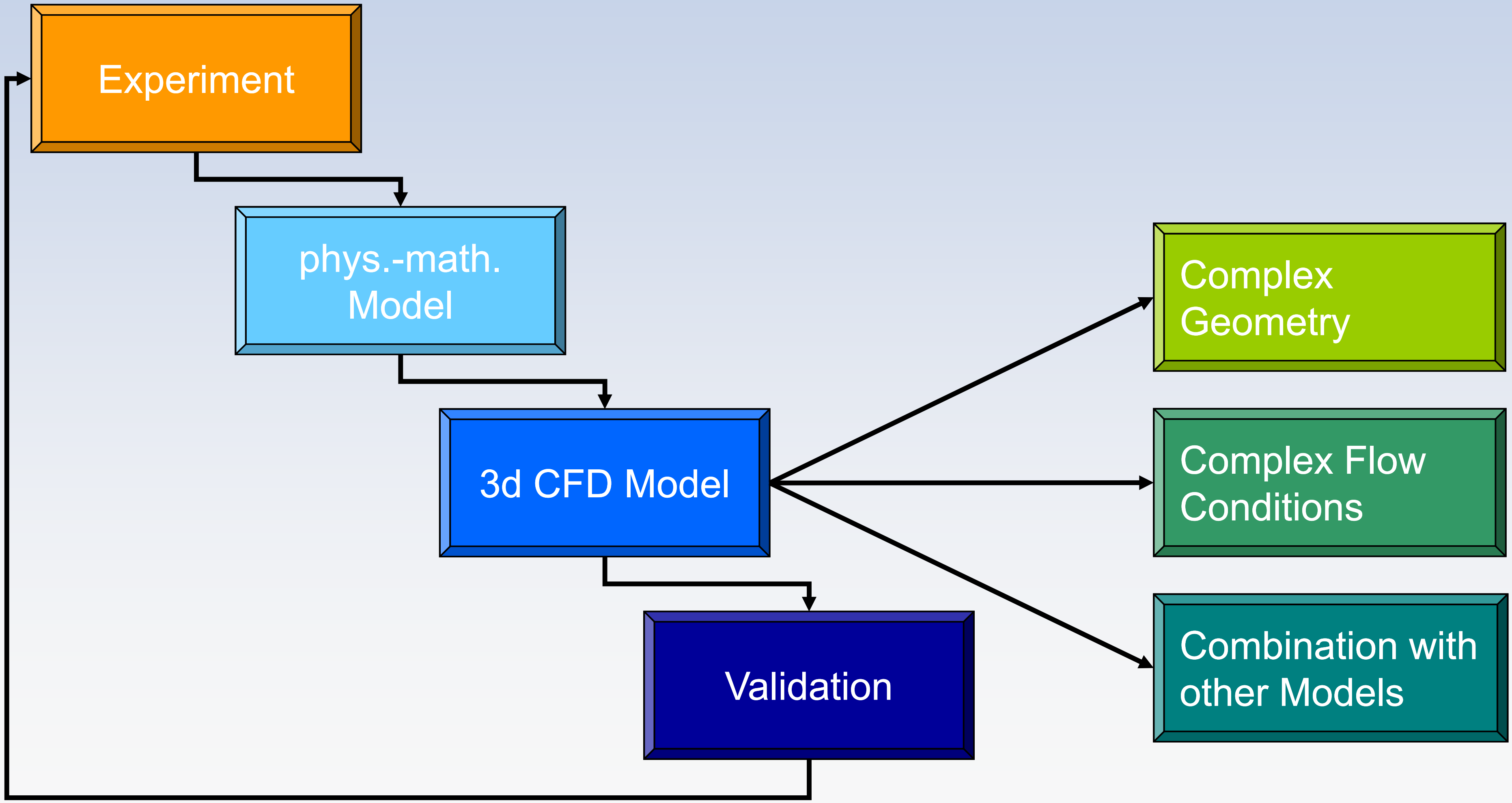


Courtesy by E. Krepper (FZD)

ANSYS as Part of the German CFD Network in Nuclear Reactor Safety



Methodology of CFD Model Development & Validation



Eulerian MPF Modeling - The Particle Model

Mass weighted averaged conservation equations

- **Mass, momentum, energy transport equations for each phase**

$$\frac{\partial}{\partial t}\left(\rho_k r_k\right)+\nabla\left(\rho_k r_k \mathbf{U}_k\right)=\sum_{\substack{l=1\\ l\neq k}}^{N} \Gamma_{kl}$$

$$\frac{\partial}{\partial t}\left(\rho_k r_k \mathbf{U}_k\right)+\nabla\cdot\left(\rho_k r_k \mathbf{U}_k \mathbf{U}_k\right)=-r_k\nabla P-\nabla\cdot\left(r_k \Pi^k\right)+\mathbf{F}_k+\mathbf{I}_k$$

$$\mathbf{I}_k = \underbrace{\mathbf{F}_\Gamma}_{\substack{\text{secondary}\\ \text{mom. transfer}}} + \underbrace{\mathbf{F}_D}_{\text{drag}} + \underbrace{\mathbf{F}_L}_{\text{lift}} + \underbrace{\mathbf{F}_{WL}}_{\substack{\text{wall}\\ \text{lubrication}}} + \underbrace{\mathbf{F}_{TD}}_{\substack{\text{turbulent}\\ \text{dispersion}}} + \underbrace{\mathbf{F}_{VM}}_{\text{virtual mass}}$$

- turbulence models for each phase
  (e.g. k-ε / k-ω SST model, 0-eq. disp. phase turb. Model)
- heat transfer equations for each phase with interfacial transfer closure
- interfacial forces need empirical closure
- high void fraction effects, bubble induced turbulence, etc.

Lift force, Wall lubrication force & turbulent dispersion

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Lift force:

- due to asymmetric wake and deformed asymmetric particle shape

→Tomiyama C_L correlation

$$\mathbf{F}_L = C_L r_G \rho_L (\mathbf{U}_L - \mathbf{U}_G) \times \nabla \times \mathbf{U}_L$$

$$C_L = C_L(\mathrm{Re}_P, \mathrm{Re}_\nabla, Eo)$$

Wall lubrication force:

- surface tension prevents bubbles from approaching solid walls

→Antal, Tomiyama & Frank W.L.F. models

$$\mathbf{F}_{WL} = -C_{wall} r_G \rho_L \left| \mathbf{U}_{rel} - (\mathbf{U}_{rel} \bullet \mathbf{n}_W)\mathbf{n}_W \right|^2 \mathbf{n}_W$$

$$C_{wall} = C_W(\mathrm{Eo}, \mathrm{y/d_P})$$

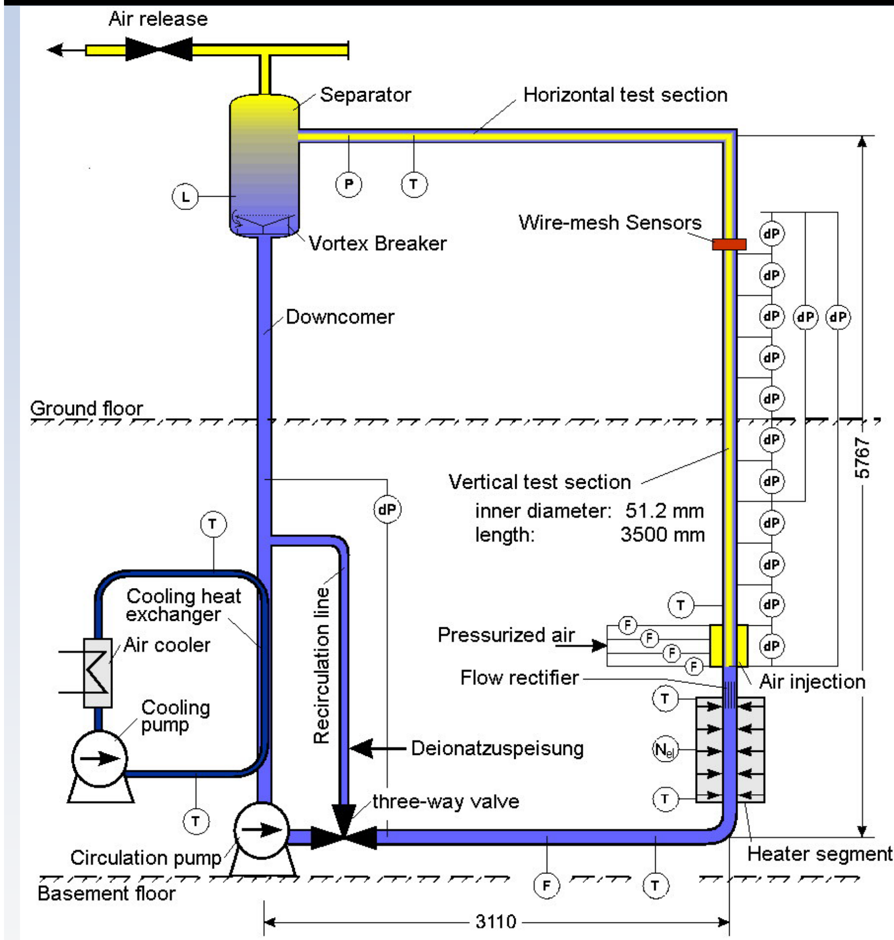
Turbulent dispersion force:

- turbulent dispersion = action of turb. eddies via interphase drag

$$\mathbf{F}_{TD} = \frac{3}{4} \rho_F \frac{\overline{C_D}}{d_P} \frac{\nu_{tF}}{\sigma_{rF}} \left| U_F - U_P \right| \overline{r_P} \left(\frac{\nabla \overline{r_P}}{\overline{r_P}} - \frac{\nabla \overline{r_F}}{\overline{r_F}} \right)$$

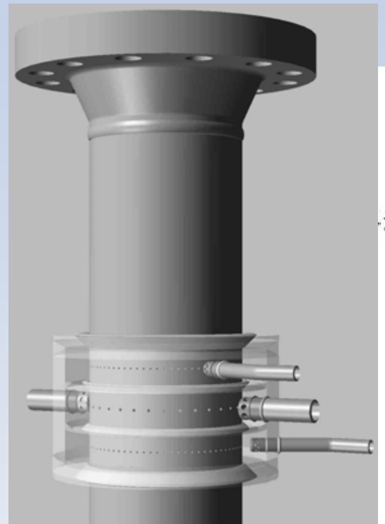
FAD model by Burns et al. (ICMF’04)

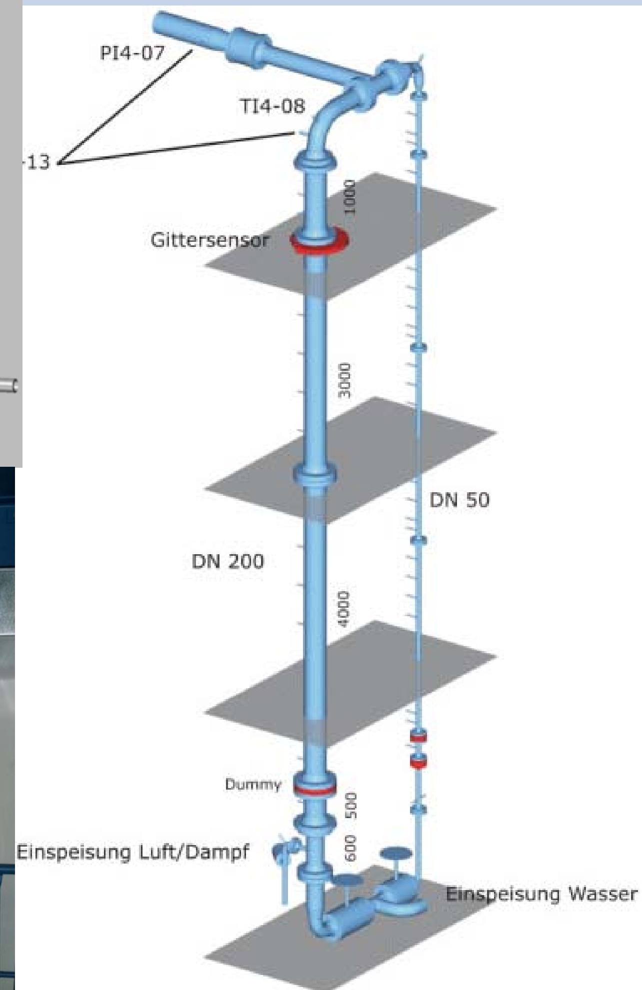
Bubbly Flow Model Validation
FZR MT-Loop and TOPFLOW Database



MT-Loop

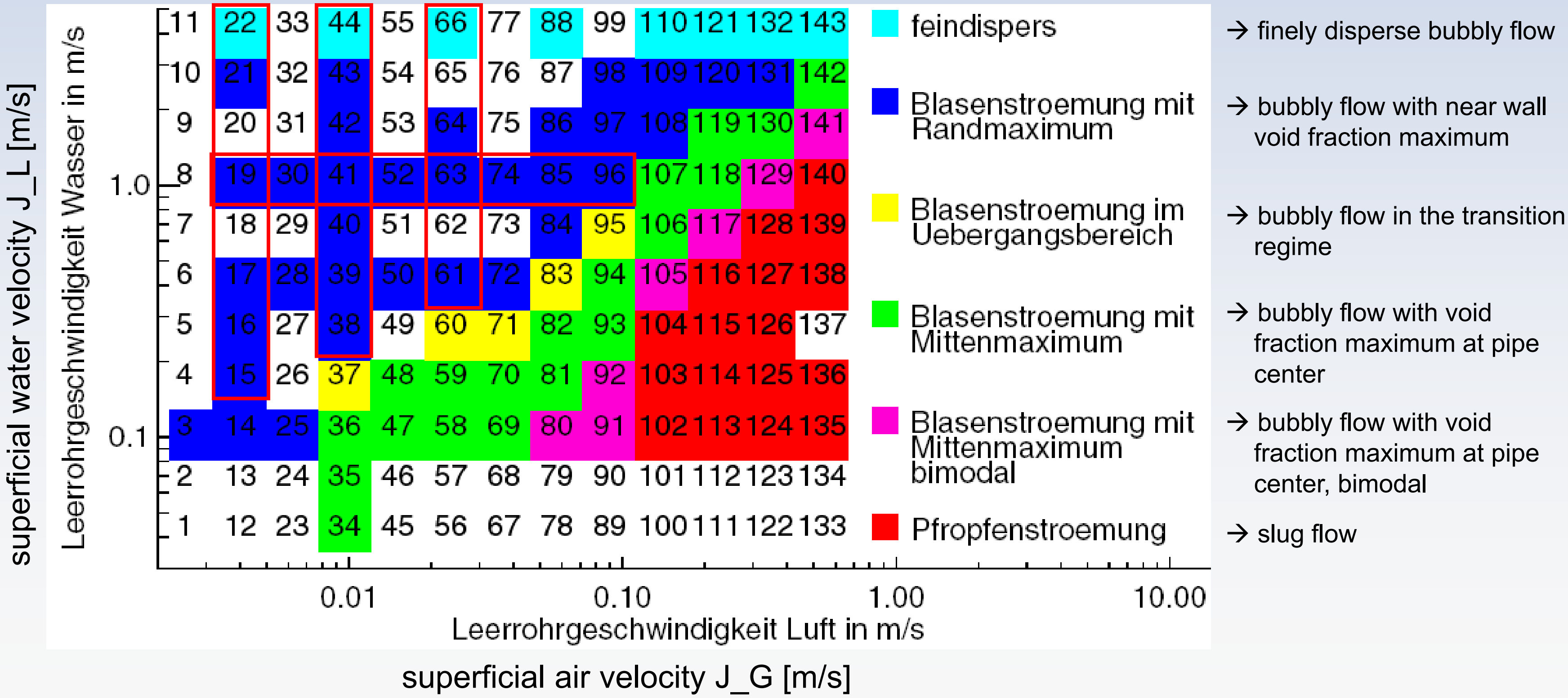
TOPFLOW



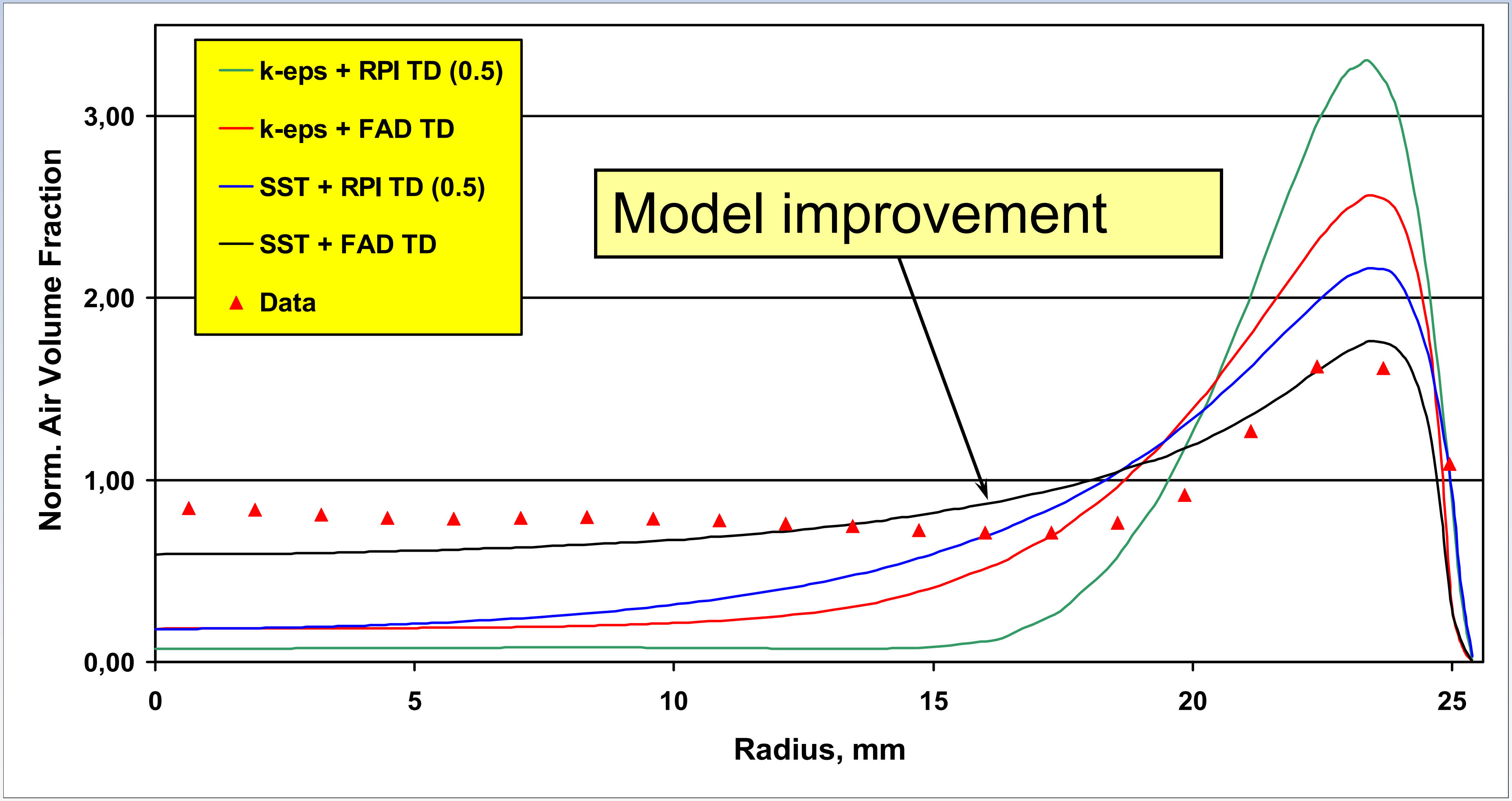


CFX Model Validation
MT-Loop & TOPFLOW Test Matrix

- **M01 experimental test series on MT-Loop**
- **evaluation based on air volume fraction profiles at L/D=59,2 (z=3.03m) from the sparger system**
- **- numerically investigated test case conditions**



Validation: Bubbly Flows
Turbulent Dispersion Force

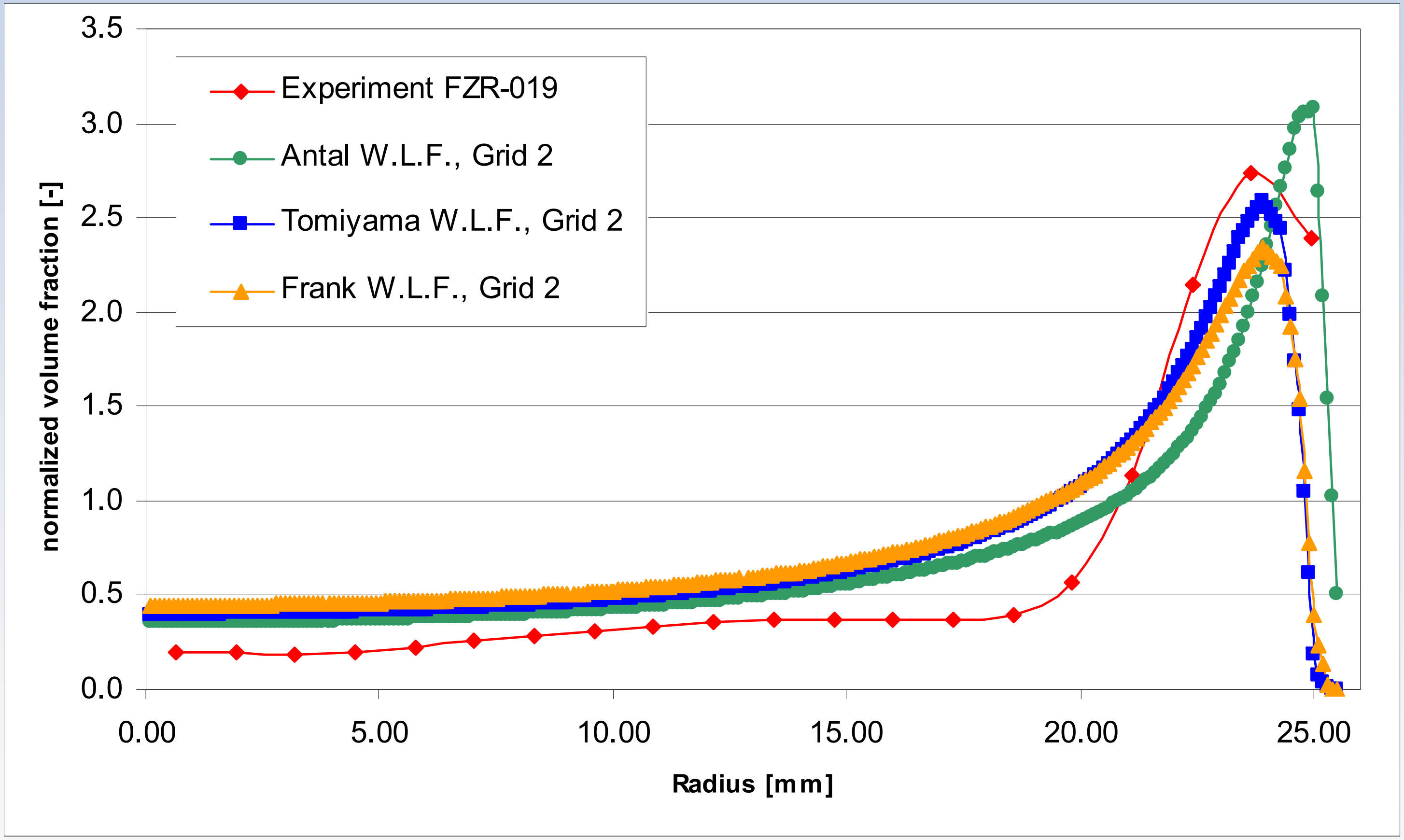


Monodispersed Bubbly Flow
MT-Loop Test Case FZR-019

FZD-019:

J_L=1.017 m/s
J_G=0.004 m/s
d_P=4.8 mm

Grace drag
Tomiyama lift
T./A./F. Wall L. Force
FAD Turb. Disp.
SST turb. model
Sato model
Δt=0.002s
2210 Iterations

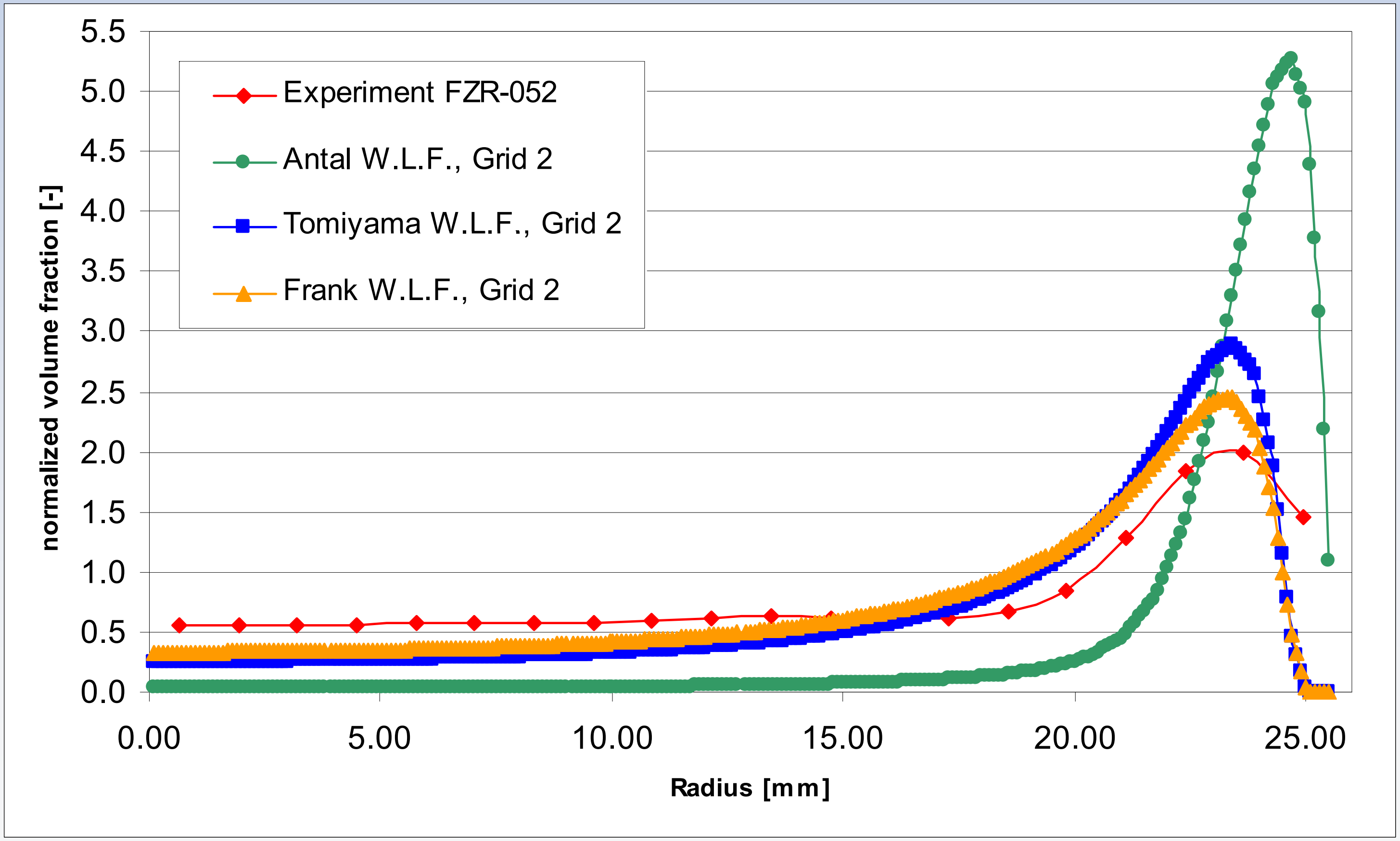


Monodispersed Bubbly Flow
MT-Loop Test Case FZR-052

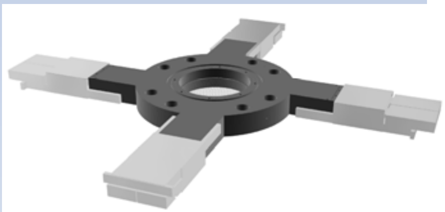
FZD-052:

J_L=1.017 m/s
J_G=0.0151 m/s
d_P=4.4 mm

Grace drag
Tomiyama lift
T./A./F. Wall L. Force
FAD Turb. Disp.
SST turb. model
Sato model
Δt=0.002s
2400 Iterations

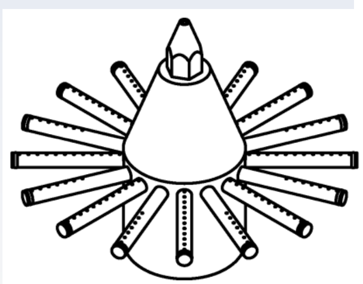


TOPFLOW Test Facility @ FZD

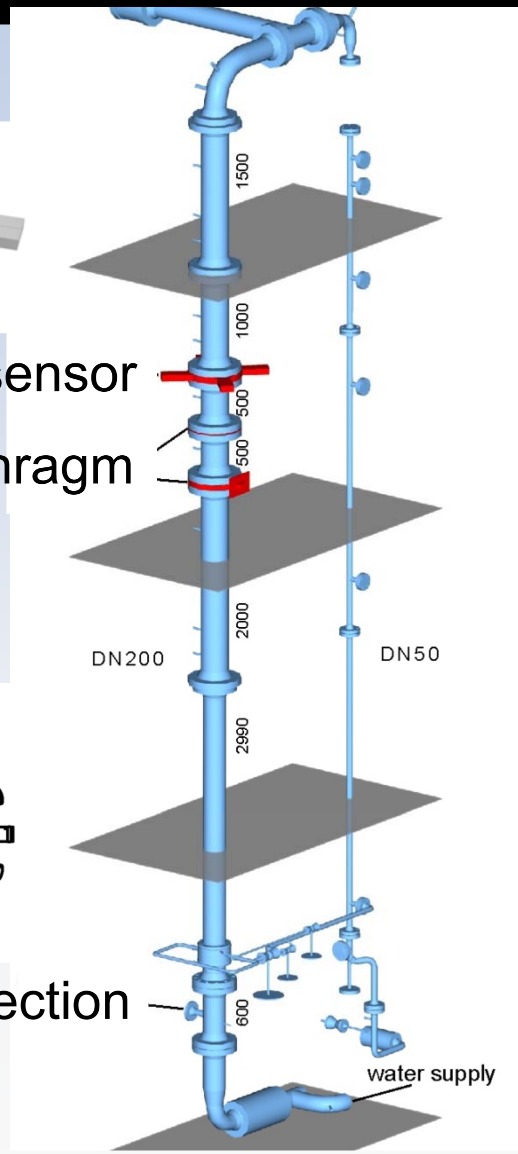


wire-mesh sensor

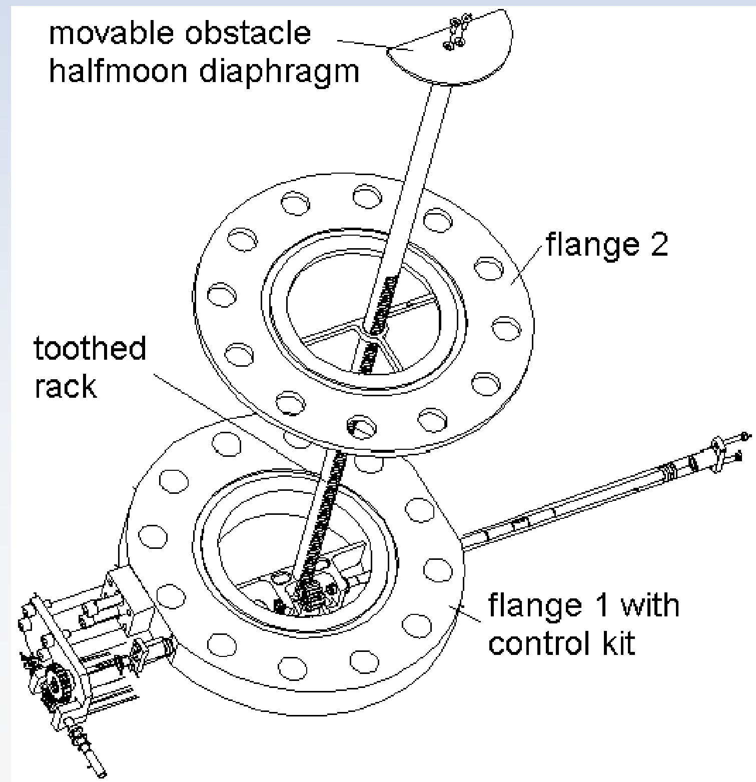
movable diaphragm



gas injection



movable diaphragm



TOPFLOW-074 Test Case Conditions from Test Matrix

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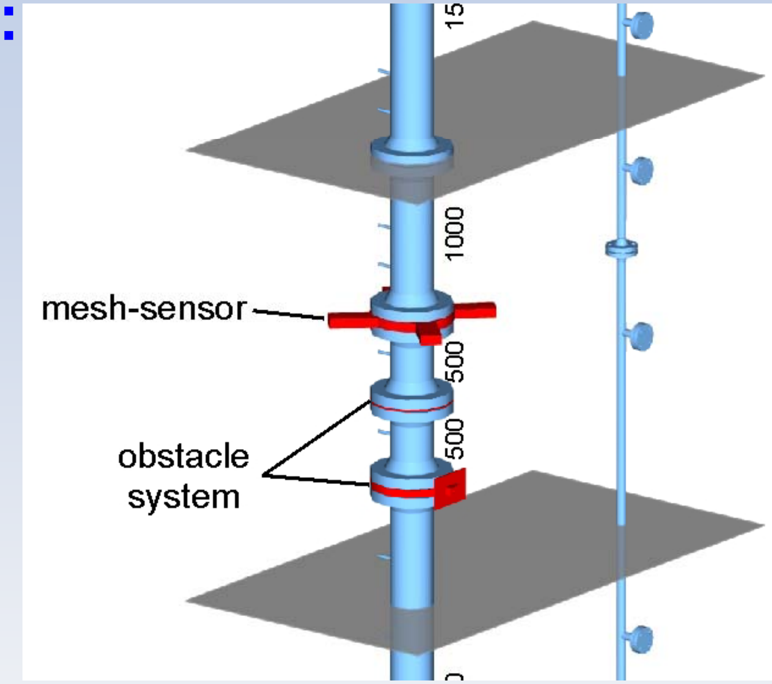
- **Selection of test case conditions:**

superficial gas velocity

superficial water velocity (m/s)	0.0368	0.0574	0.0898	0.14	0.219	0.342	0.534	0.835
1.611	075	086	097	108	119	130	141	152
1.017	074	085	096	107	118	129	140	151
0.405	072	083	094	105	116	127	138	149
0.102	069	080	091	102	113	124	135	146



- TOPFLOW-074 test case was subject of validation in the past
- Superficial velocities: J_G=0.0368 m/s
  J_L=1.017 m/s
- Wire-mesh sensor measurements at locations:
  z=±10, 15, 20, 40, 80, 160, 250, 520mm

3d Bubbly Flow Around Obstacle Water Velocity Comparison

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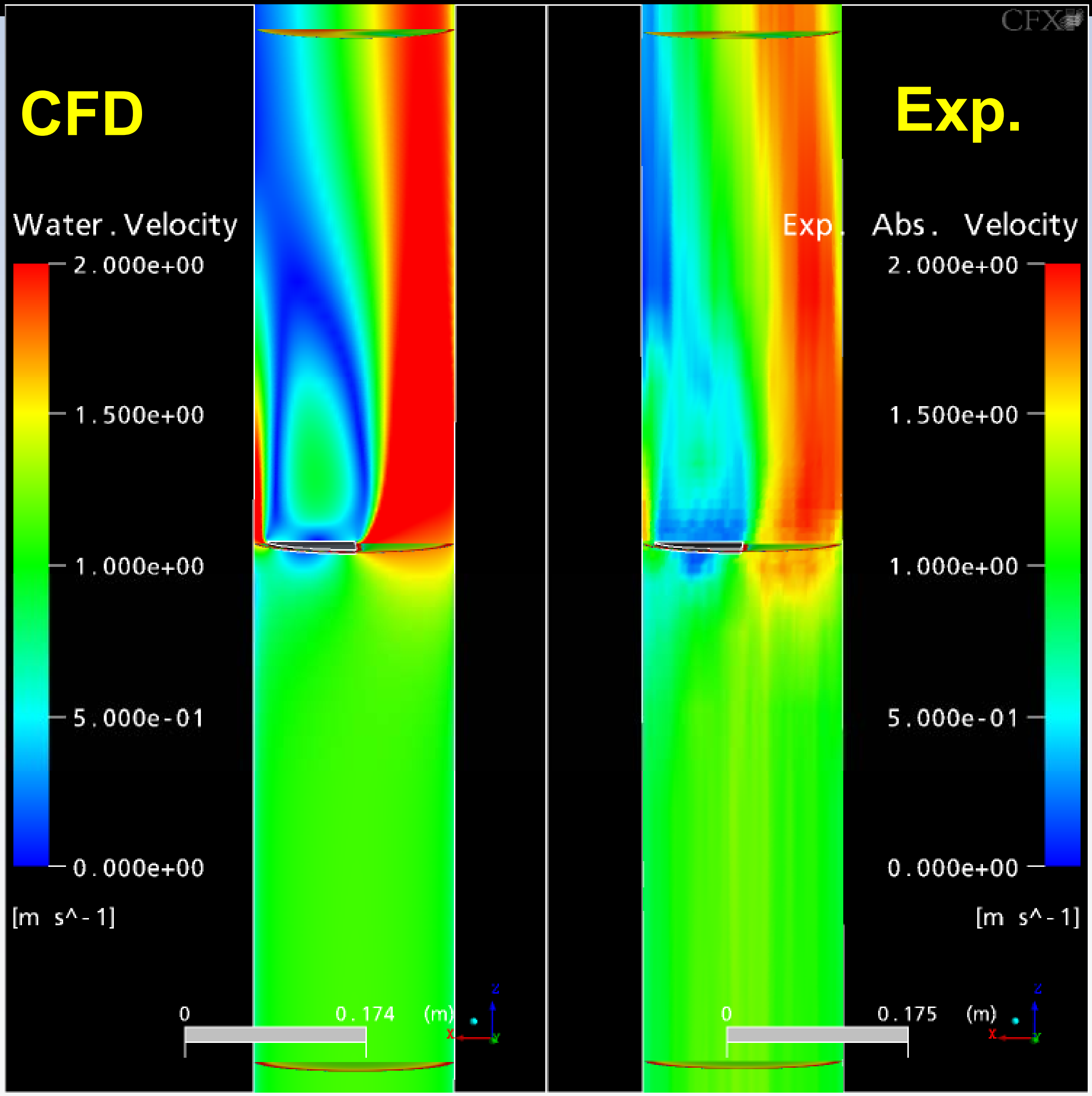
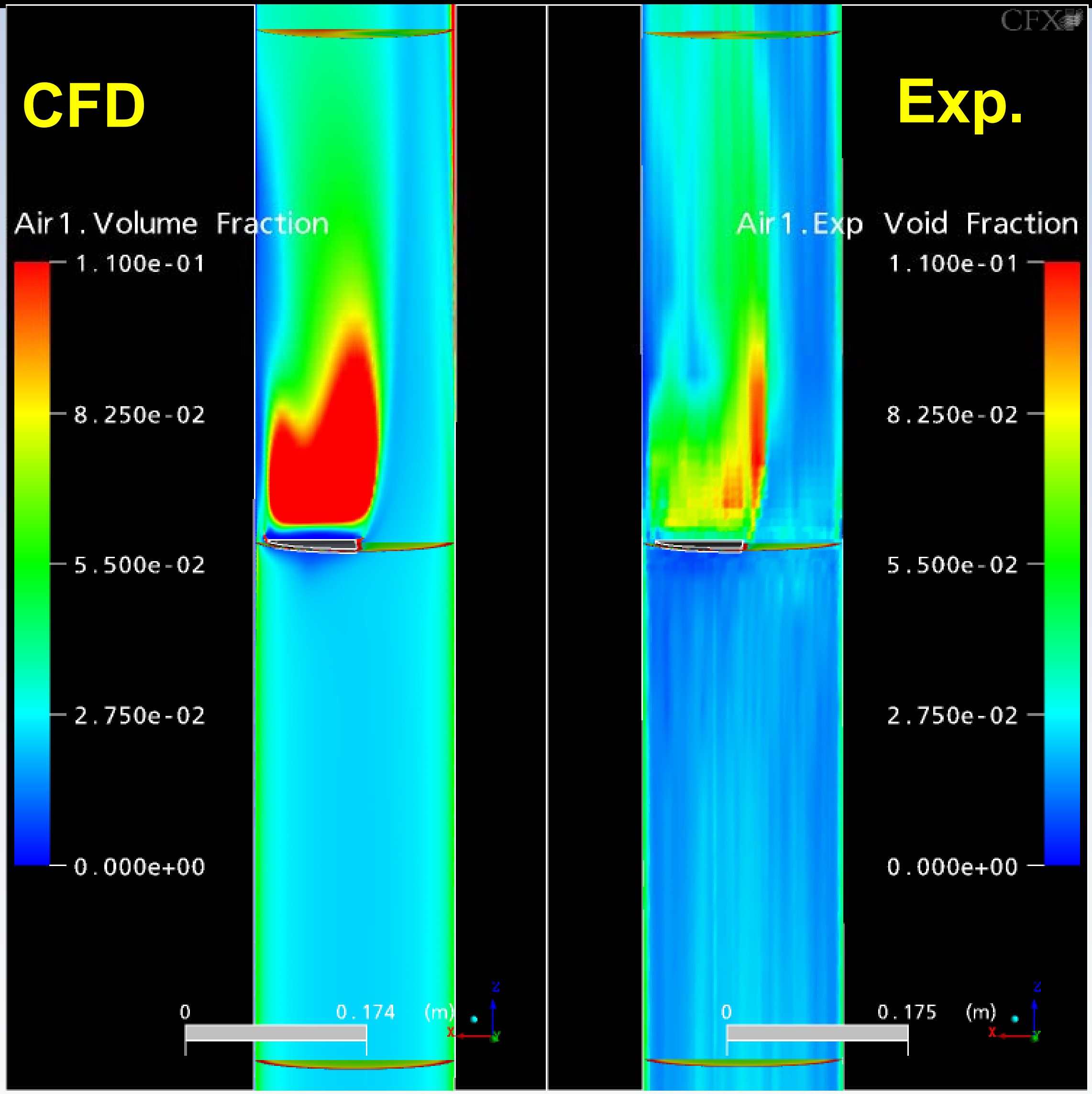
- **Comparison CFD ⇔ Experiment**
- **Absolute water velocity distribution in symmetry plane**
- **Import of exp. data into CFX-Post**
- **Pre-interpolation of exp. data to $\Delta z=0.01$m**



3d Bubbly Flow Around Obstacle Air Void Fraction Comparison

- **Comparison CFD ⇔ Experiment**
- **Air void fraction distribution in symmetry plane**



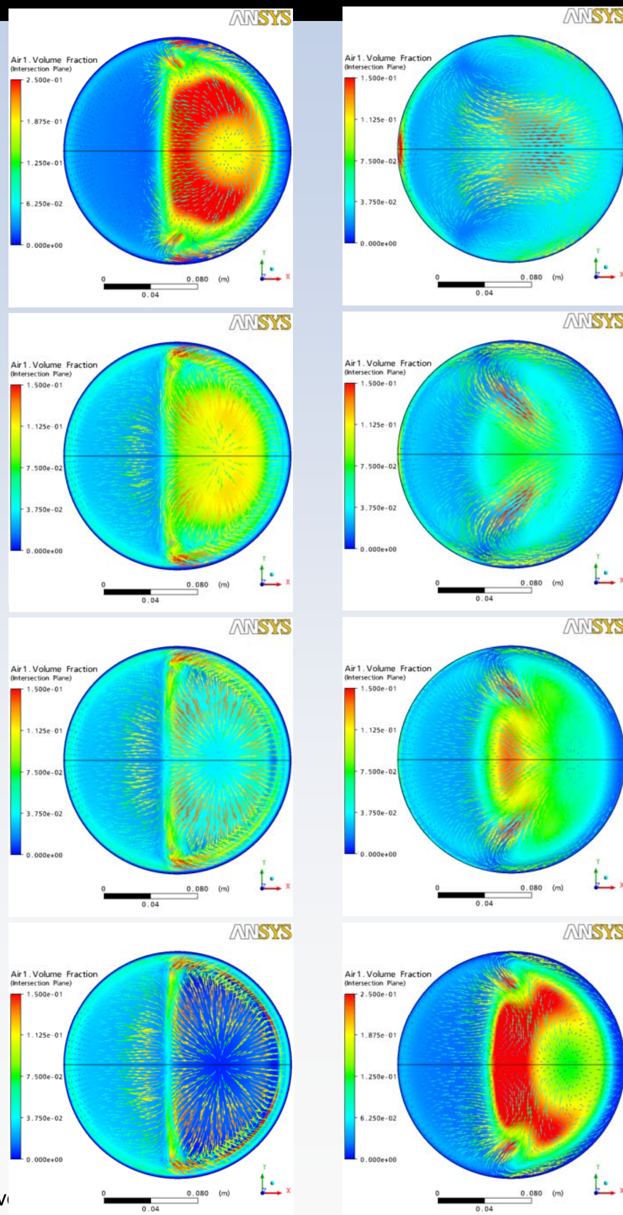
3d Bubbly Flow Around Obstacle
Air Void Fraction Comparison

4) z=40mm

3) z=20mm

2) z=15mm

1) z=10mm

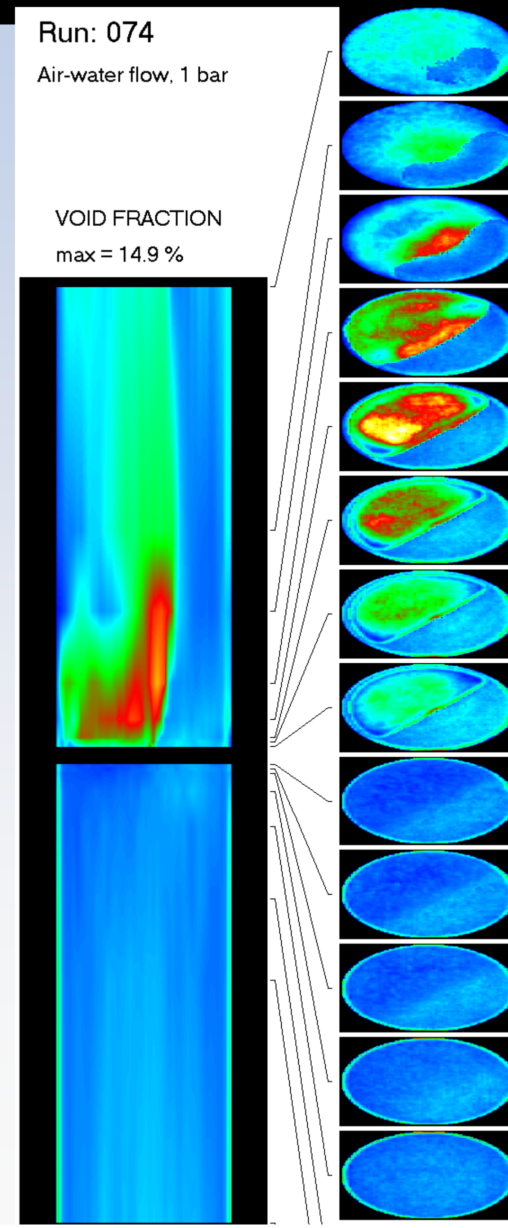


8) z=520mm

7) z=250mm

6) z=160mm

5) z=80mm



8)

7)

6)

5)

4)

3)

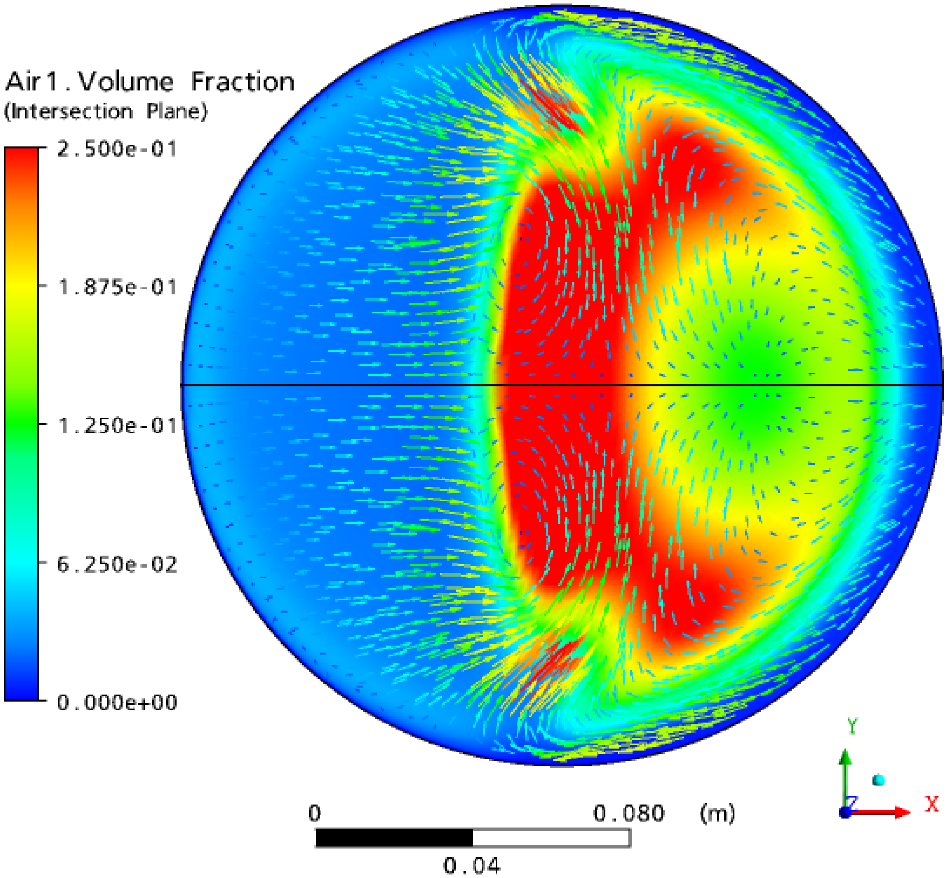
2)

1)

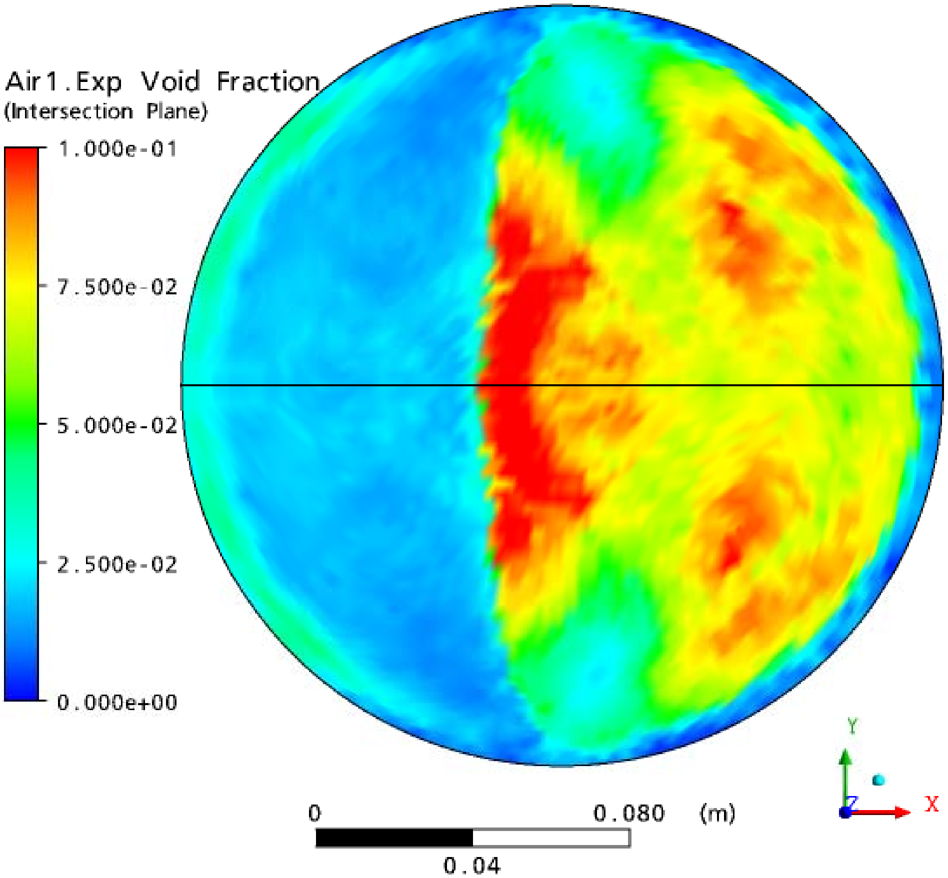
3d Bubbly Flow Around Obstacle Cross-Sectional Air Void Fraction

5) z=80mm

CFX Simulation

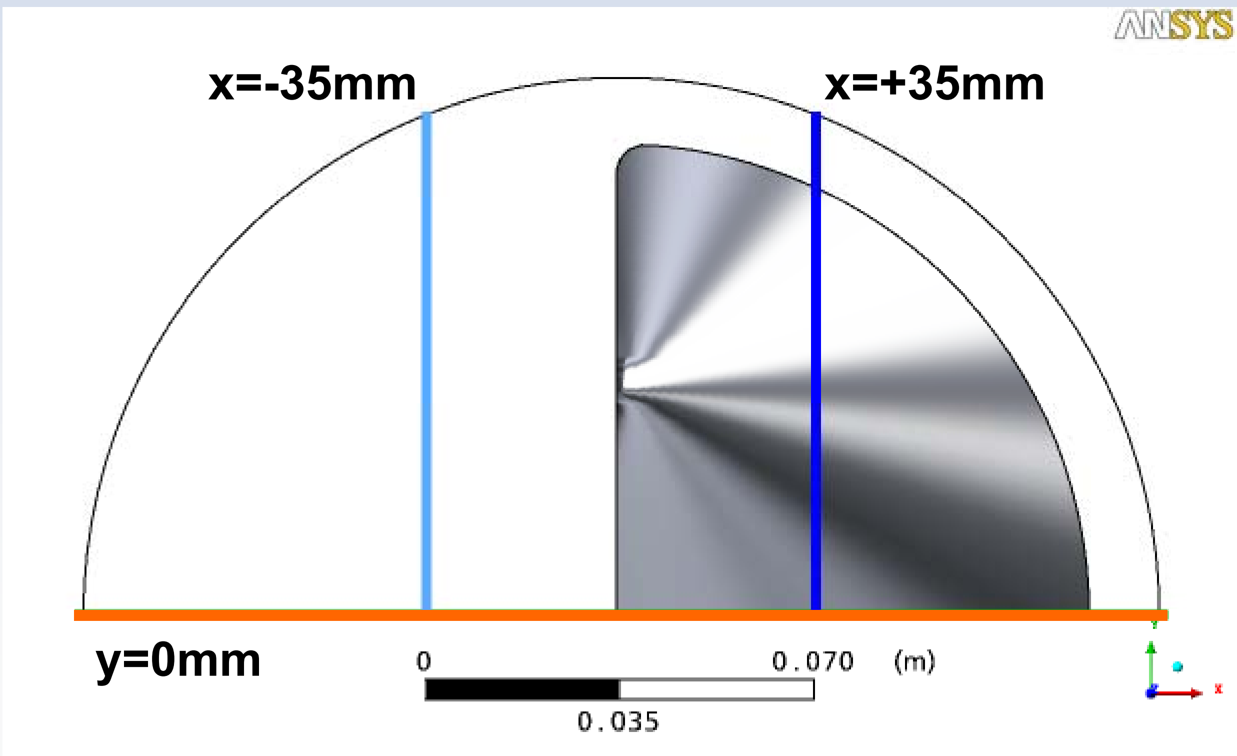


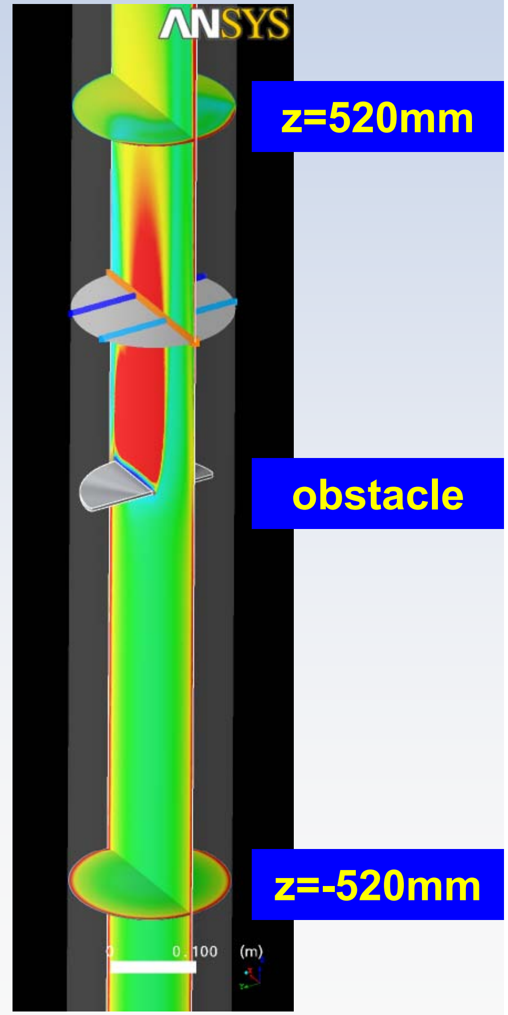
TOPFLOW Experiment



ANSYS CFX ⇔ Experimental Data Quantitative Comparison

- **Quantitative data comparison @ cross sections**
  z=±10, ±15, ±20, ±40, ±80, ±160, ±250, ±520mm:
  – absolute water velocity
  – air volume fraction

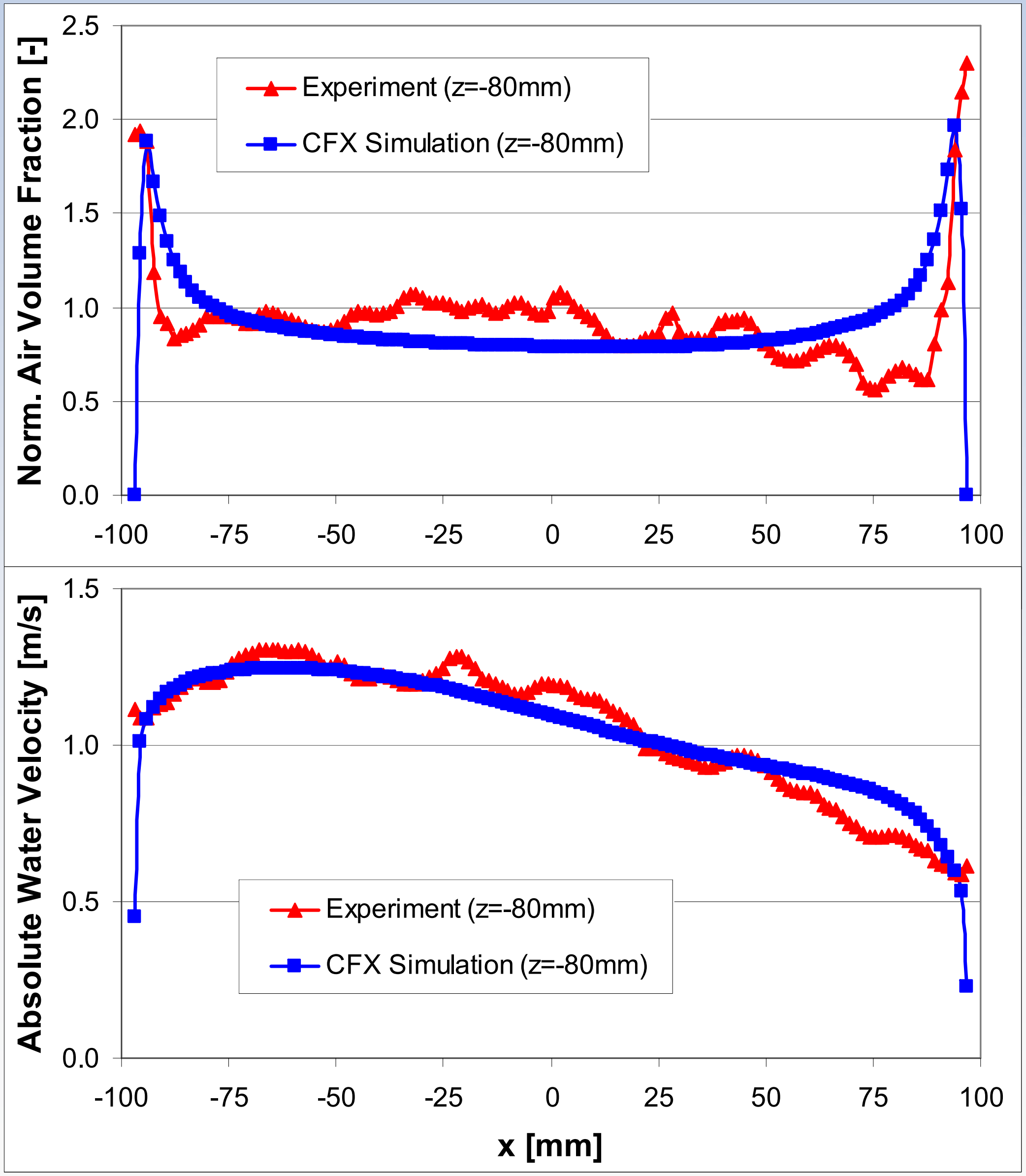


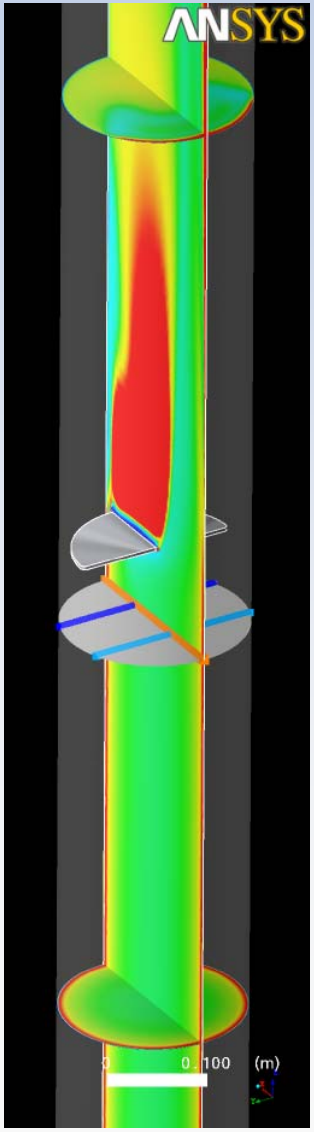


ANSYS CFX ⇔ Experimental Data Quantitative Comparison

z=-80mm

y=0mm

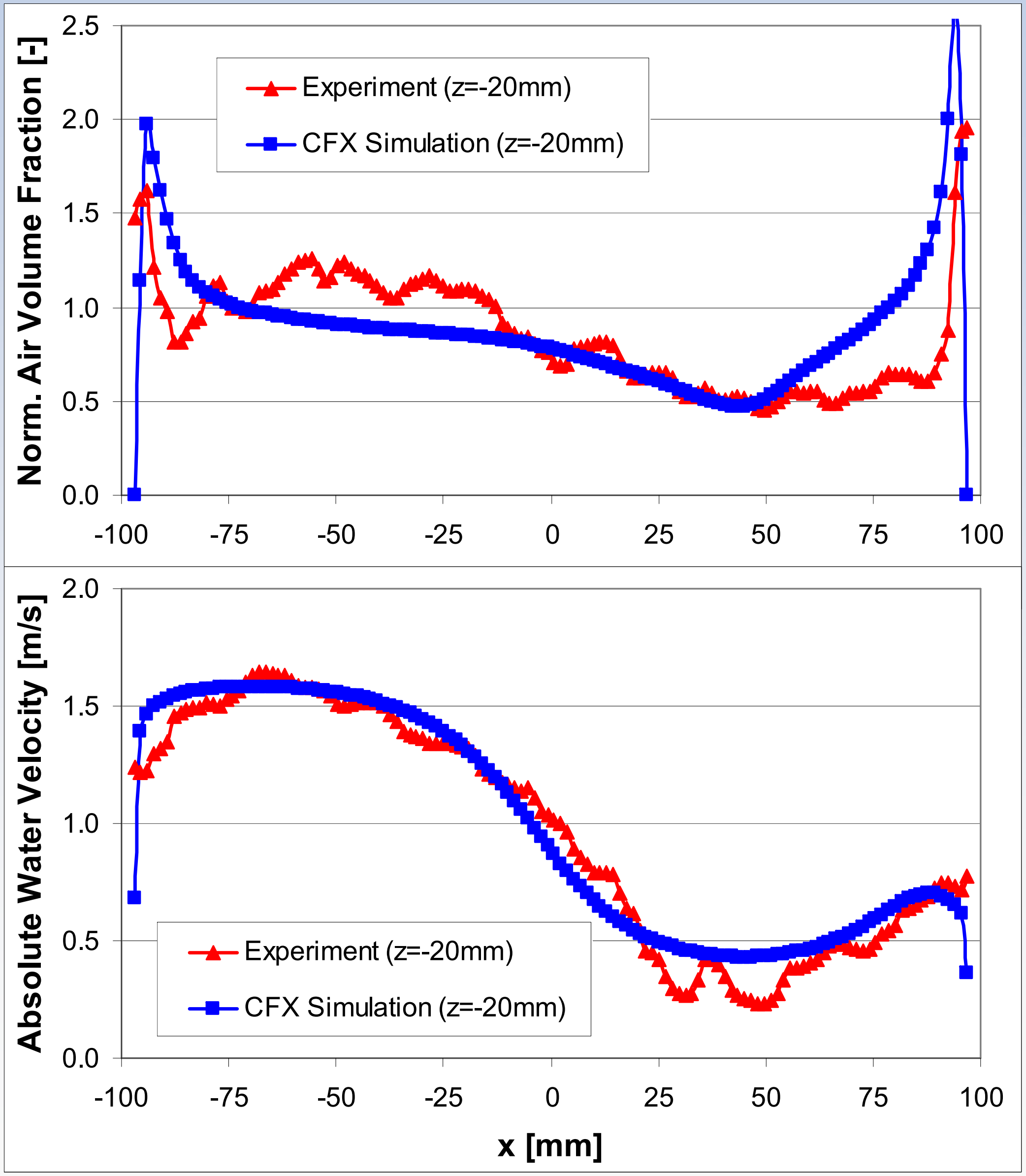


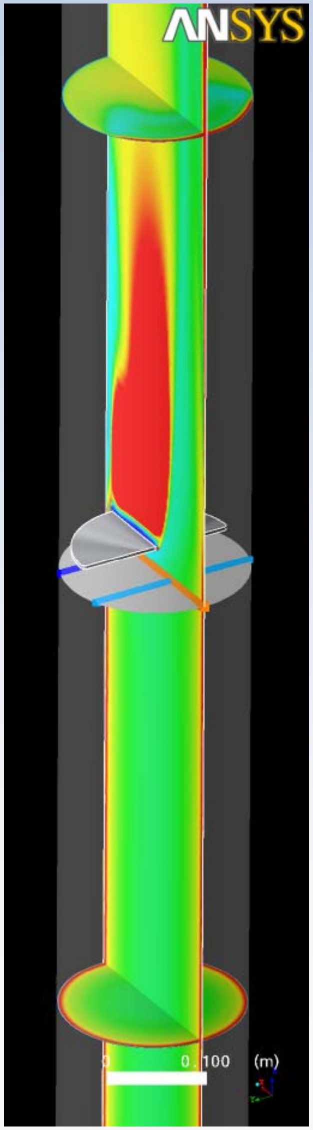


ANSYS CFX ⇔ Experimental Data Quantitative Comparison

z=-20mm

y=0mm

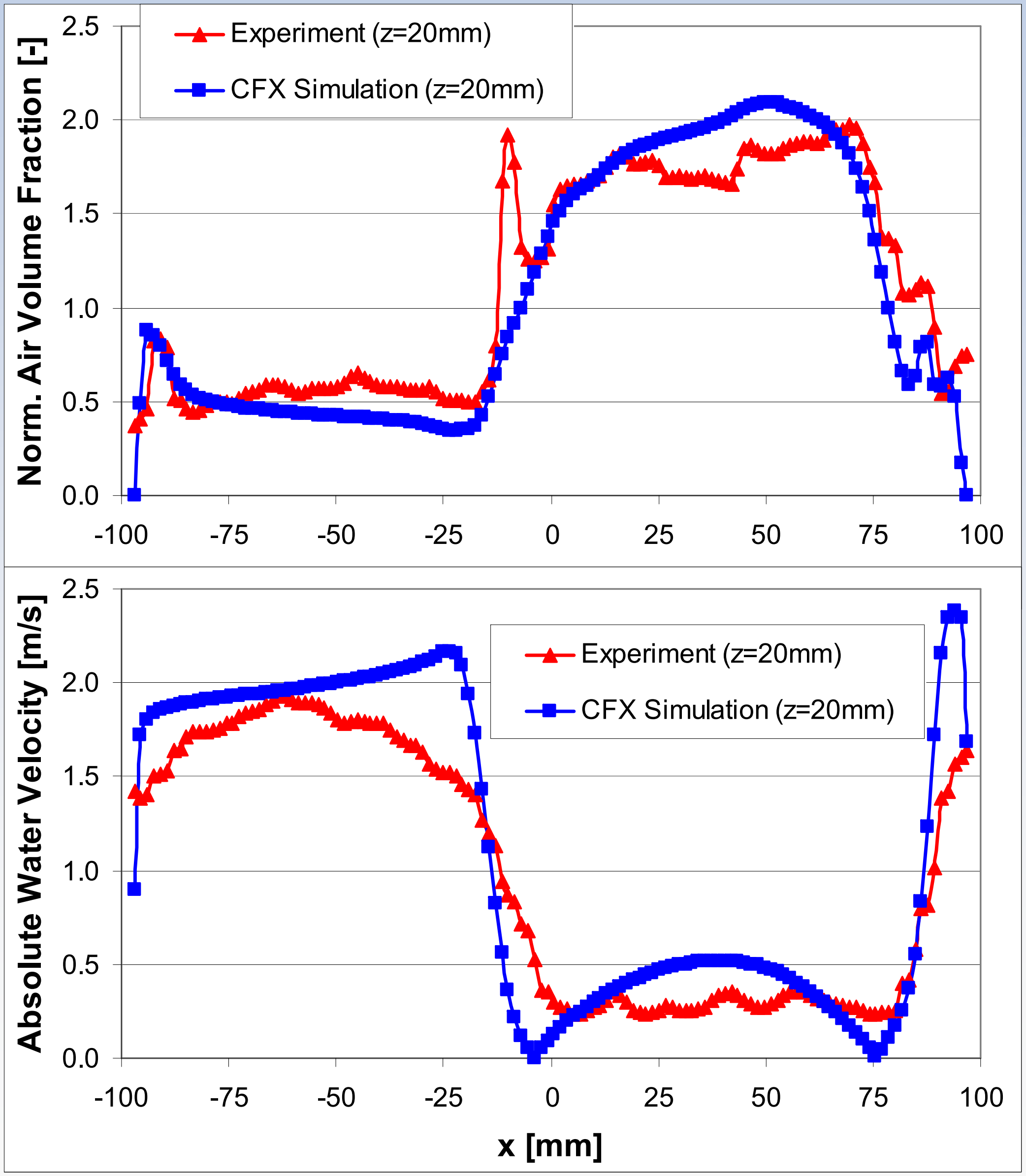


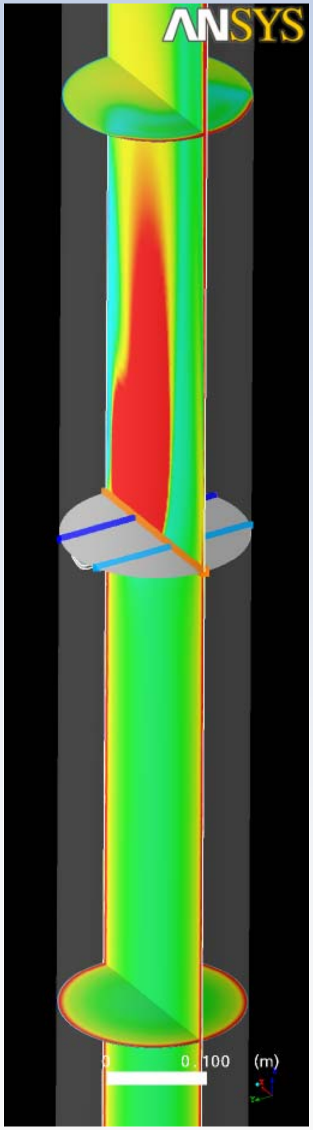


ANSYS CFX ⇔ Experimental Data Quantitative Comparison

z=20mm

y=0mm

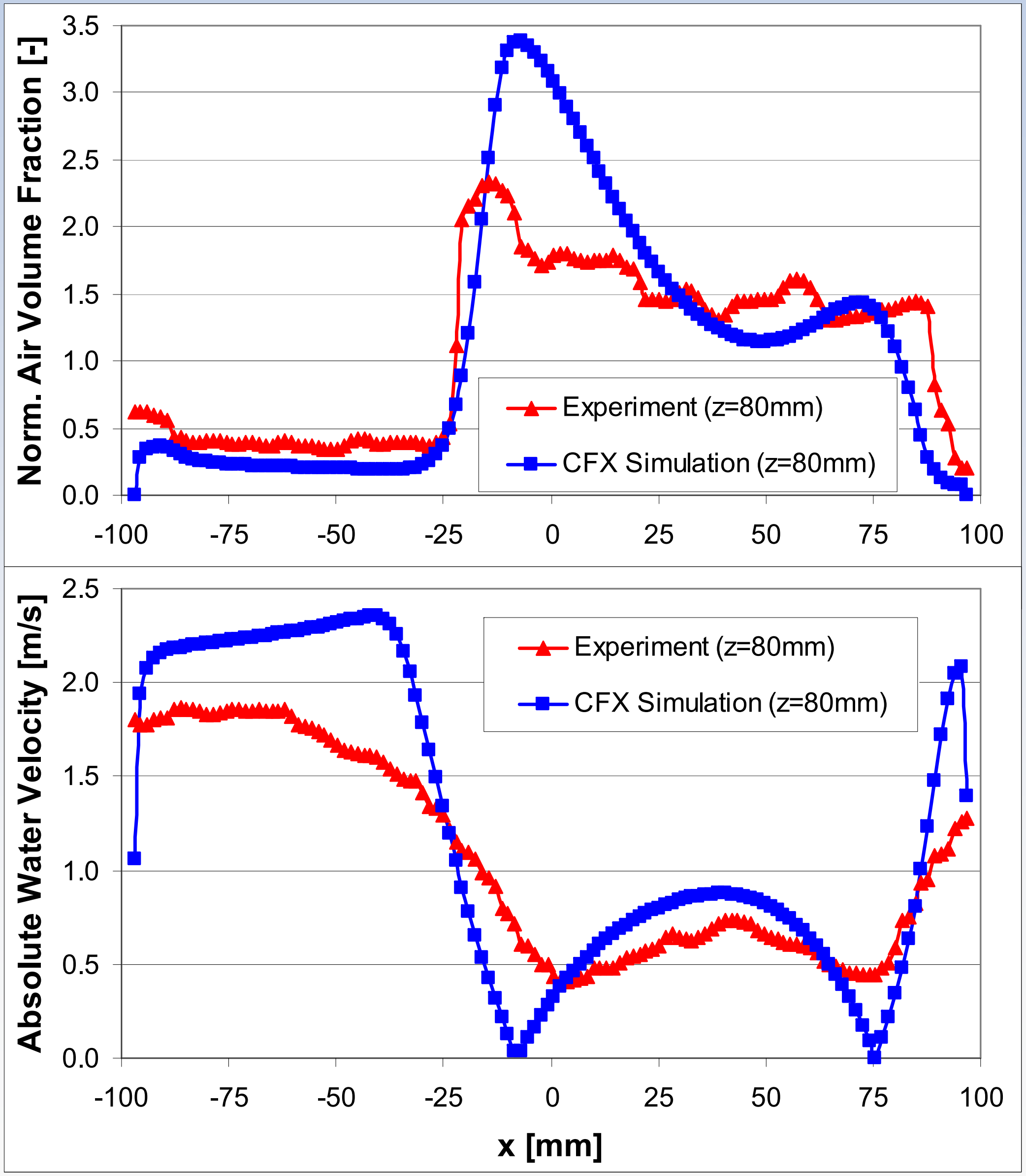


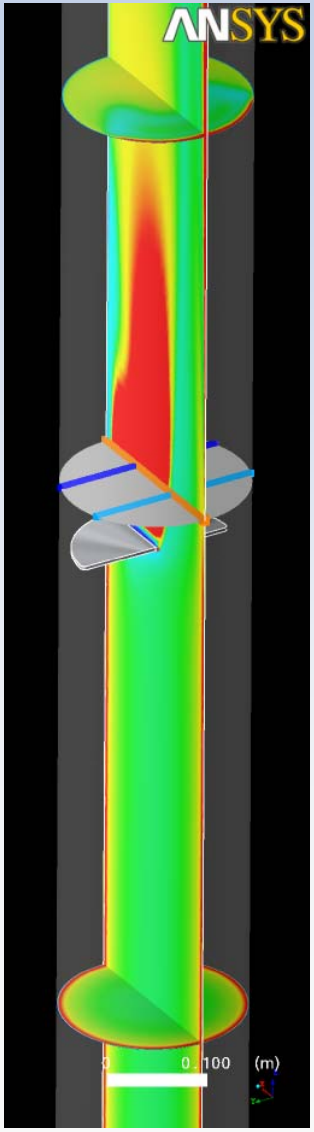


ANSYS CFX ⇔ Experimental Data Quantitative Comparison

z=80mm

y=0mm

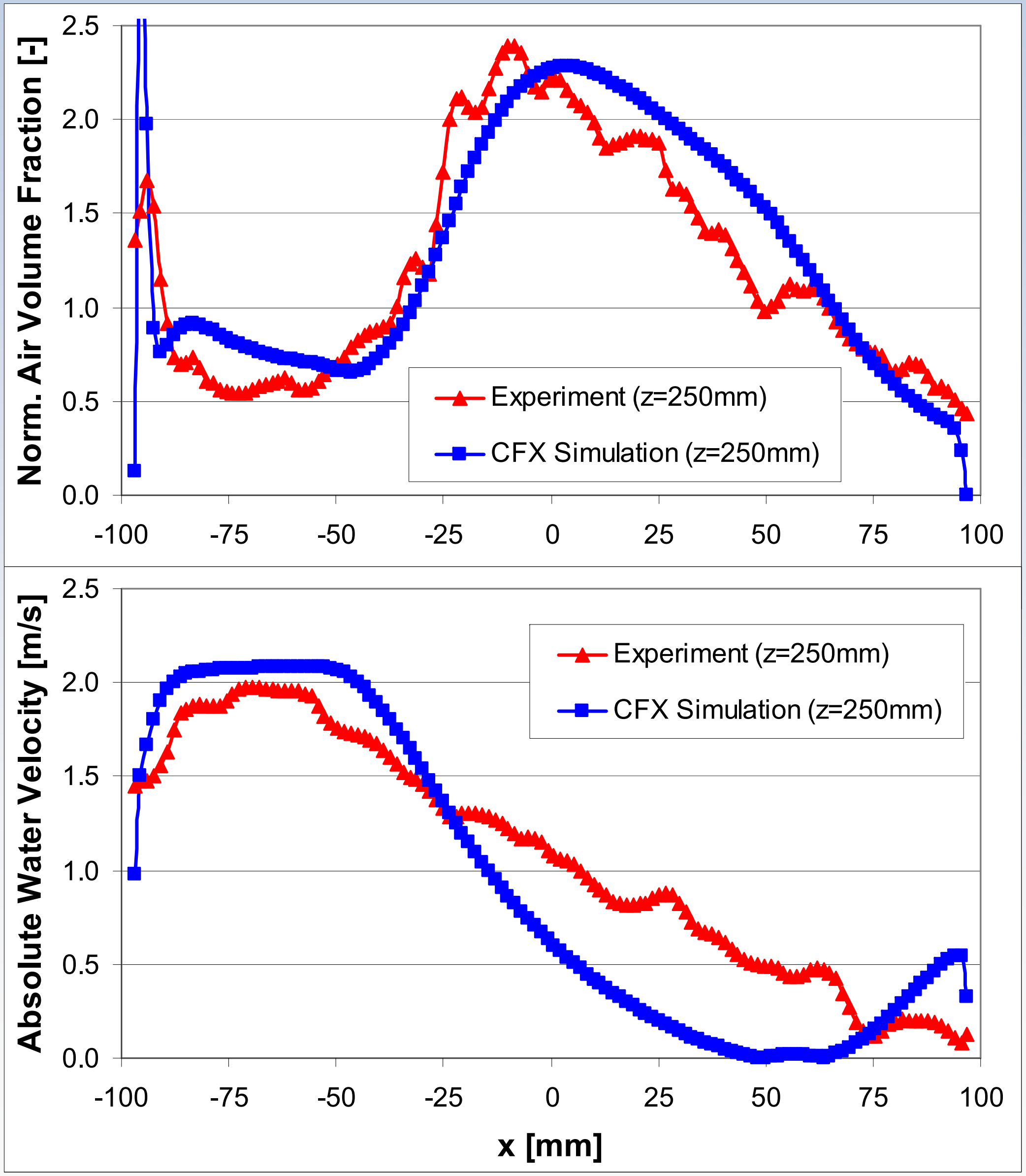


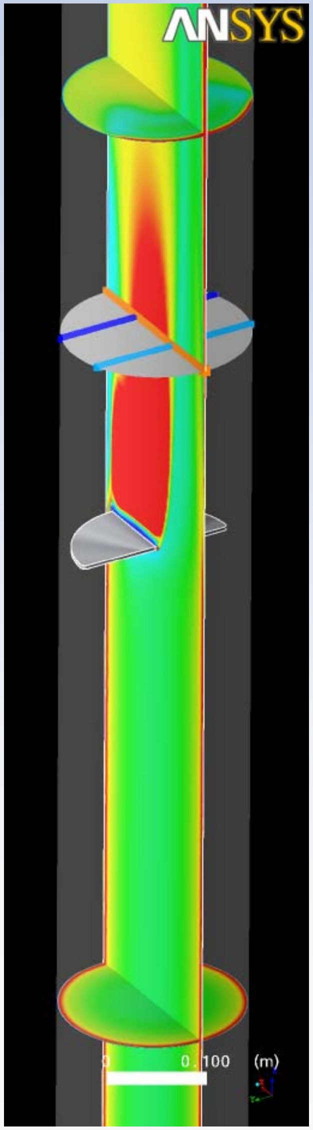


ANSYS CFX ⇔ Experimental Data Quantitative Comparison

z=250mm

y=0mm





Polydispersed Bubbly Flow Caused by Breakup & Coalescence

Transition from disperse bubbly flow to slug flow:

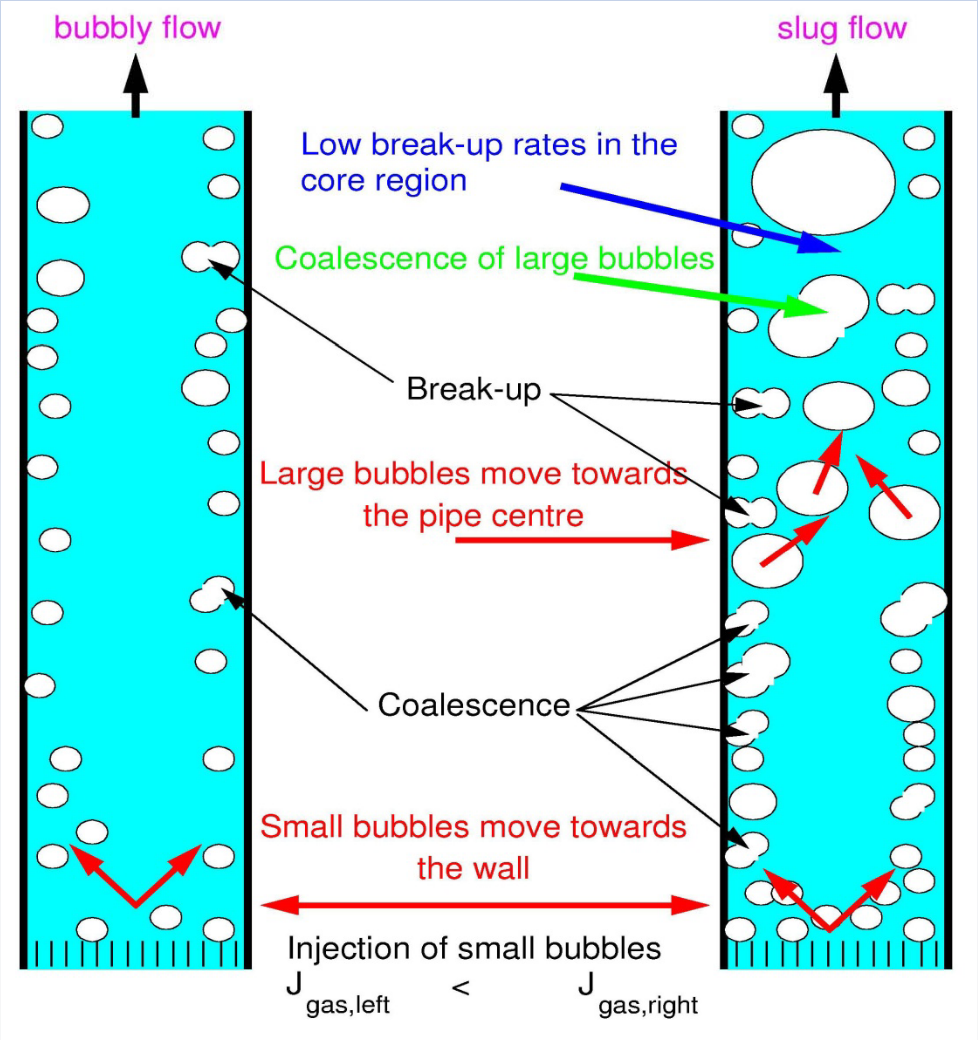
Balance between:

- **coalescence of bubbles**
- **turbulent bubble breakup**

→ bubble size distribution; polydisperse bubbly flow

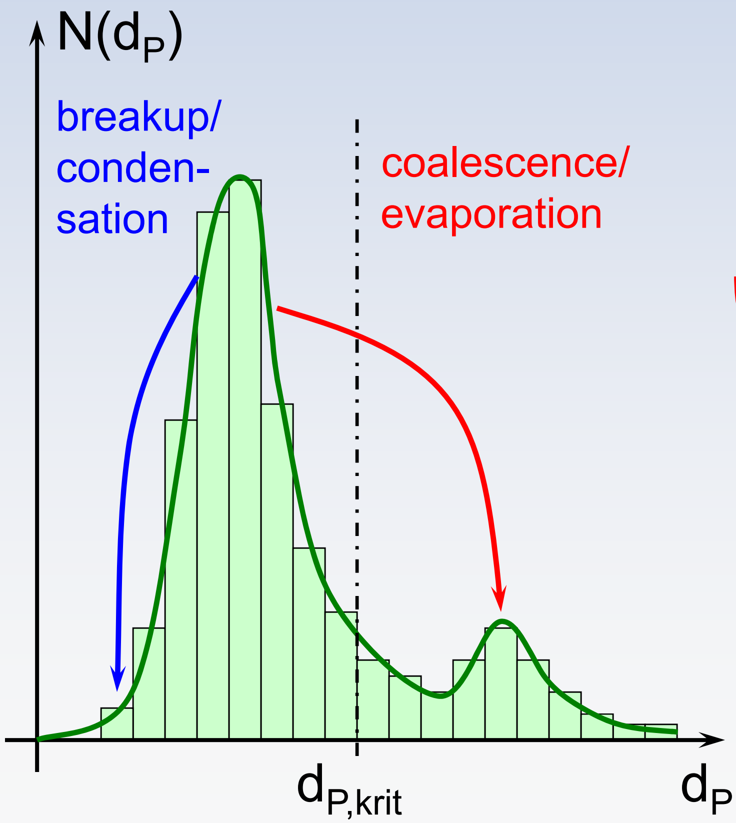
→ counter-current radial motion of small and large bubbles; more than one velocity field

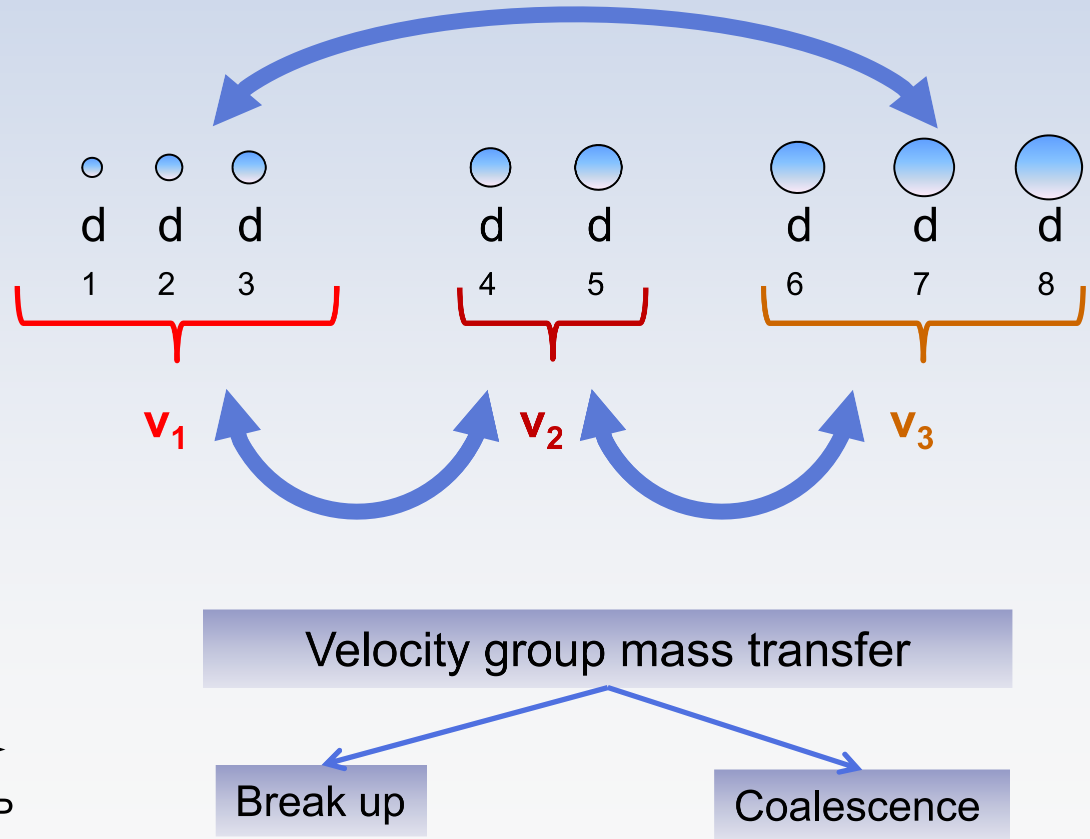
→ new population balance model (inhomogeneous MUSIG)



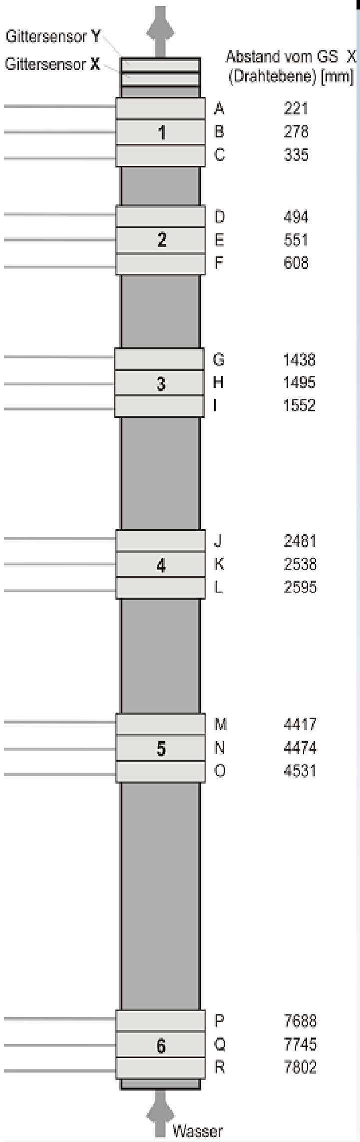
Inhomogeneous MUSIG Model

- momentum equations are solved for N gas phases (vel. groups)
- size fraction equations for M_i bubble size classes in each vel. group
- bubble coalescence and break-up over all ΣM_i MUSIG groups

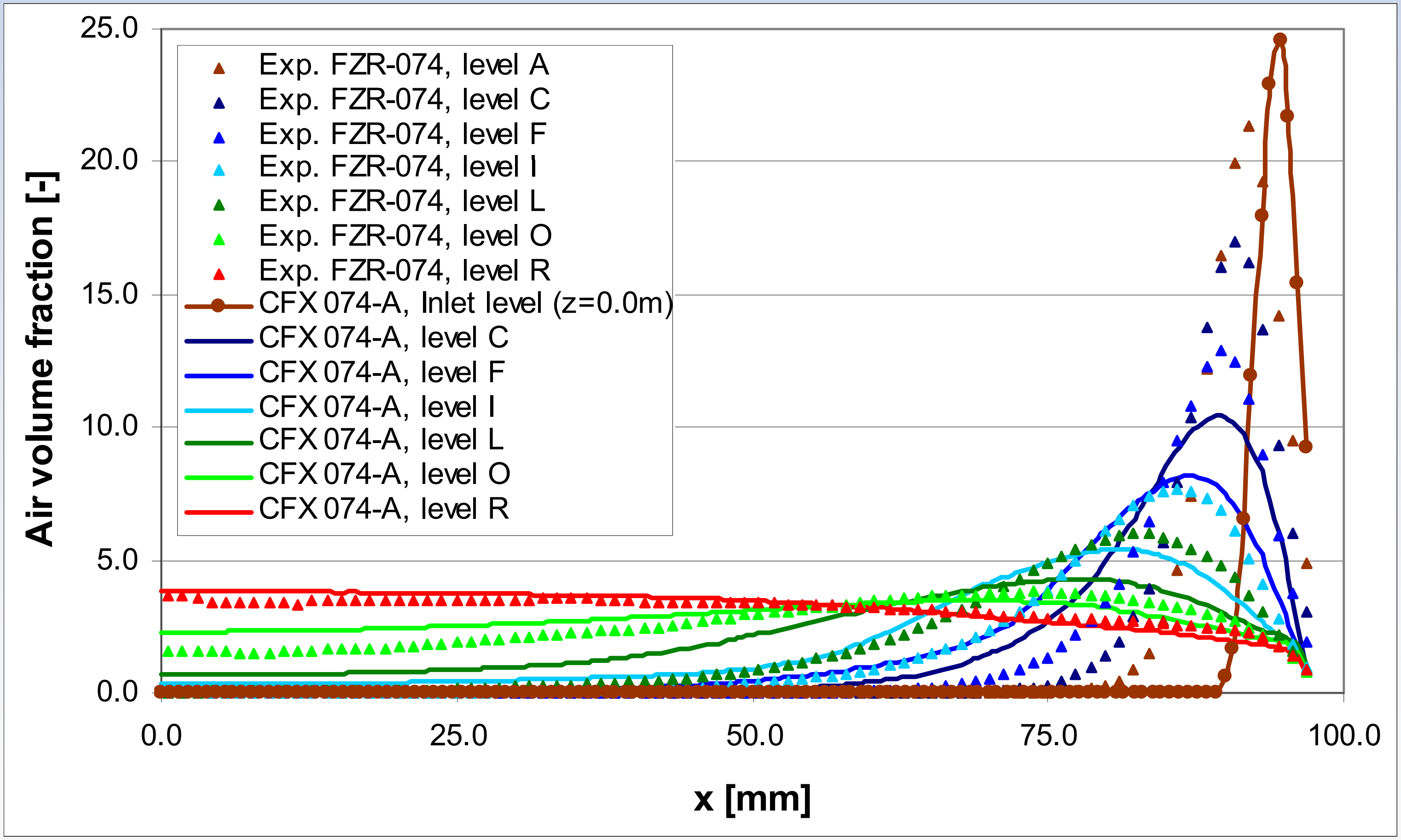




Validation of 3x7 Inhomogeneous MUSIG Model on TOPFLOW-074



- **good agreement at levels A, L through R**
- **too fast spreading of the bubble plume from inlet due to too intensive turbulent dispersion**



MUSIG Model Extension

- **Basic population balance equations**

New terms

$$\frac{dn(m,\vec{r},t)}{dt} = \frac{\partial}{\partial t} n(m,\vec{r},t) + \frac{\partial}{\partial \vec{r}}\left(U(m,\vec{r},t)\,n(m,\vec{r},t)\right) + \frac{\partial n(m,\vec{r},t)}{\partial m}\frac{\partial m(\vec{r},t)}{\partial t} = B_B - D_B + B_C - D_C$$

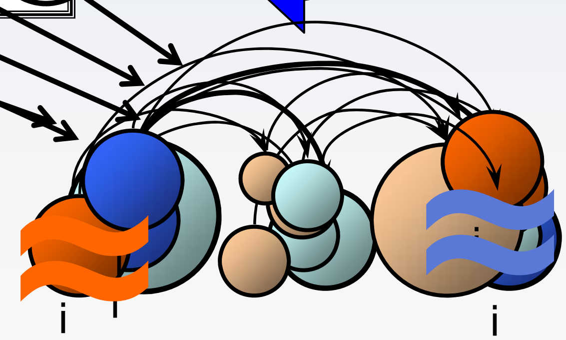
Bubble number density

Breakup/Coalescence terms

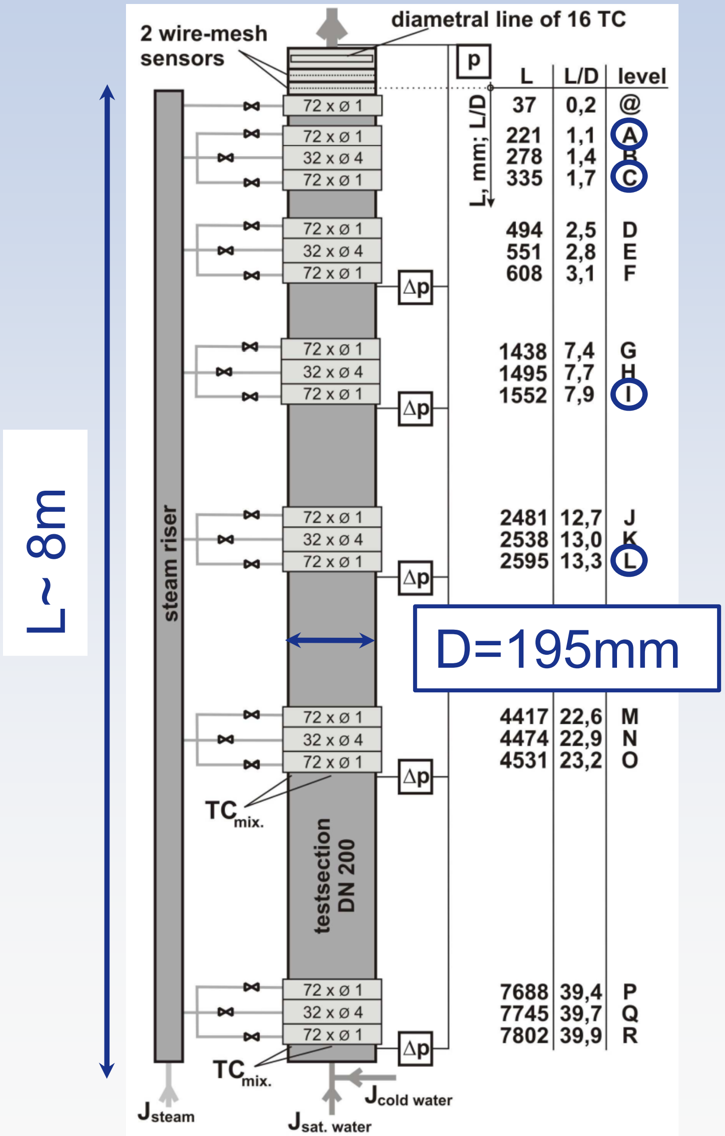
- **Size fraction equations**

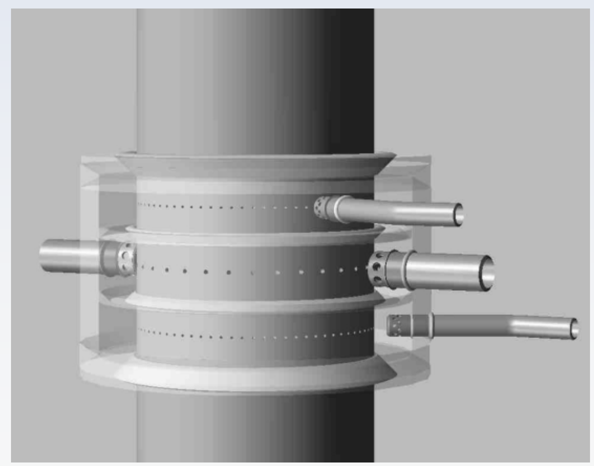
$$\boxed{\frac{\partial}{\partial t}(\rho_i r_d f_i) + \frac{\partial}{\partial x^j}(\rho_i r_d U_i^j f_i) = S_{B_B} - S_{D_B} + S_{B_C} - S_{D_C} + S_i}$$

$$S_i = \begin{cases} \dfrac{m_i}{m_i - m_{i-1}}\Gamma_i - \dfrac{m_i}{m_{i+1} - m_i}\Gamma_{i+1} & \text{for evaporation} \\[2ex] \dfrac{m_i}{m_i - m_{i-1}}\Gamma_{i-1} - \dfrac{m_i}{m_{i+1} - m_i}\Gamma_i & \text{for condensation} \end{cases}$$



TOPFLOW Test Facility @ FZD

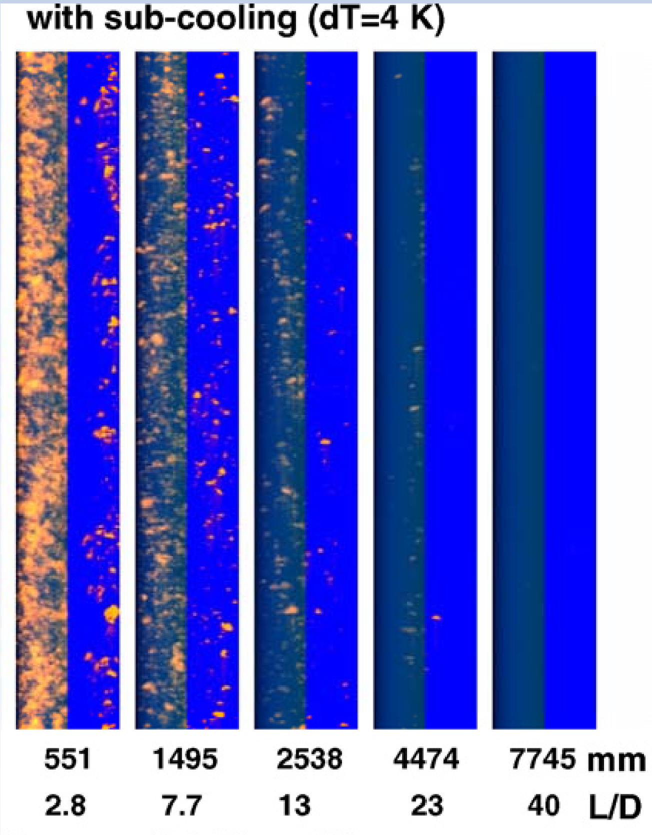




Courtesy of FZD

Condensation Test Case

- **P=2 [MPa]**
- **J_w=1.0 [m/s]**
- **J_s=0.54 [m/s]**
- **T_s=214.4 [°C]**
- **T_w=210.5 [°C] → ΔT_w=3.9 [K]**
- **D_{inj} = 1 [mm]**
- **Detailed experimental data:**
  - Bubble size distribution
  - Radial steam volume fraction distribution



Dirk Lucas, Horst-Michael Prasser: "*Steam bubble condensation in sub-cooled water in case of co-current vertical pipe flow*",
Nuclear Engineering and Design, Volume 237, Issue 5, March 2007, Pages 497-508

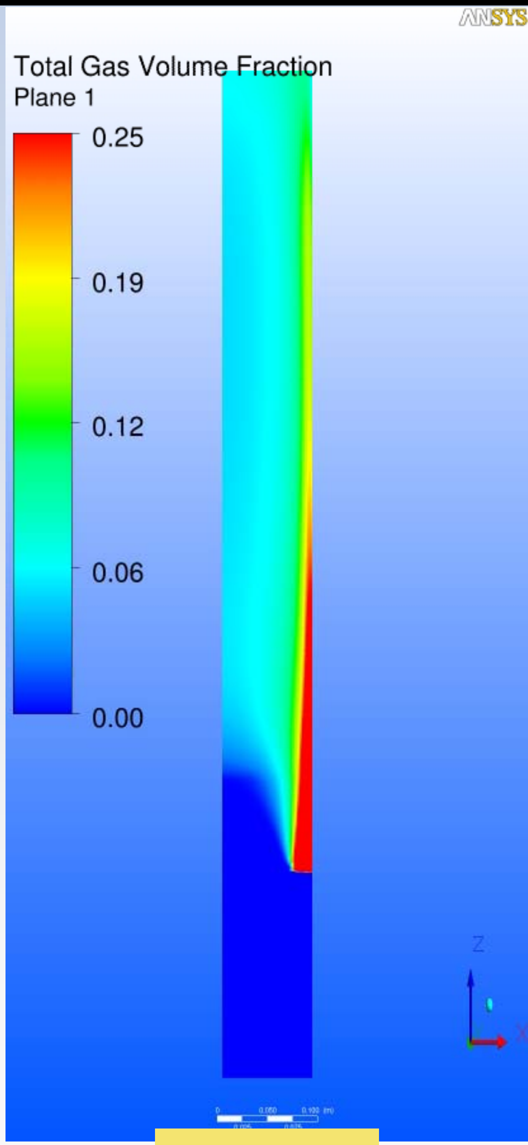
Physical Model Setup

- **Standard MUSIG & Extended MUSIG**
  - 25 bubble size classes
  - 3 velocity groups:
    0→3 [mm],3→6 [mm], 6→30 [mm]
  - Arranged in accordance with critical Tomiyama bubble diameter for bubble size dependent lift force
  - Break up model: Luo & Svendsen (F_B=0.025)
  - Coalescence model: Prince & Blanch (F_C=0.05)

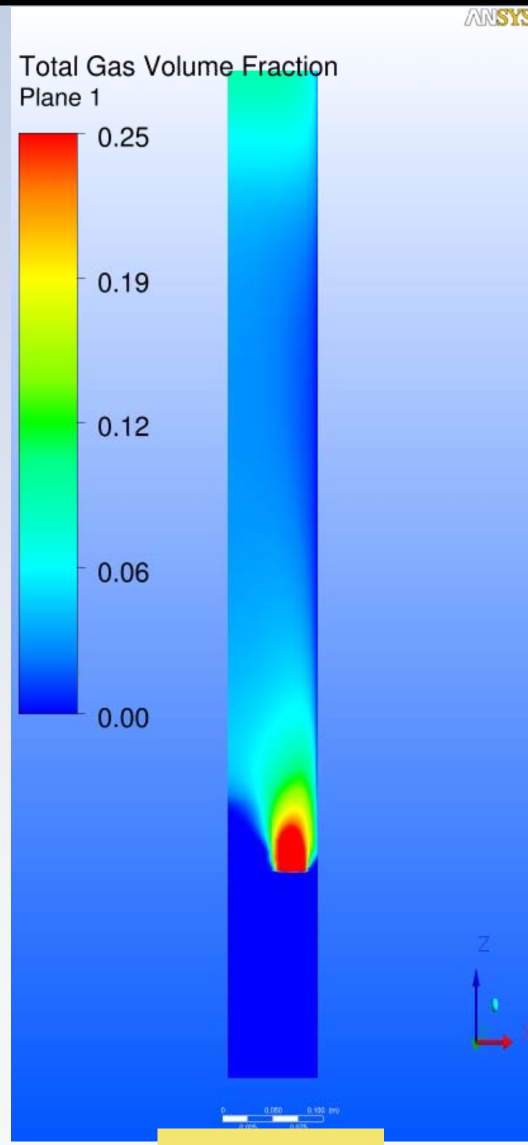
TOPFLOW Condensation Testcase

	Inlet BC	Inlet Position	WLF	TD Force	Heat Transfer
Config 1	D_{inj} = 4mm	Source point @ Wall	-	-	-
Config 2	D_{inj}= 4 mm	Source point @ 75 mm	F_{WLF}	CTD=1.5	$Nu=2+0.15Re_p^{0.8}Pr^{0.5}$
Config 3	D_{inj}= 1 mm	Source point @ 75 mm	F_{WLF}	CTD=1.5	$Nu=2+0.15Re_p^{0.8}Pr^{0.5}$

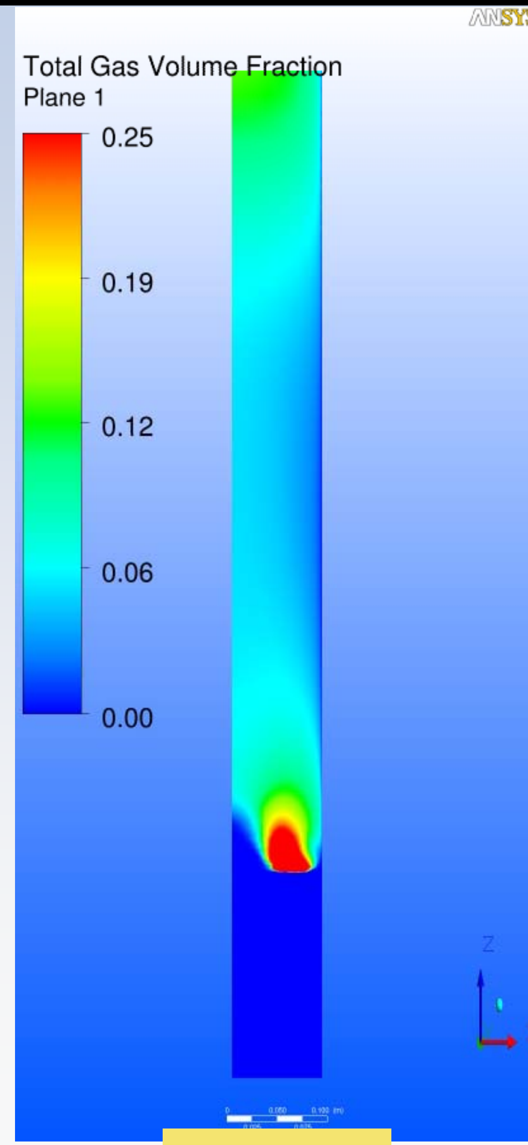
Results: Vapor Volume Fraction



Config 1

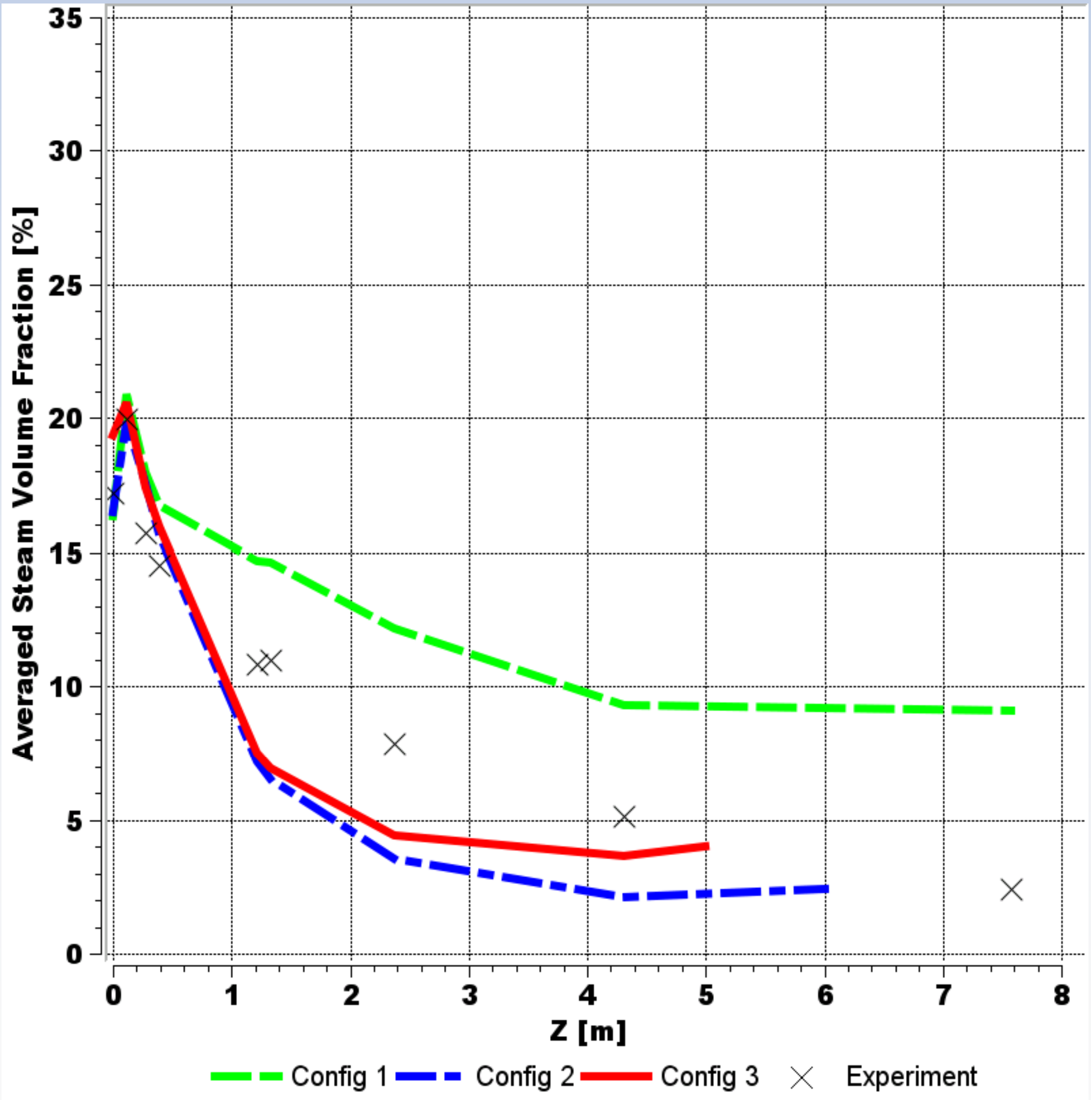


Config 2

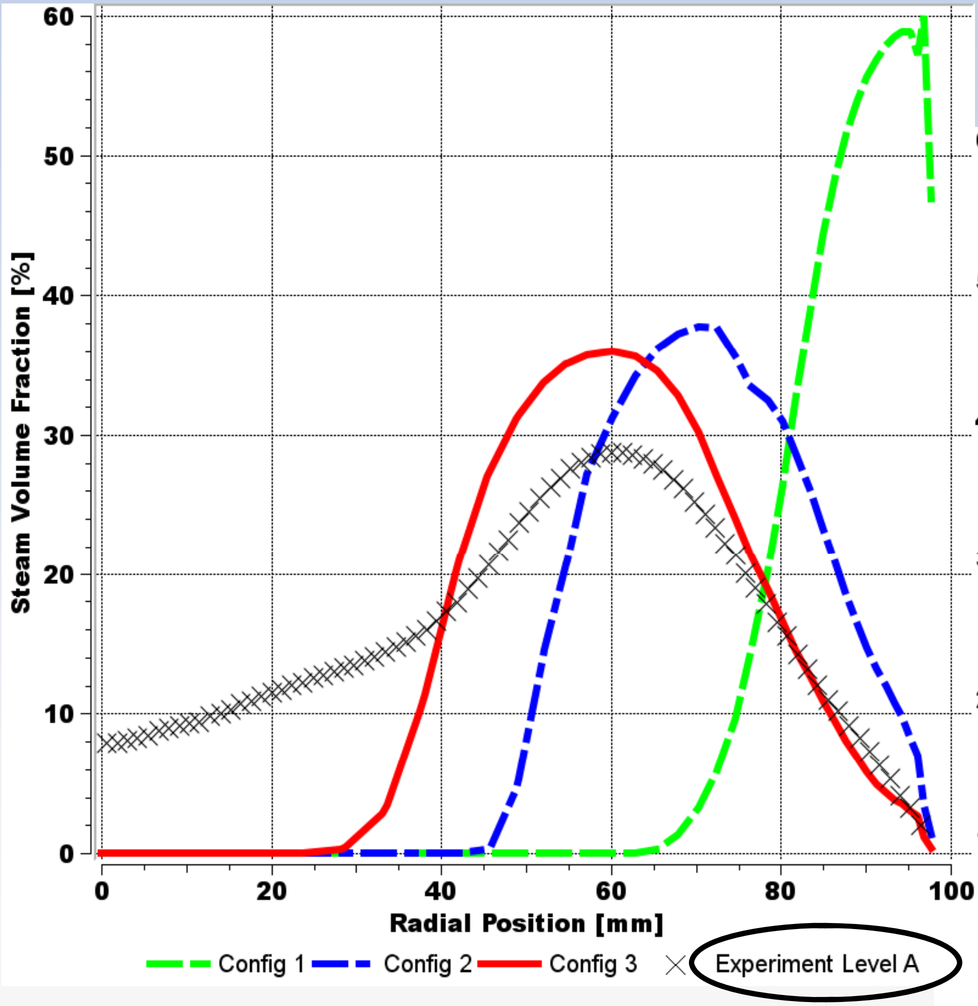


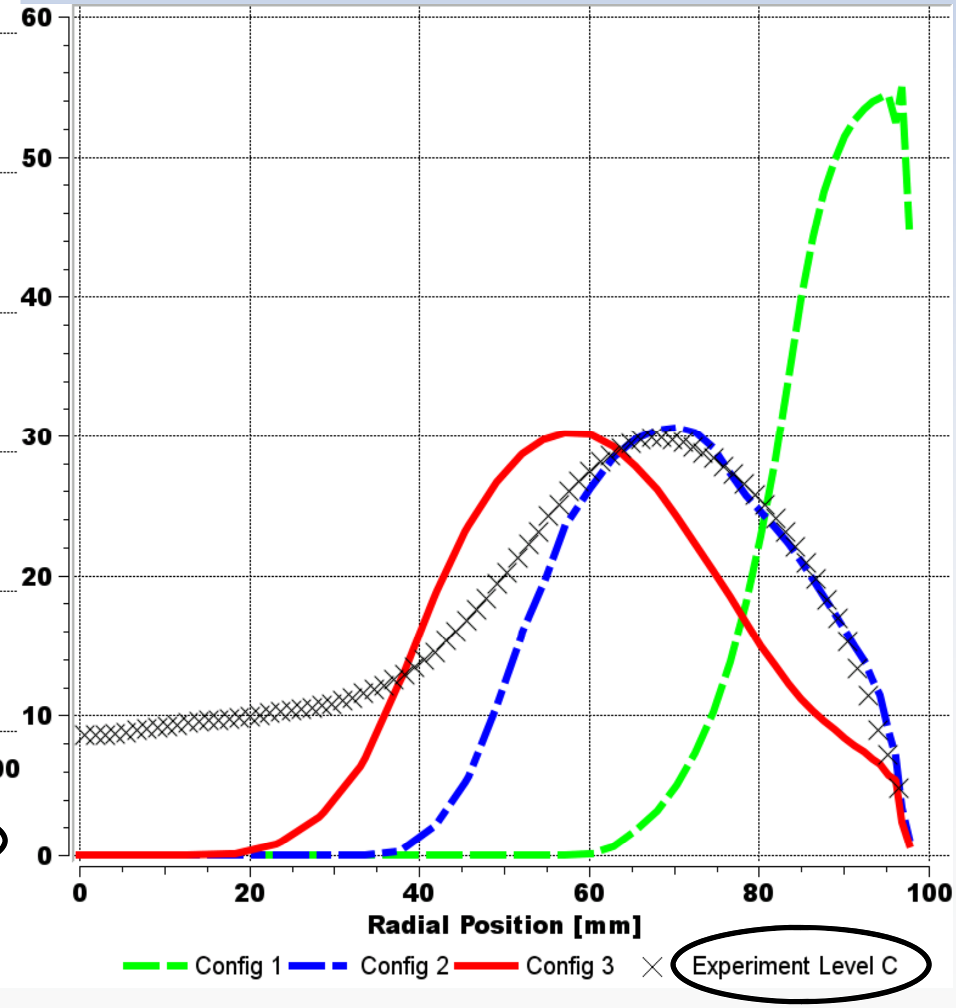
Config 3

Results: Vertical Averaged Steam Distribution

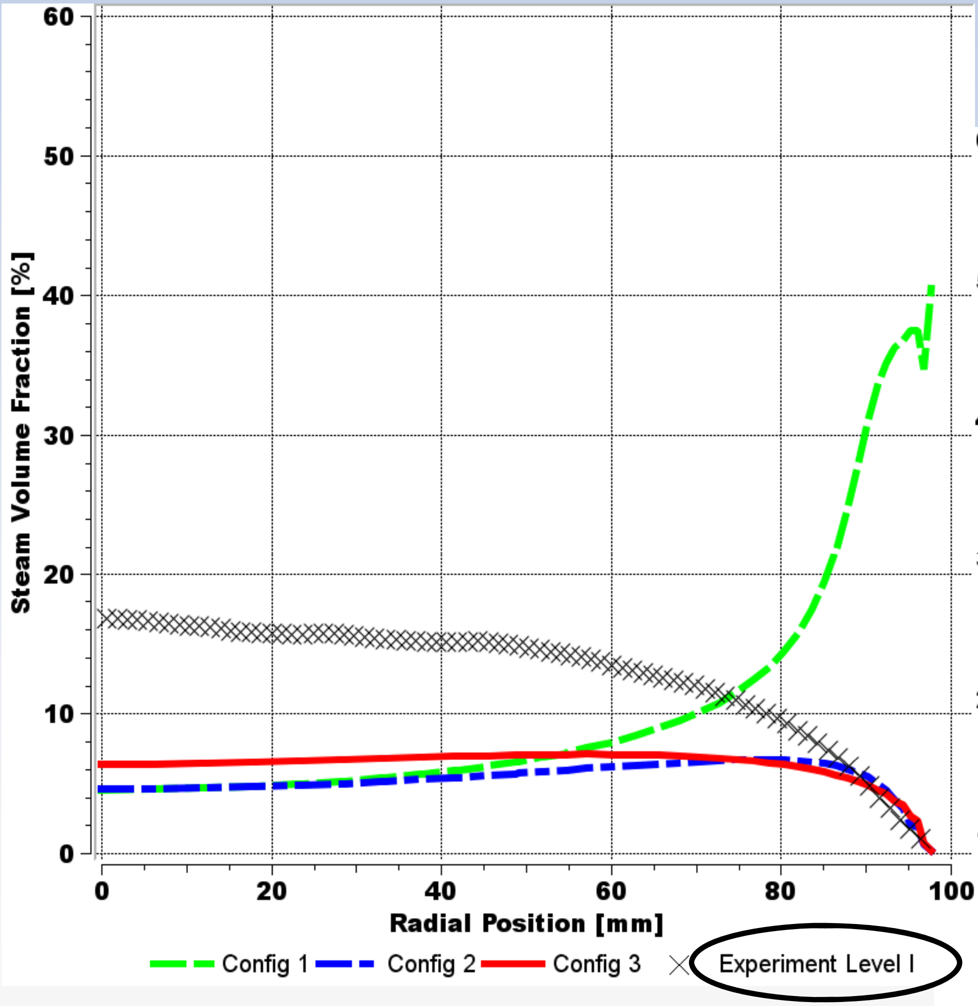


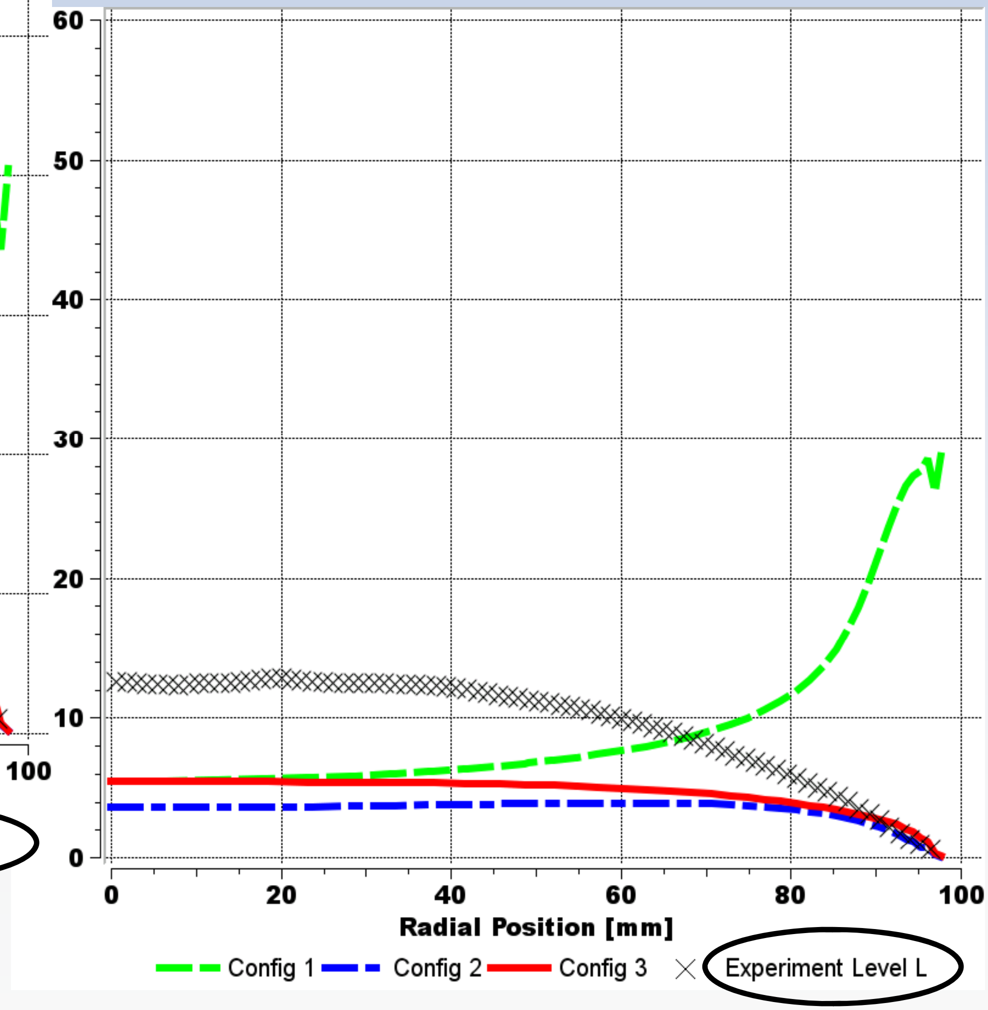
Results: Radial Steam Distribution



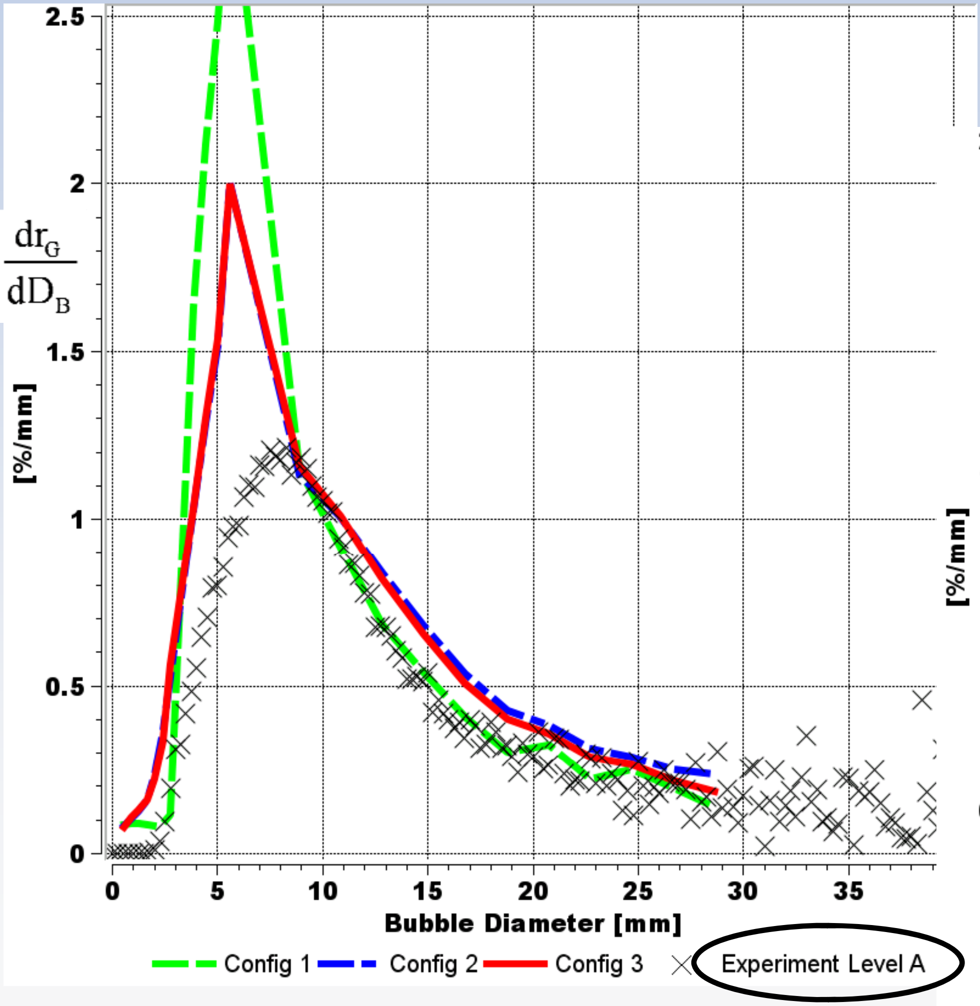


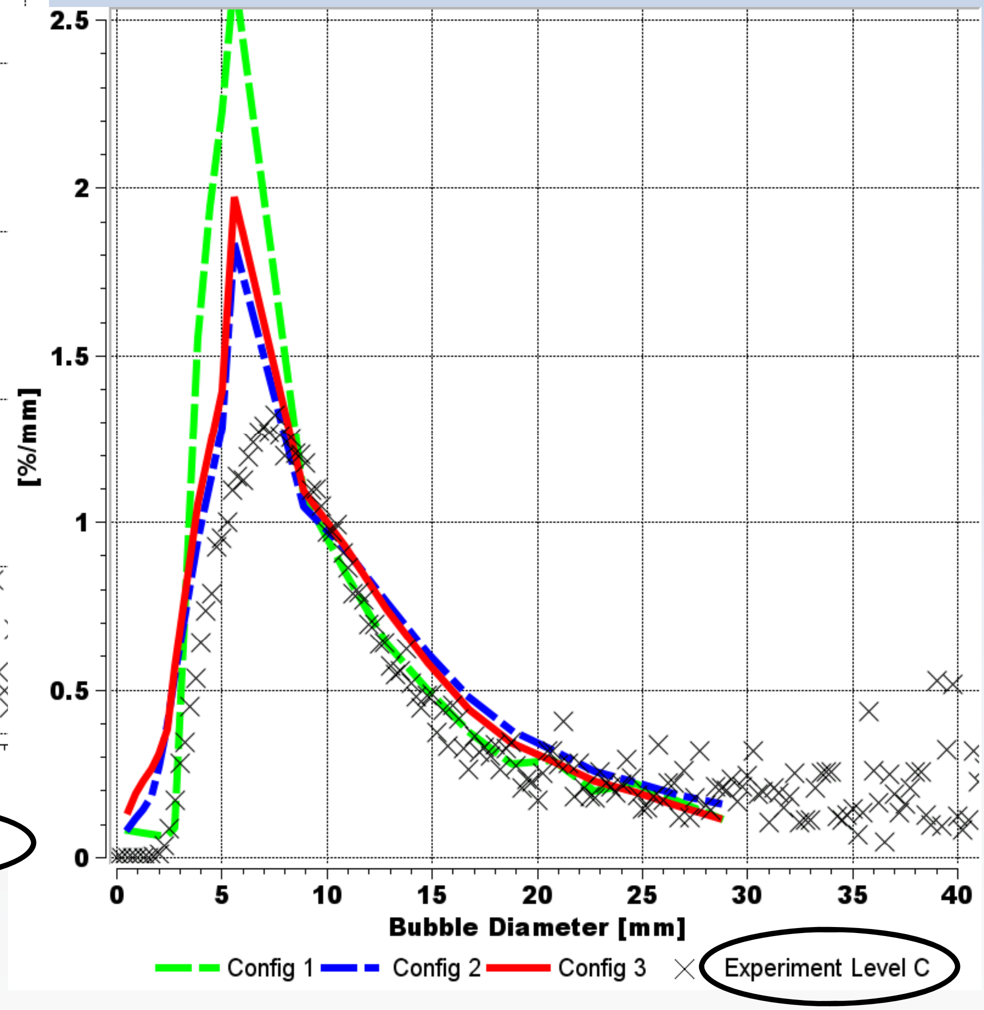
Results: Radial Steam Distribution



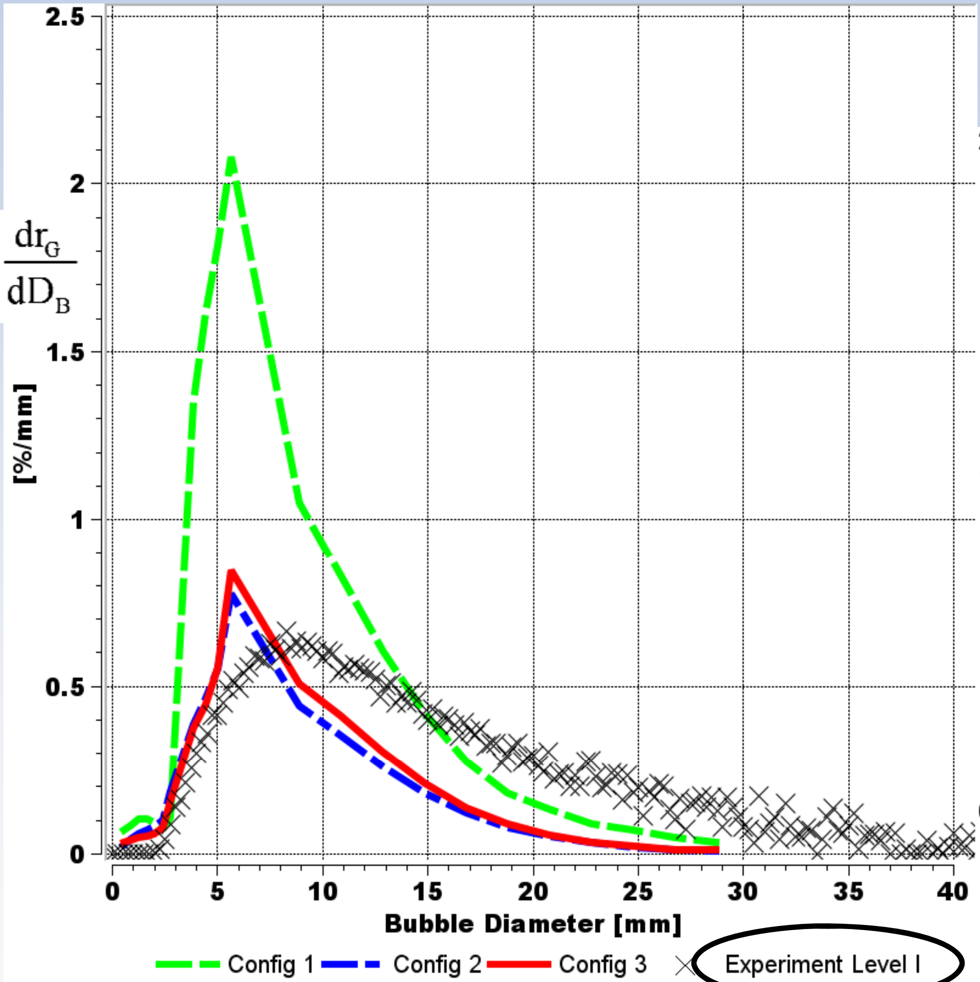


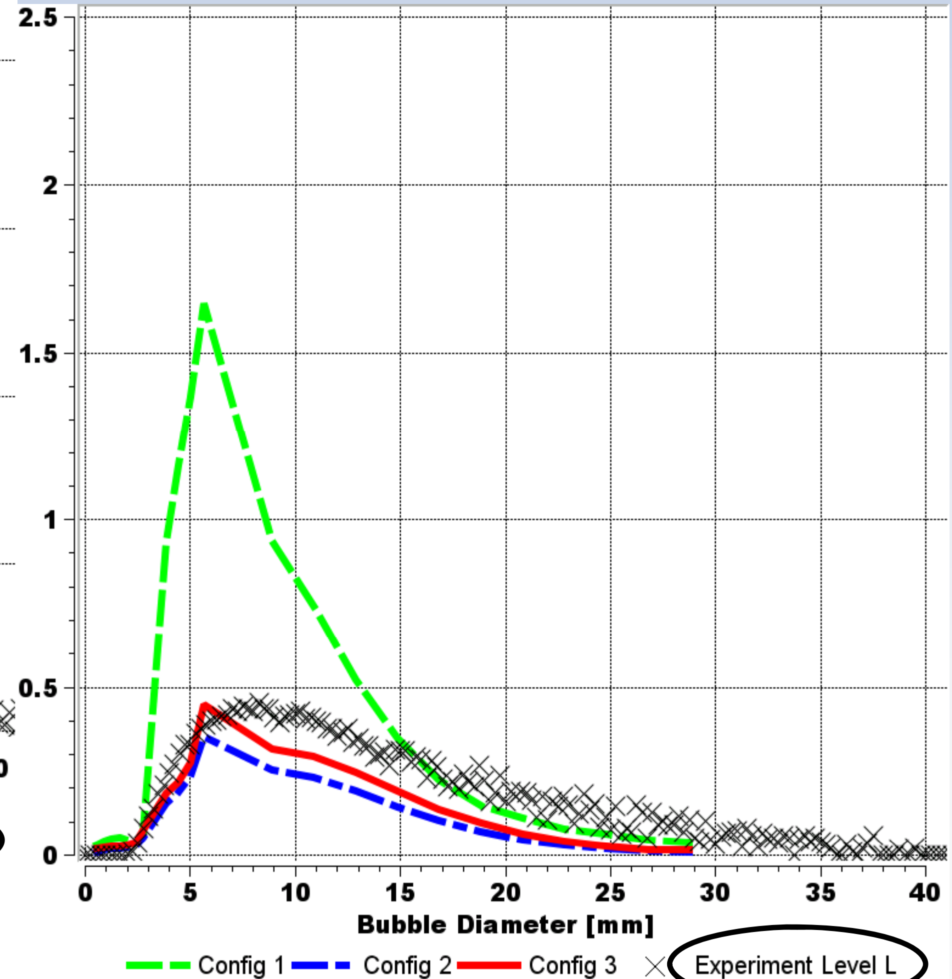
Results: Bubble Size Distribution





Results: Bubble Size Distribution



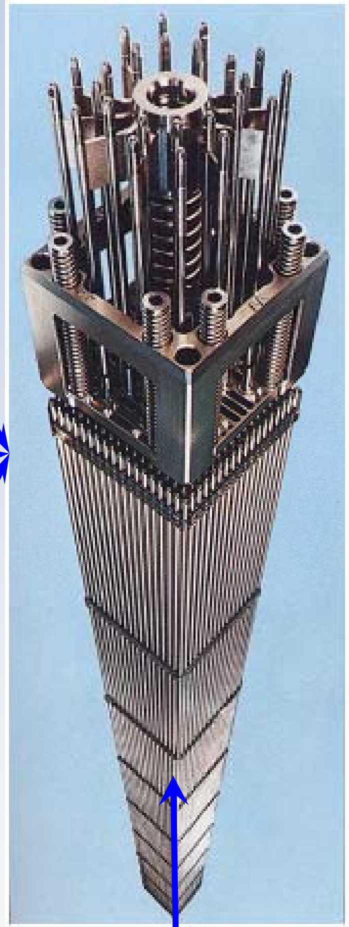


CFD Simulation for Fuel Assemblies in Nuclear Reactors

Material Properties

Turbulence

Multiphase Flow Modeling



Wall Boiling & Bulk Condensation

Conjugate Heat Transfer (CHT)

FSI: Stresses & Deformations

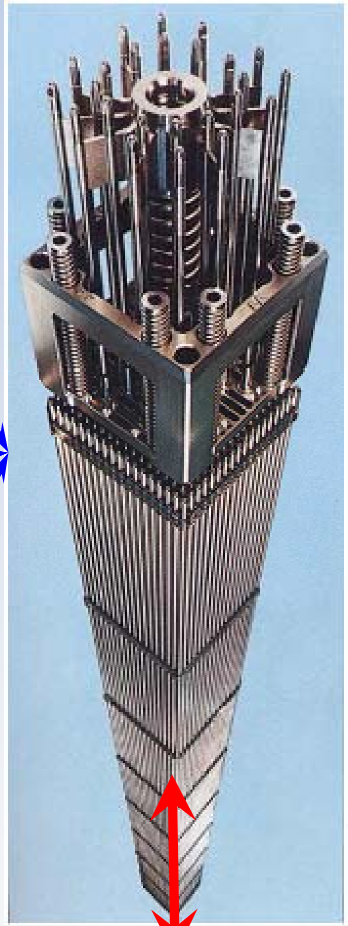
Validation against Experiments

CFD Simulation for Fuel Assemblies in Nuclear Reactors

Material Properties

Turbulence

Multiphase Flow Modeling



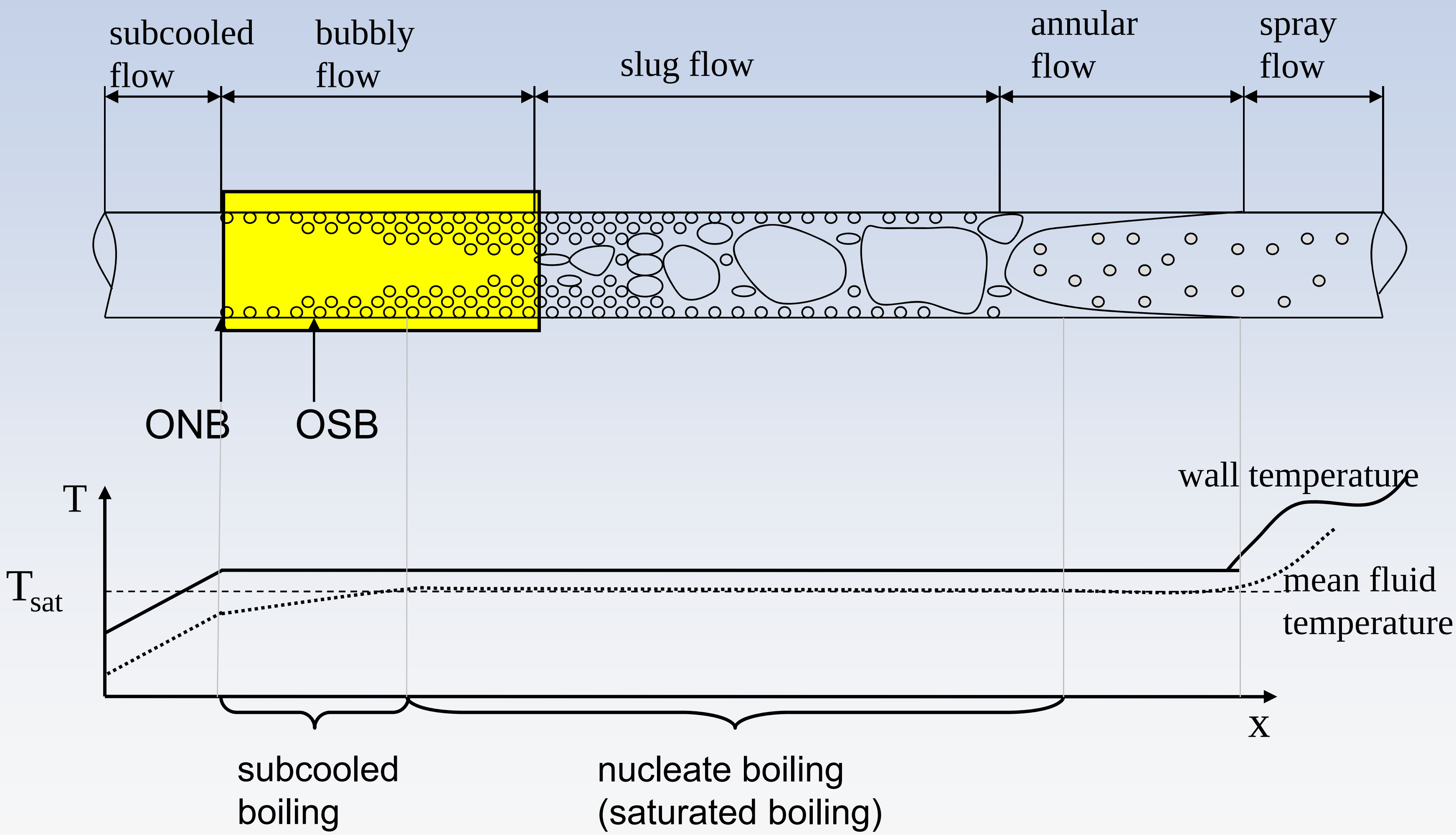
Wall Boiling & Bulk Condensation

Conjugate Heat Transfer (CHT)

FSI: Stresses & Deformations

Validation against Experiments

Multiphase Flow Regimes for Boiling Water Flow



Mechanistic wall heat partioning model:

$$\dot{q}_{Wall} = \dot{q}_F + \dot{q}_Q + \dot{q}_E$$

convective heat flux

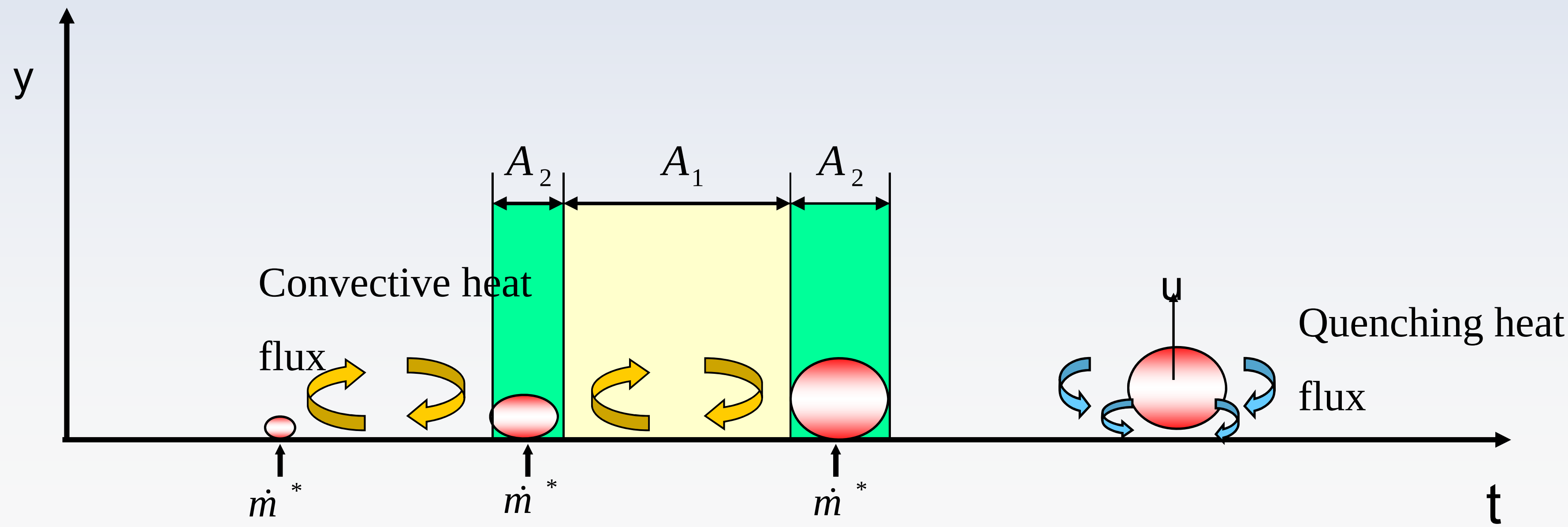
$$\dot{q}_F = A_1 \cdot h_F \cdot (T_W - T_L)$$

quenching heat flux

$$\dot{q}_Q = A_2 \cdot h_Q \cdot (T_W - T_L)$$

evaporation heat flux

$$\dot{q}_E = \dot{m} \cdot (h_G - h_L)$$



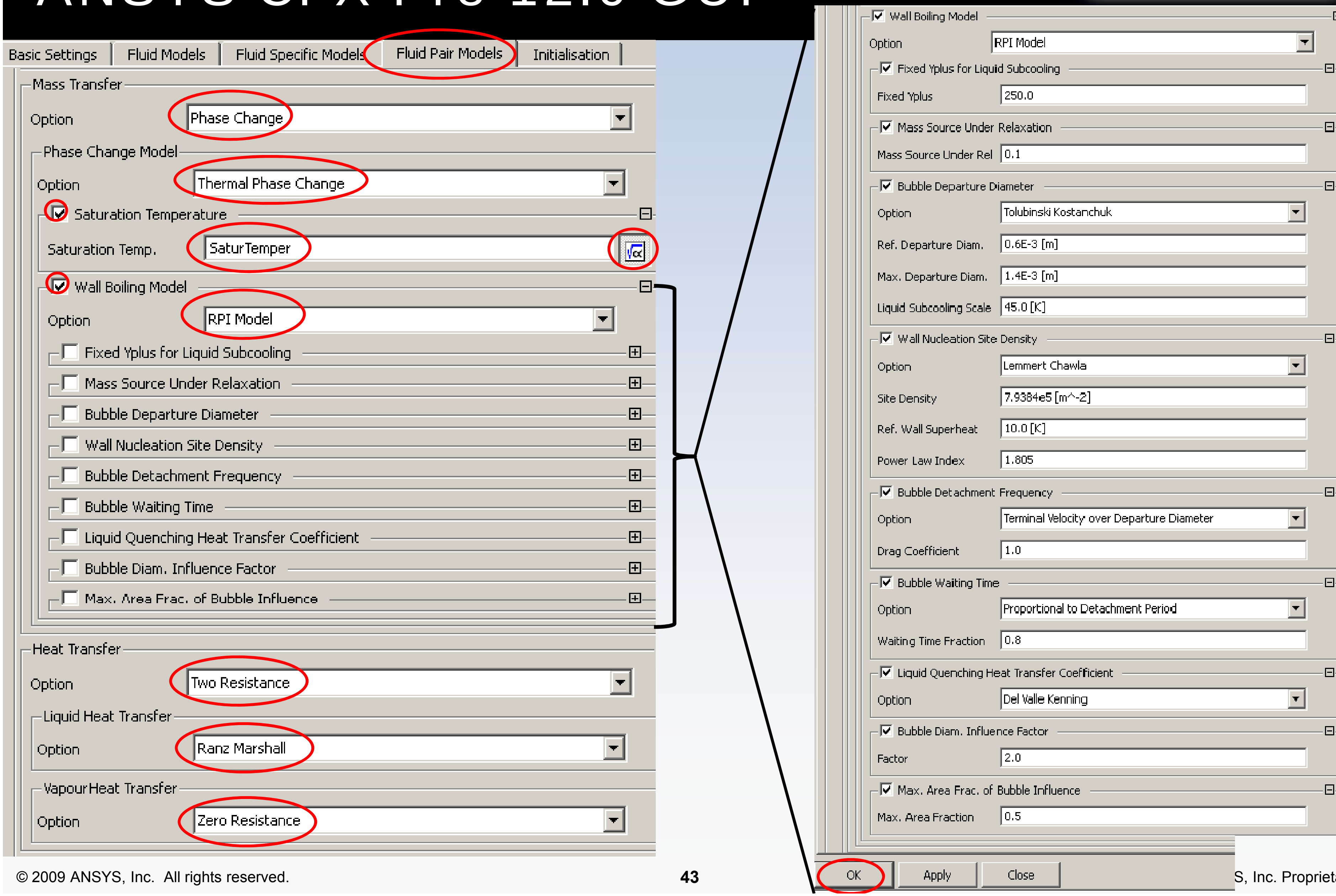
RPI-Wall Boiling Model – Submodels for Model Closure

Submodels for closure of RPI wall boiling model:

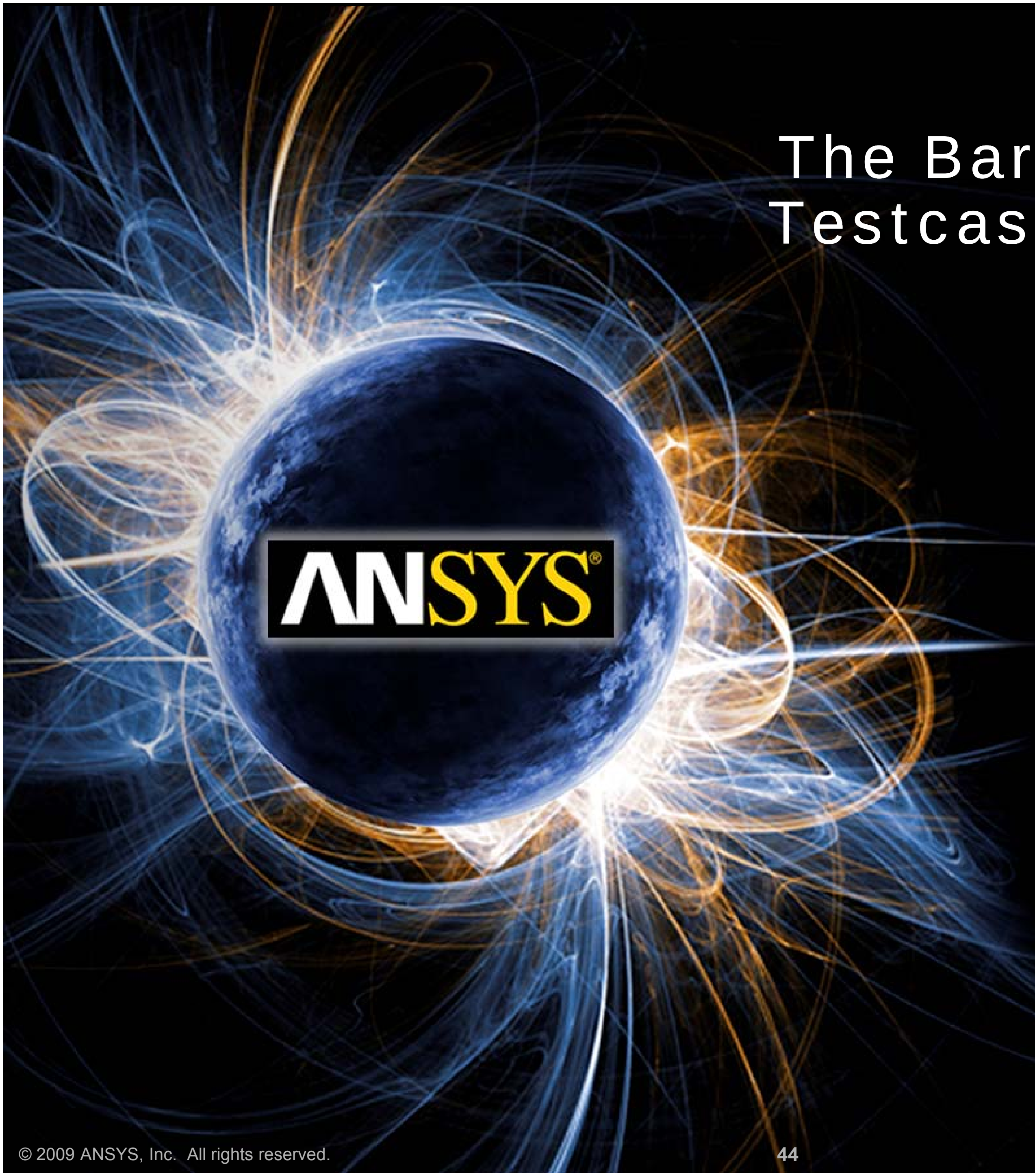
- Nucleation site density: Lemmert & Chawla , User Defined
- Bubble departure diameter:
  Tolubinski & Kostanchuk, Unal, Fritz, User Defined
- Bubble detachment frequency:
  Terminal rise velocity over Departure Diameter, User Defined
- Bubble waiting time:
  Proportional to Detachment Period, User Defined
- Quenching heat transfer: Del Valle & Kenning, User Defined
- Turbulent Wall Function for liquid convective heat transfer coefficient

- **Correlation for bulk flow mean bubble diameter required:**
  → e.g. Kurul & Podowski correlation via CCL
- **Supported combination of wall boiling & CHT in the solid**
  - GGI & 1:1 solid-fluid interfaces

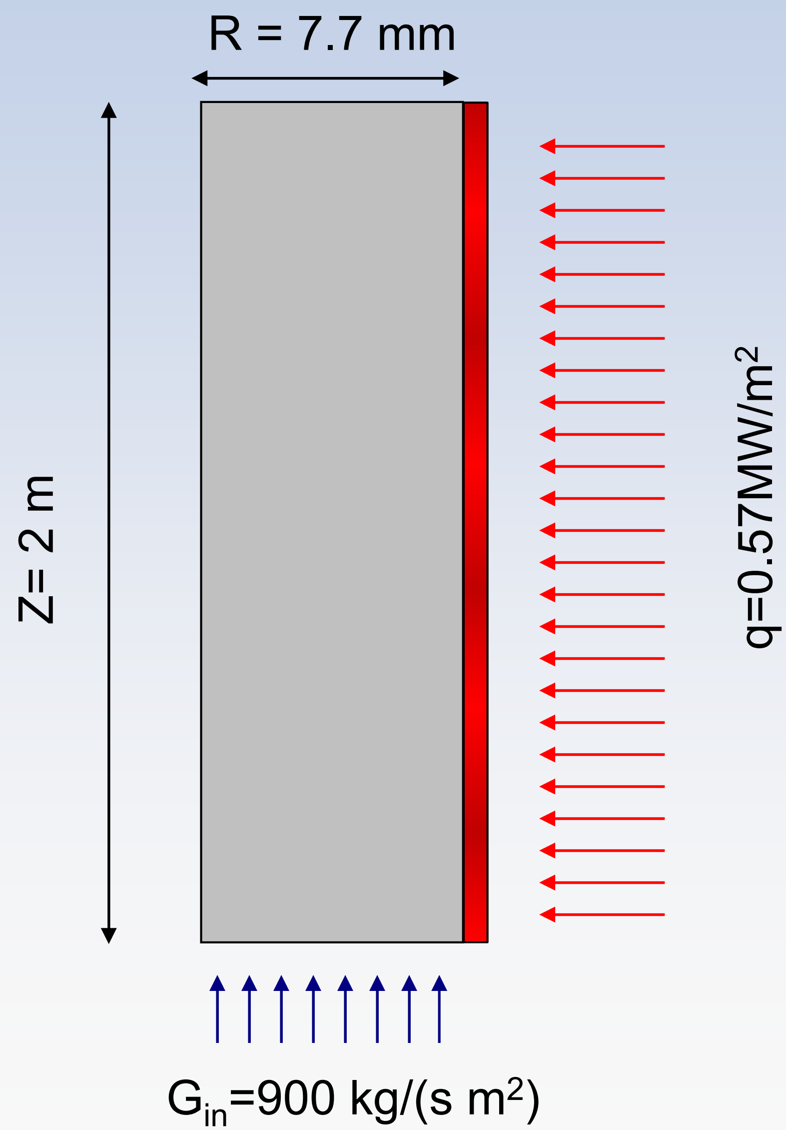
RPI Wall Boiling Model in the ANSYS CFX-Pre 12.0 GUI



The Bartolomej et al. Testcase (1967,1982)



The Bartolomej Test Case



Variable	Value
P	4.5MPa
R	7.7 mm
G_{in}	900 kg/(s m2)
$\dot{q}$	0.57MW/m2
Subcooling	58.2 K

Multiphase Flow Model

- **Steam-Water 2-phase flow:**
  - Water: continuous phase
  - Water Steam: disperse bubbles (particle model)
- **Material properties (EOS):**
  - IAPWS-IF97 water - water steam property tables
- **Modified law for interfacial area**
  - Kurul & Podowski type bulk bubble diameter: $d_B=f(T_{sub})$
  - Accounting for higher volume fraction of the steam phase
- **Turbulence Model**
  - SST turbulence model for continuous phase
  - 0-eq. disperse phase turb. model + Sato bubble induced turbulence

Inter-Phase Mass, Momentum and Energy Transfer

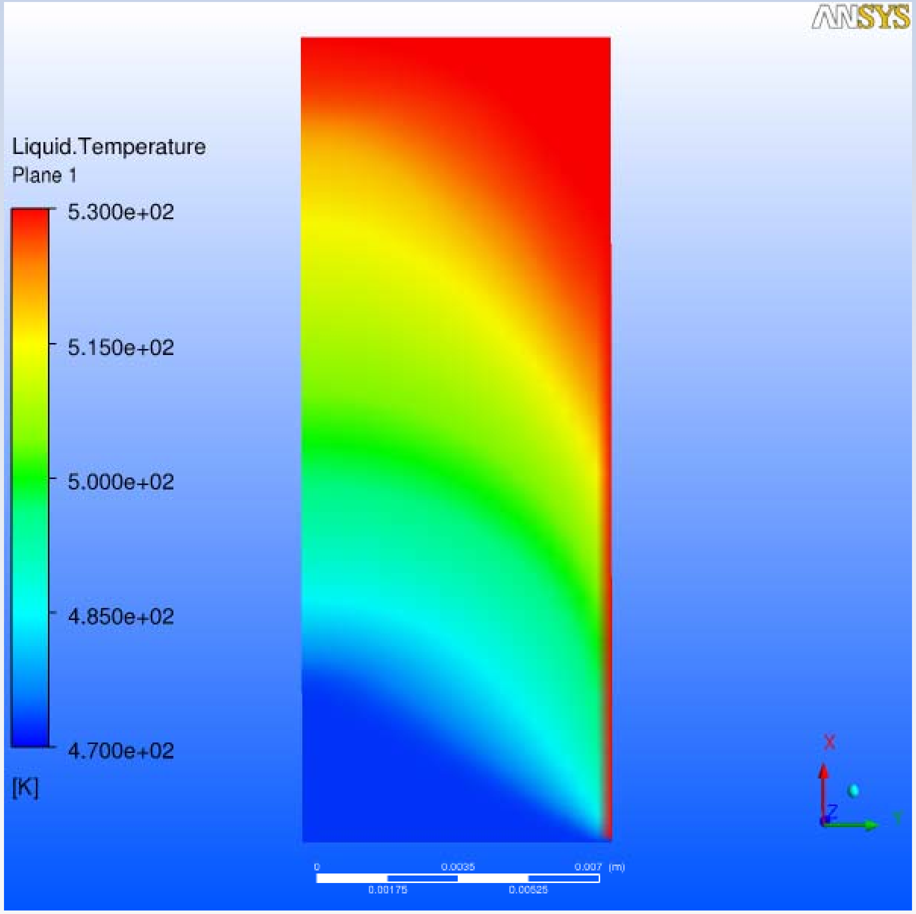
- **Mass transfer model**
  - Thermal Phase Change Model (bulk boiling/condensation model)
  - RPI wall boiling model
- **Momentum transfer models**
  - Grace drag
  - FAD turbulent dispersion force
  - Tomiyama lift force
  - Wall lubrication force (none, Antal, Tomiyama)
- **Heat transfer models**
  - Water: Thermal Energy
  - Water Steam: Saturation temperature
  - Two resistance model
  - Ranz Marshall correlation for bubble heat transfer

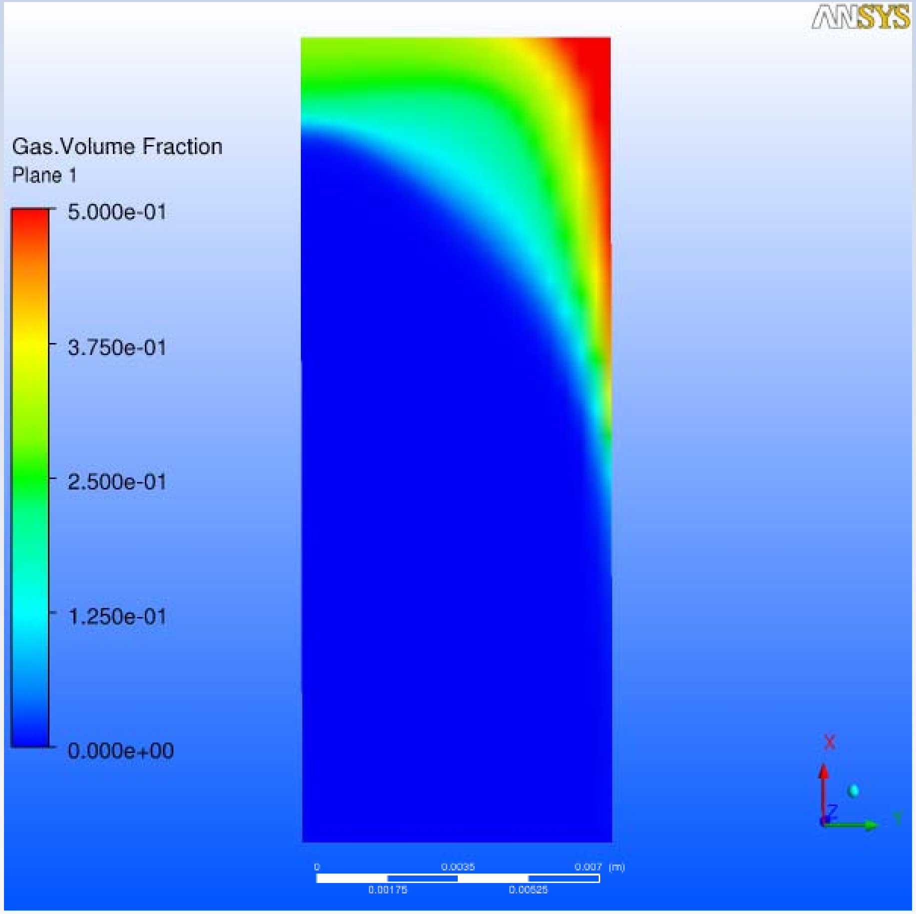
Numerical Grids

- **Validation on mesh hierarchy with regular refinement factor of 4 (2d meshes)**

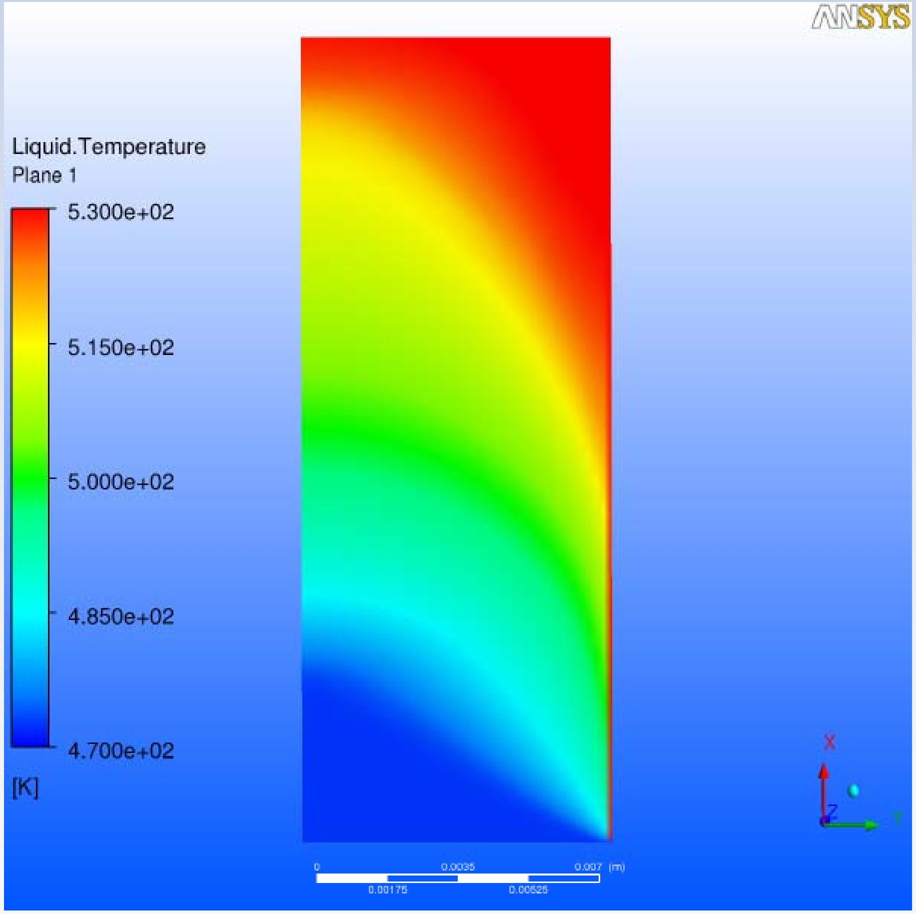
Grid	Grid1	Grid2	Grid3
# Nodes (uniform)	20x150	40x300	80x600
Max y^+	264	133	69
Δt [s]	10^{-2}	10^{-3}	5×10^{-4}

Grid1

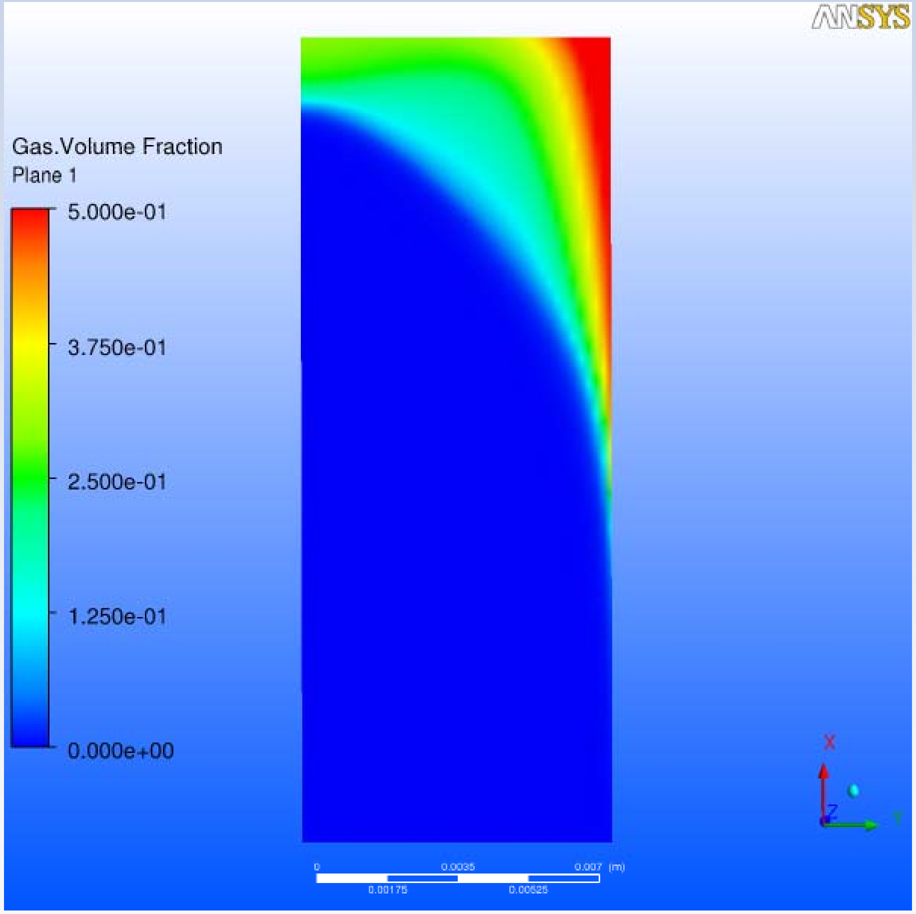

Liquid.Temperature
Plane 1
5.300e+02
5.150e+02
5.000e+02
4.850e+02
4.700e+02
[K]
0
0.0035
0.007 (m)
0.00175
0.00525
X


Gas.Volume Fraction
Plane 1
5.000e-01
3.750e-01
2.500e-01
1.250e-01
0.000e+00
0
0.0035
0.007 (m)
0.00175
0.00525
X

Grid 2

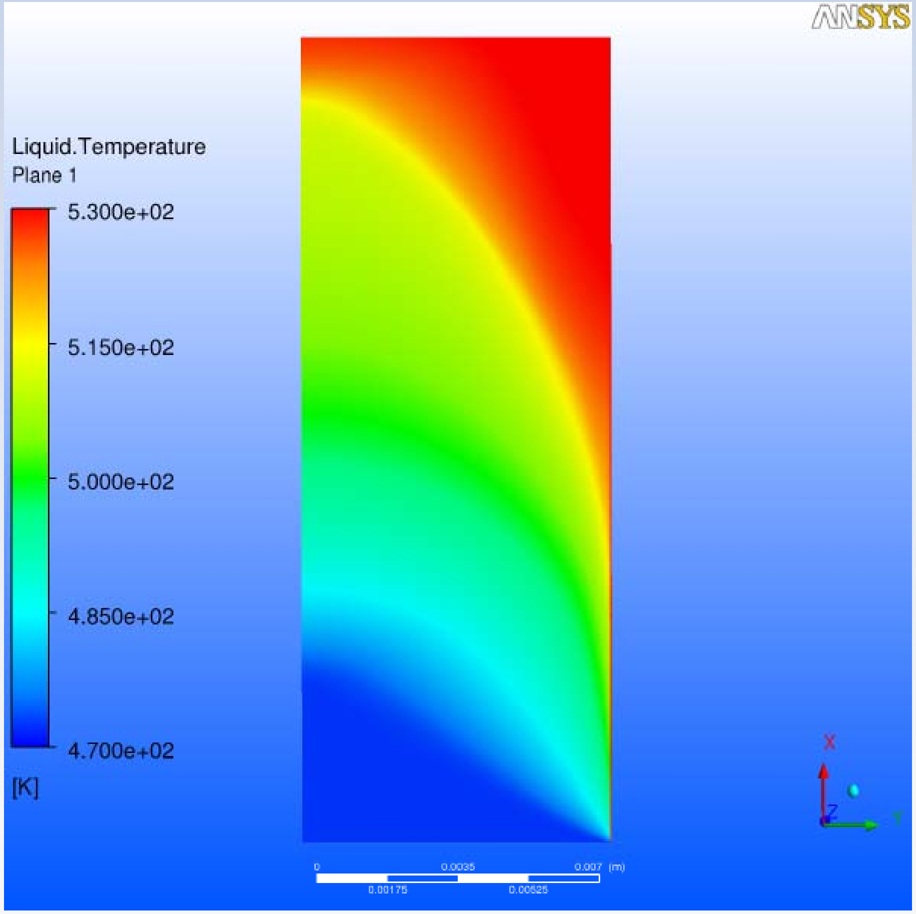


Liquid.Temperature
Plane 1
5.300e+02
5.150e+02
5.000e+02
4.850e+02
4.700e+02
[K]
0
0.0035
0.007 (m)
0.00175
0.00525

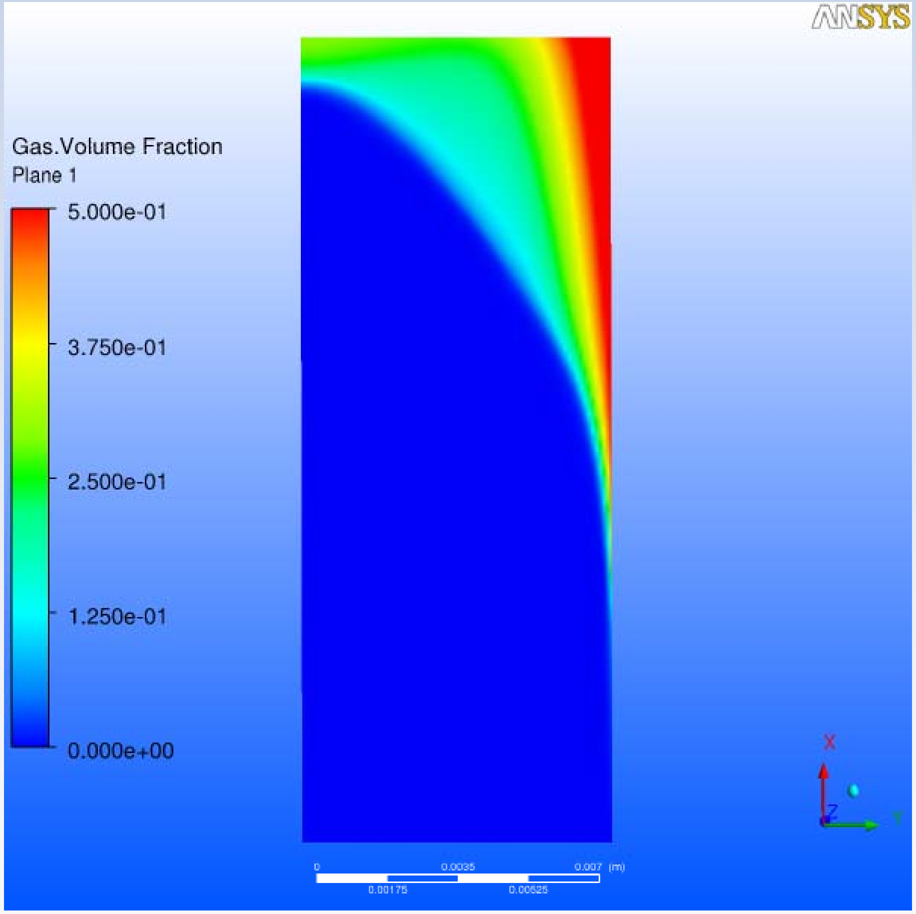


Gas.Volume Fraction
Plane 1
5.000e-01
3.750e-01
2.500e-01
1.250e-01
0.000e+00
0
0.0035
0.007 (m)
0.00175
0.00525

Grid 3

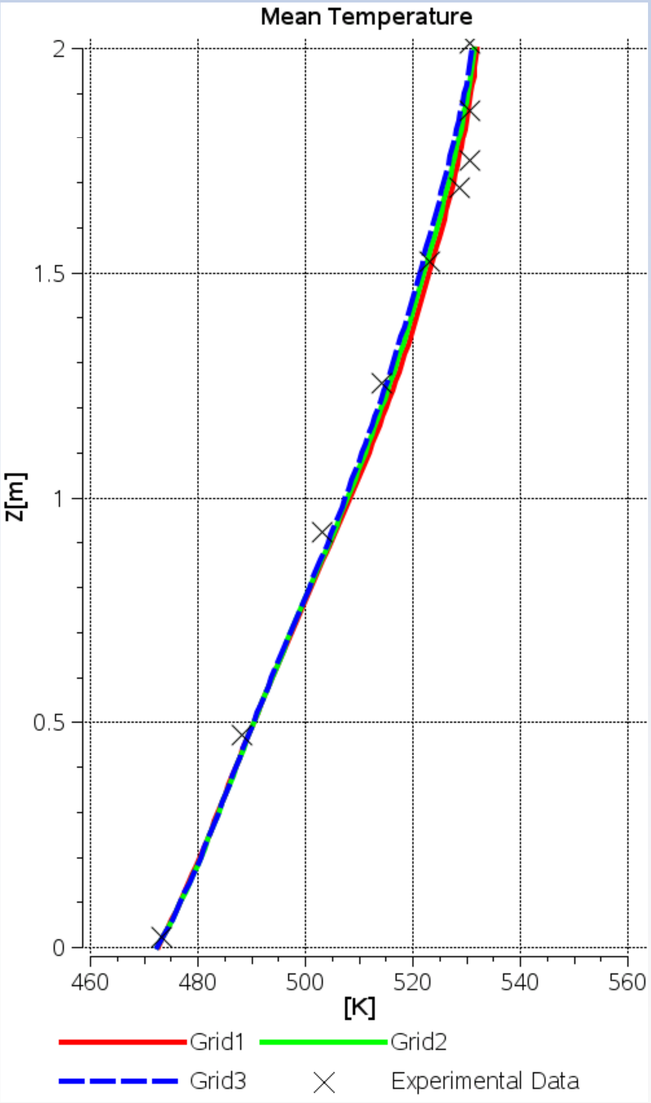


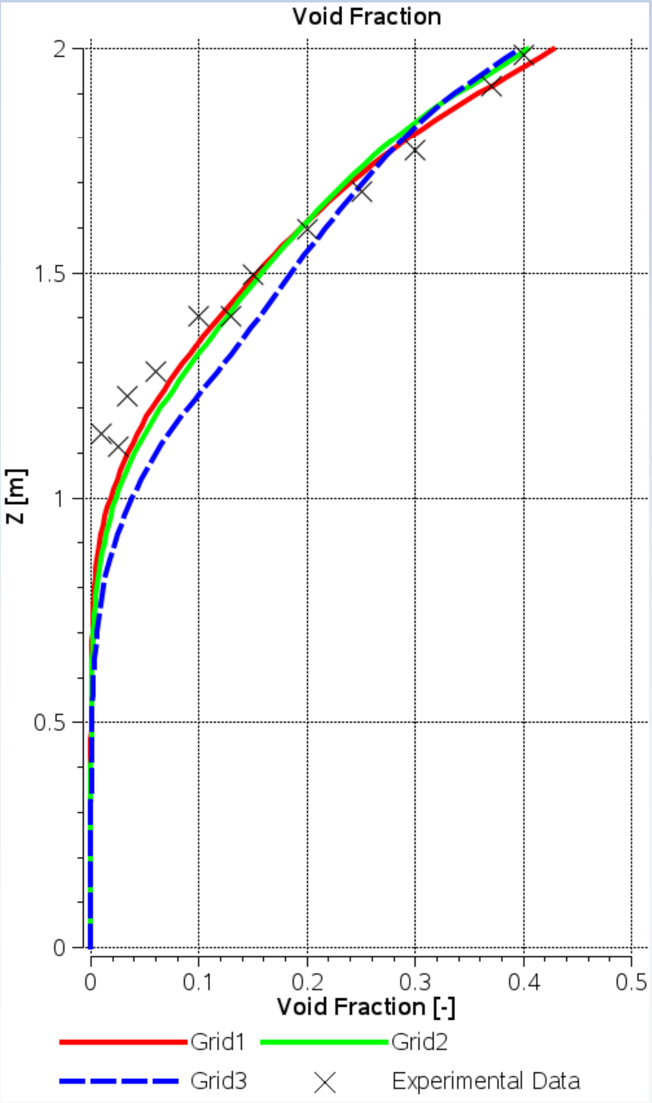
Liquid.Temperature
Plane 1
5.300e+02
5.150e+02
5.000e+02
4.850e+02
4.700e+02
[K]



Gas.Volume Fraction
Plane 1
5.000e-01
3.750e-01
2.500e-01
1.250e-01
0.000e+00

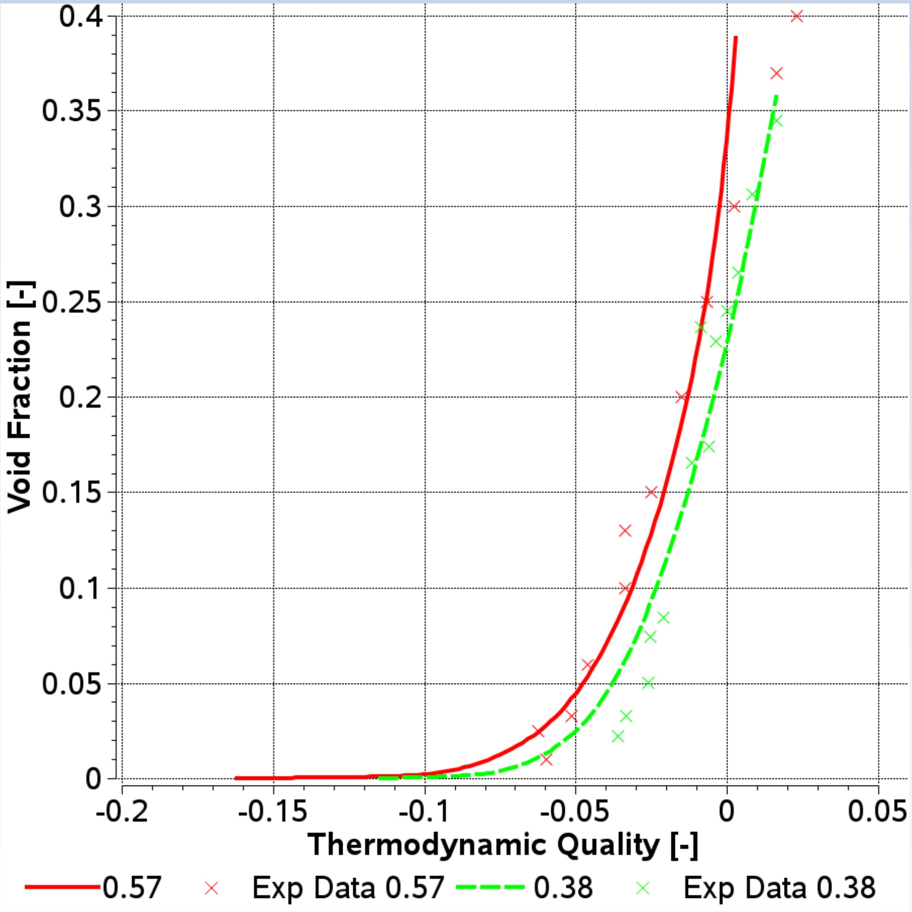
Comparison to Experimental Data



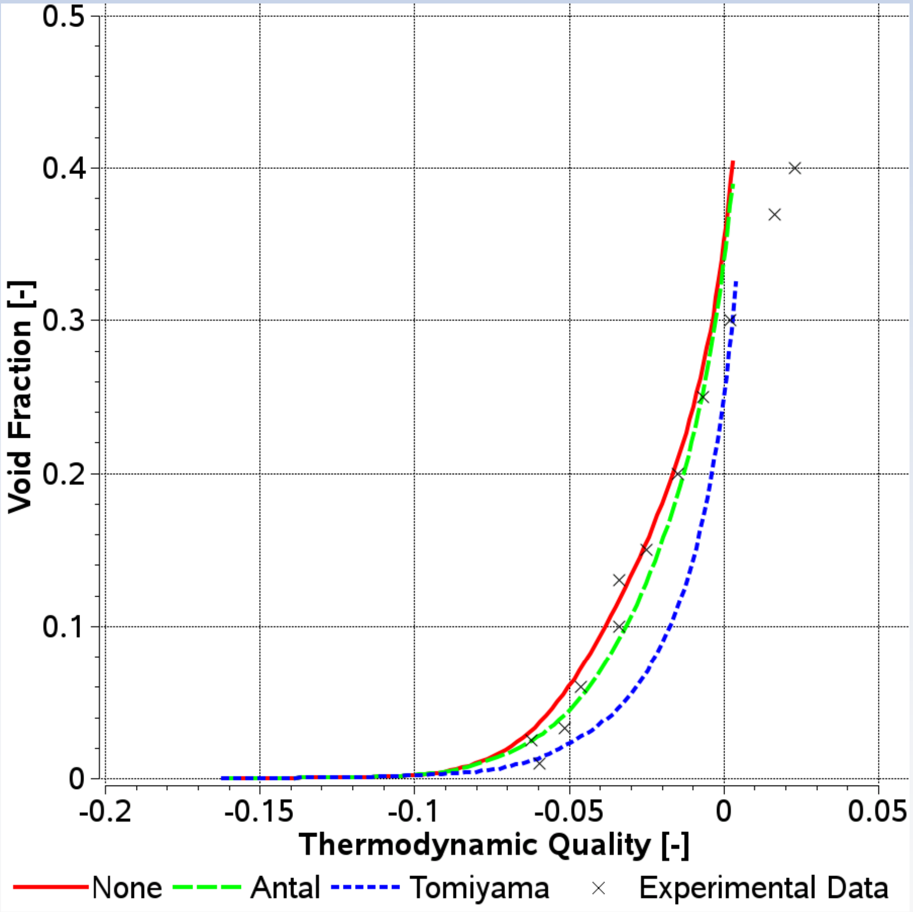


Comparison to Experimental Data - Parameter & Model Variation

Influence of wall heat flux:



Influence of wall lubrication force model:

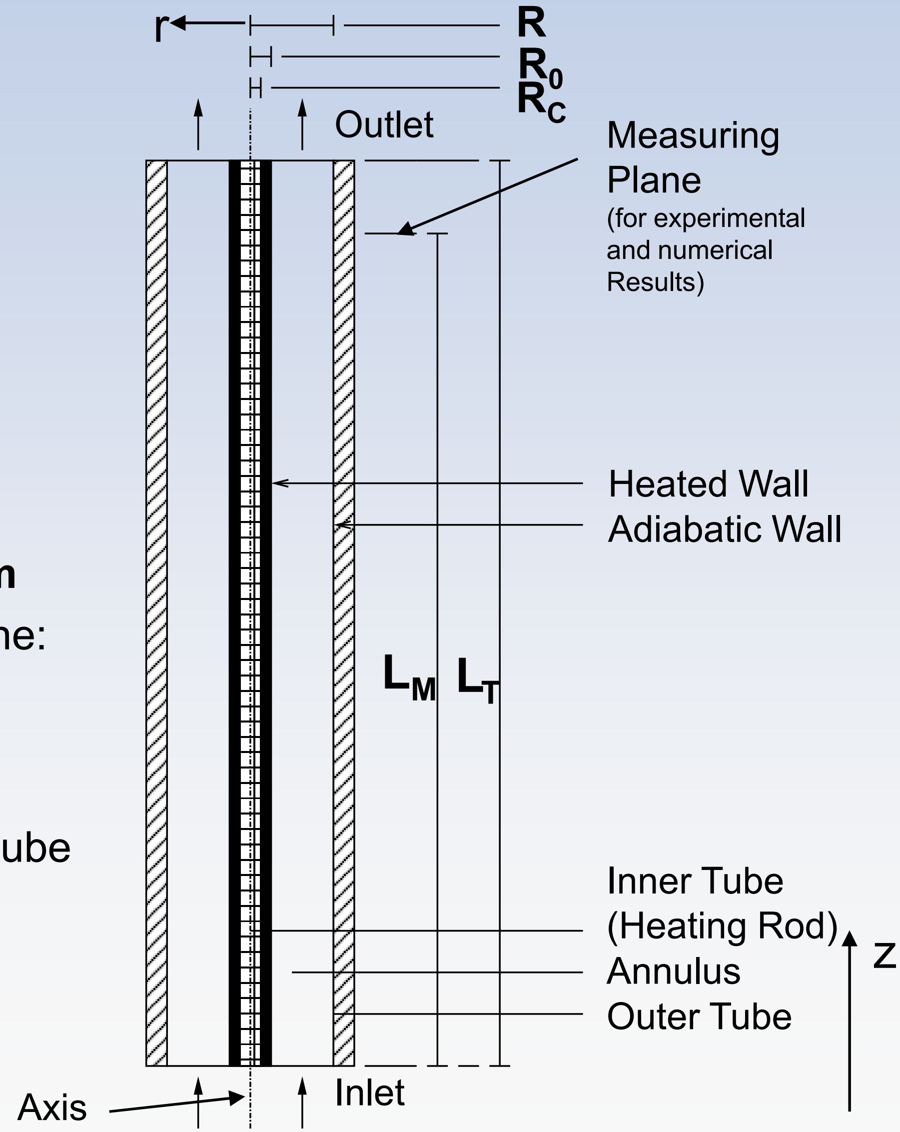


The Lee et al. Testcase (ICONE-16, 2008)

Lee et al. (2008) Testcase

- **Axially symmetric circular annulus**
- **Radial dimensions**
  - Inner radius of outer tube: **R = 18.75 mm**
  - Outer radius of inner tube: **R_0 = 9.5 mm**
  - Core radius: **R_C = 3/4 R_0**
  - Annulus width: **9.25 mm**
- **Axial dimensions**
  - Total heating section height: **L_T = 1670 mm**
  - Distance between inlet and measuring plane: **L_M = 1610 mm**
- **Radial Position: R_P**
  - Dimensionless, radial distance from inner tube (R_P = 0) to outer tube (R_P = 1) across the annulus:

$$R_P = \frac{(r - R_0)}{(R - R_0)}$$



Geometry and Mesh

Geometry & Mesh generation:

Figure 1: 25° segment of the geometry

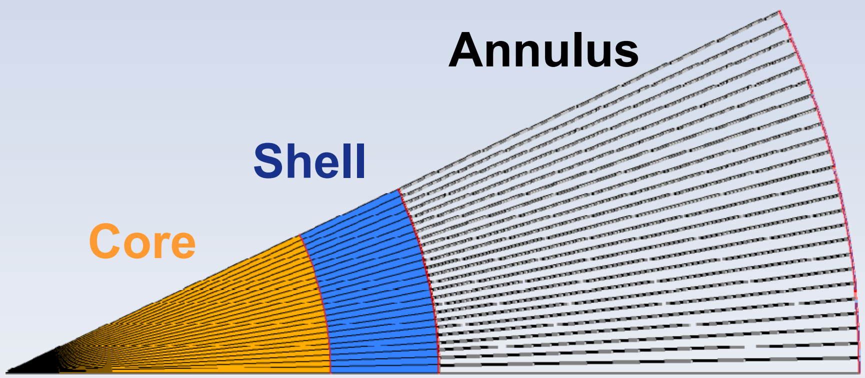


Figure 2: 1° simulated segment of the geometry

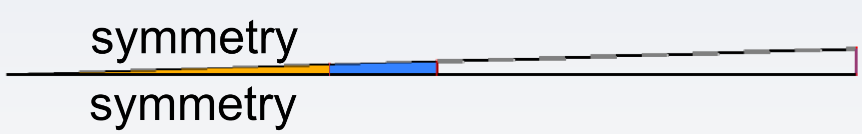


Figure 3: 1° segment with one-layer mesh example

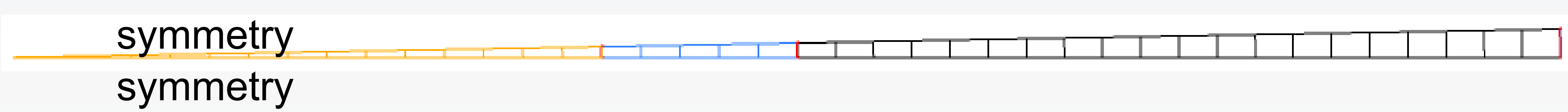
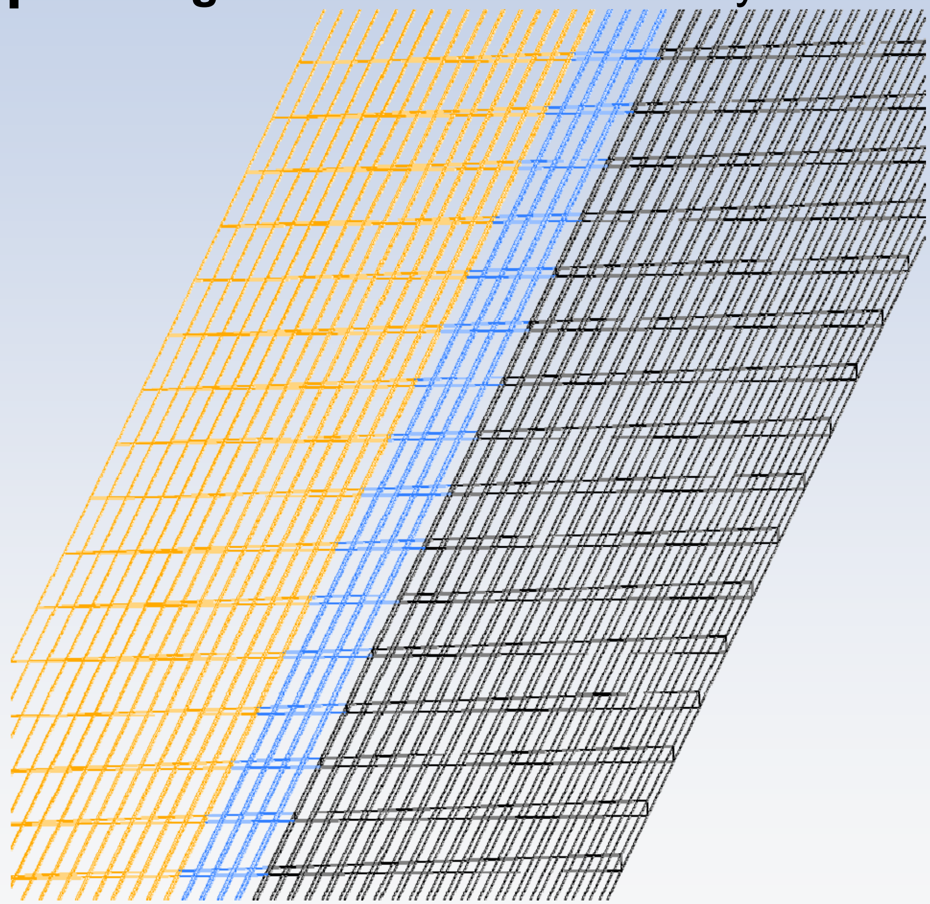


Figure 4: Generated one layer mesh



Mesh Hierarchy

Mesh Name		Grid 01 (coarse)		Grid 02 (medium)		Grid 03 (fine)	
Domains (1 = HFO, 2 = CHT) *		1	2	1	2	1	2
No. of Nodes		1: 6342 2: 12684		1: 24682 2: 49364		1: 97362 2: 194724	
No. of Elements (hexahedra)		1: **20x150** 2: **40x150**		1: **40x300** 2: **80x300**		1: **80x600** 2: **160x600**	
y^+_{max} (at 1st node near wall)	**Set16**	~84		~41		~24	
	Set25	~88		~45		~25	
Tstep Δt [s]	**Set16**	0.001		0.002		0.0002	
	Set25	0.1		0.0125		0.0002	

Selection of Extreme/Limiting Testcase Conditions

ANSYS

- **Concentrating on 2 (out of 12) datasets:**

Set 25
(least of all steam)

Set 16
(most of all steam)

- **Parameter comparison**

Set No.*	q" [kW m^-2]	G [kg m^-2s]	T_{in} [°C]	P_{in} [kPa]
16	320.4	718.8	83.8	121.1
25	220.0	1057.2	90.1	134.4

Required Parameter Modifications in Comparison to PWR Conditions

Found that submodels need modifications for BWR conditions (see also Tu&Yeoh, Anglart et al., Krepper, Koncar):

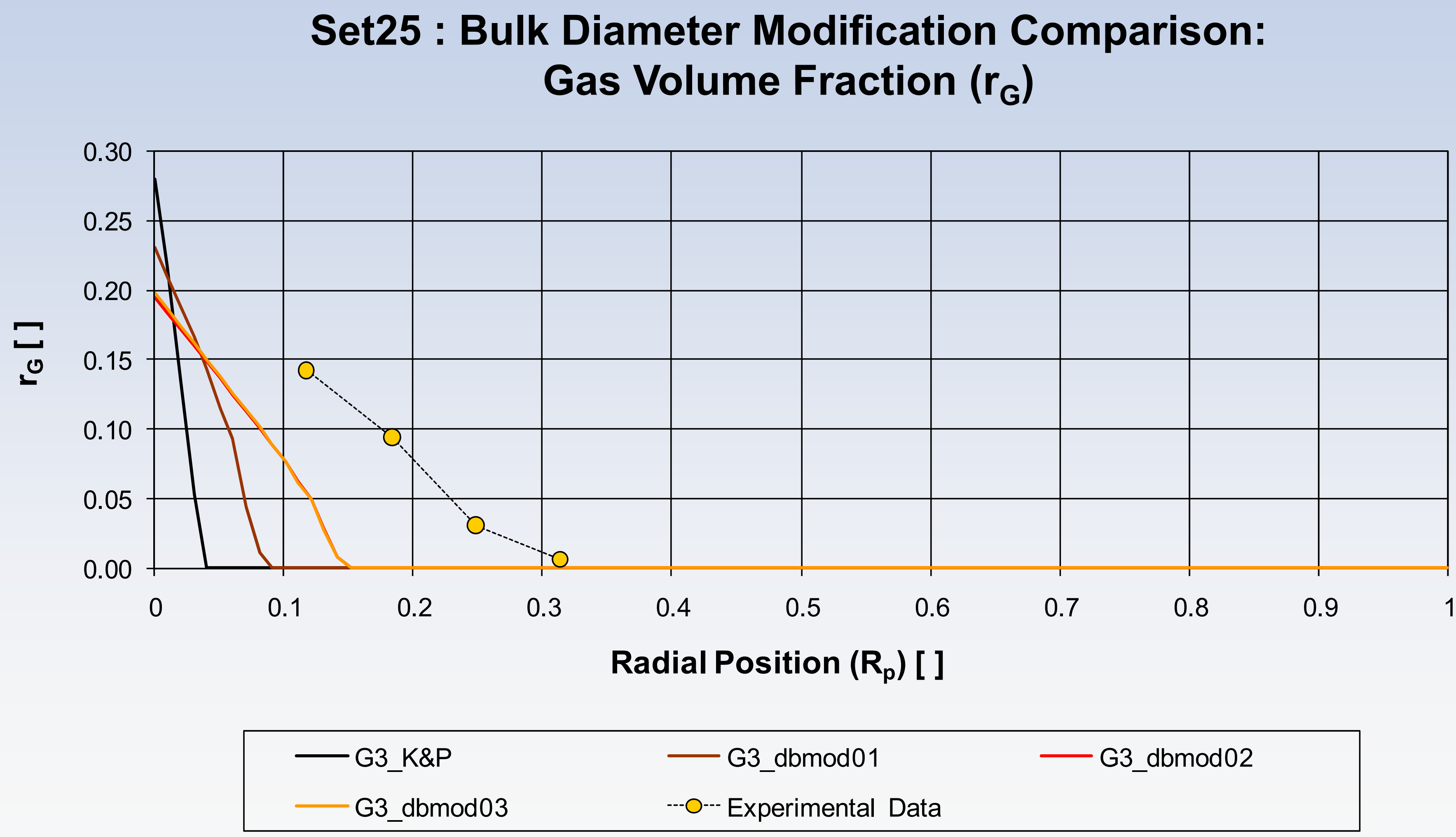
1. **Bulk bubble diameter (BBD)**
   Kurul & Podowski → $d_{B,max}$~1.5mm @ wall
   modified d_B law → $d_{B,max}$~4.0mm @ wall
2. **Bubble departure diameter (BDD)**
   Tolubinski & Kostanchuk → d_W ~0.5mm max.
   const. bubble dept. diam. → d_W =1mm - 3mm
3. **A_2 - Wall area fraction influenced by steam bubbles**
   default → 0.5
   increased up to 2.0

BBD & BDD Modifications Test Matrix Overview

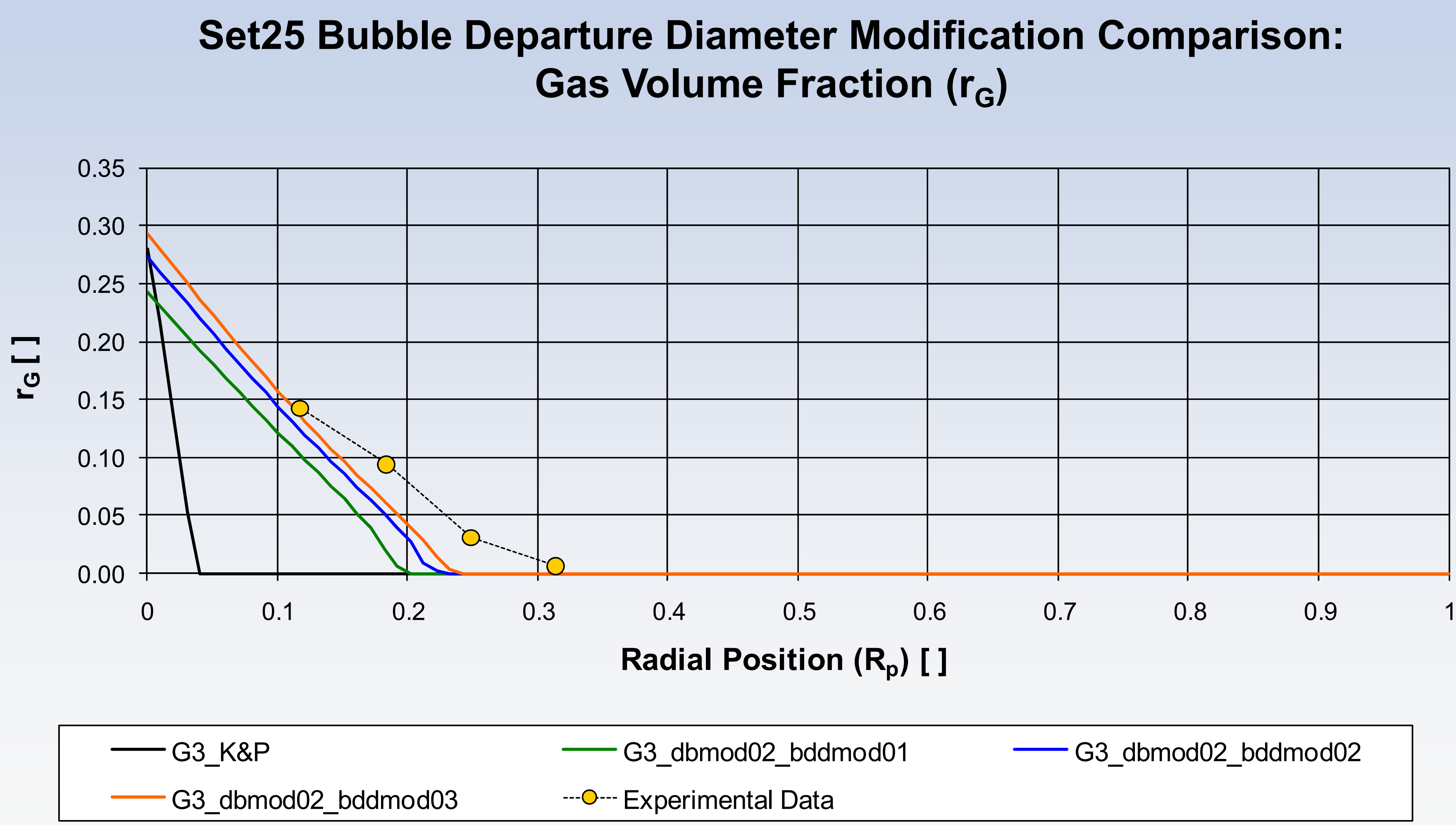
- **Trying to systematically increase Bubble Departure Diameter to investigate its influence on Heat Flux to Vapor (Q_V) profile**
  - → **Test series with increasing BDD starting from $d_{W.max} \approx 0.5$ mm**
  - → 1 mm; 2 mm; 3 mm
  - → T&K * 4.0

	BDD Tolubinsky & Kostanchuk	**BDD User defined d_W [mm]**
K&P	yes	-
bbdmod01	-	1 = const.
bbdmod02	-	2 = const.
bbdmod03	-	3 = const.

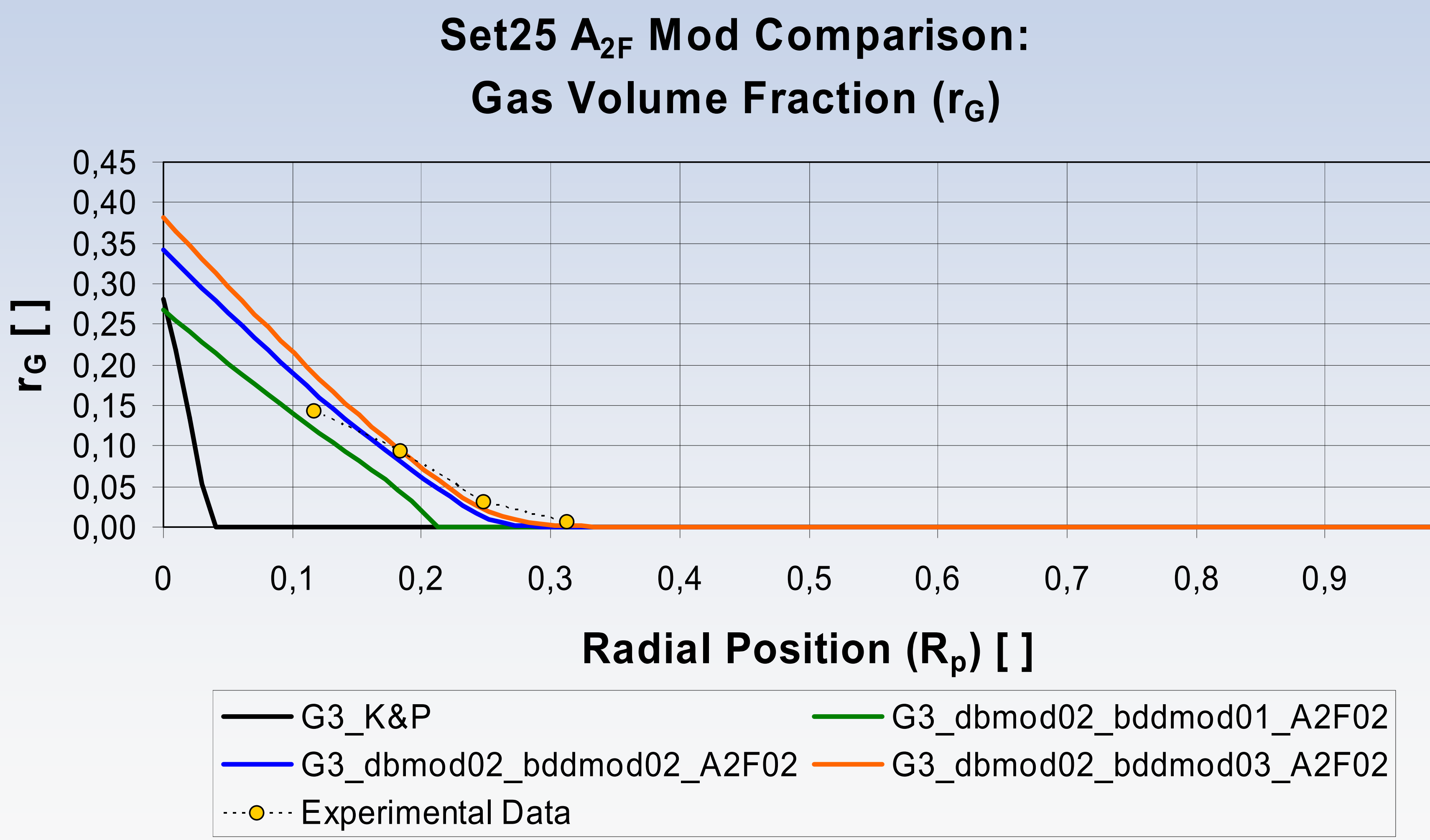
BBD Modification / Set 25:
Gas Volume Fraction @ z = 1610 [mm]



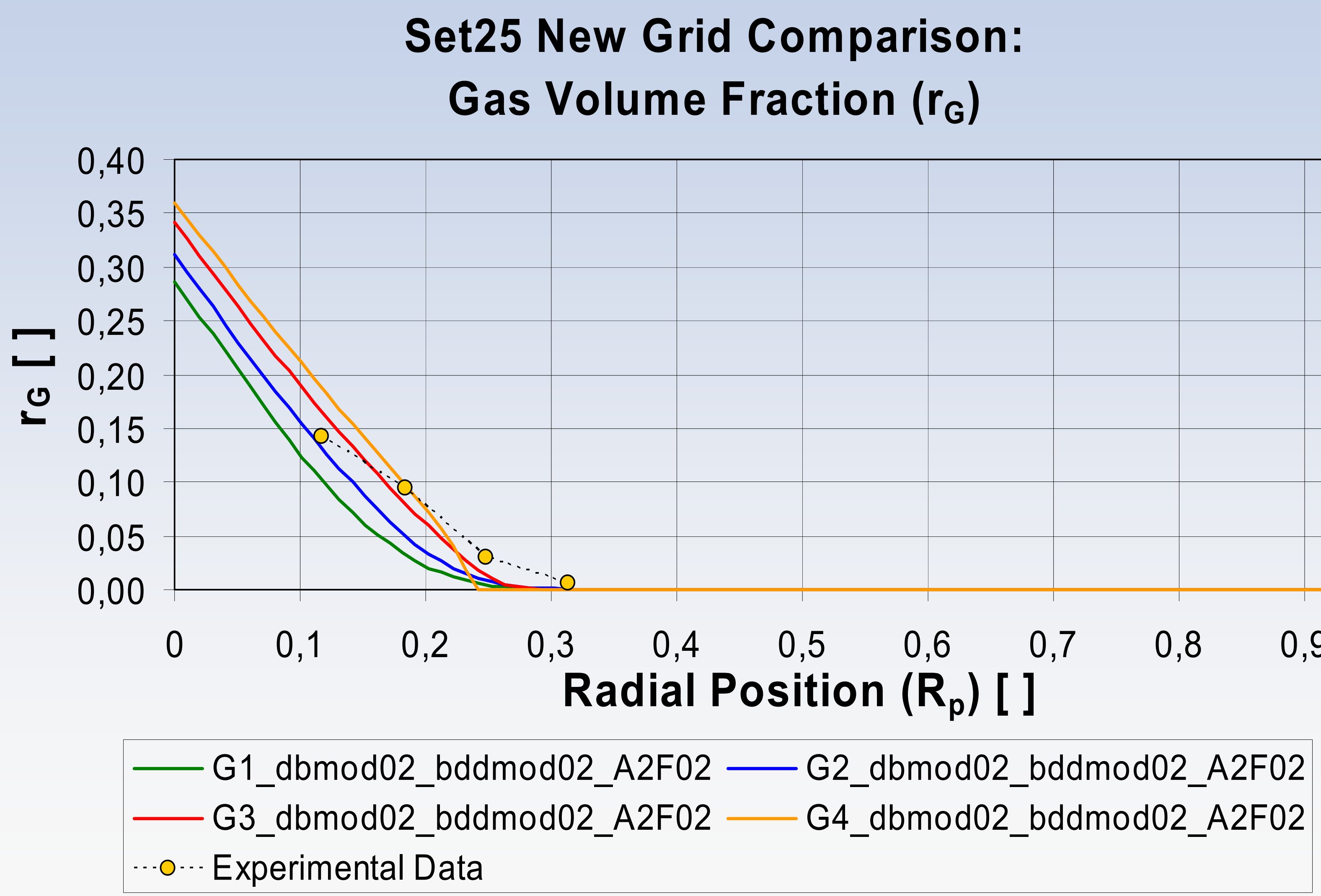
BDD Modification / Set 25: Gas Volume Fraction @ z = 1610 [mm]

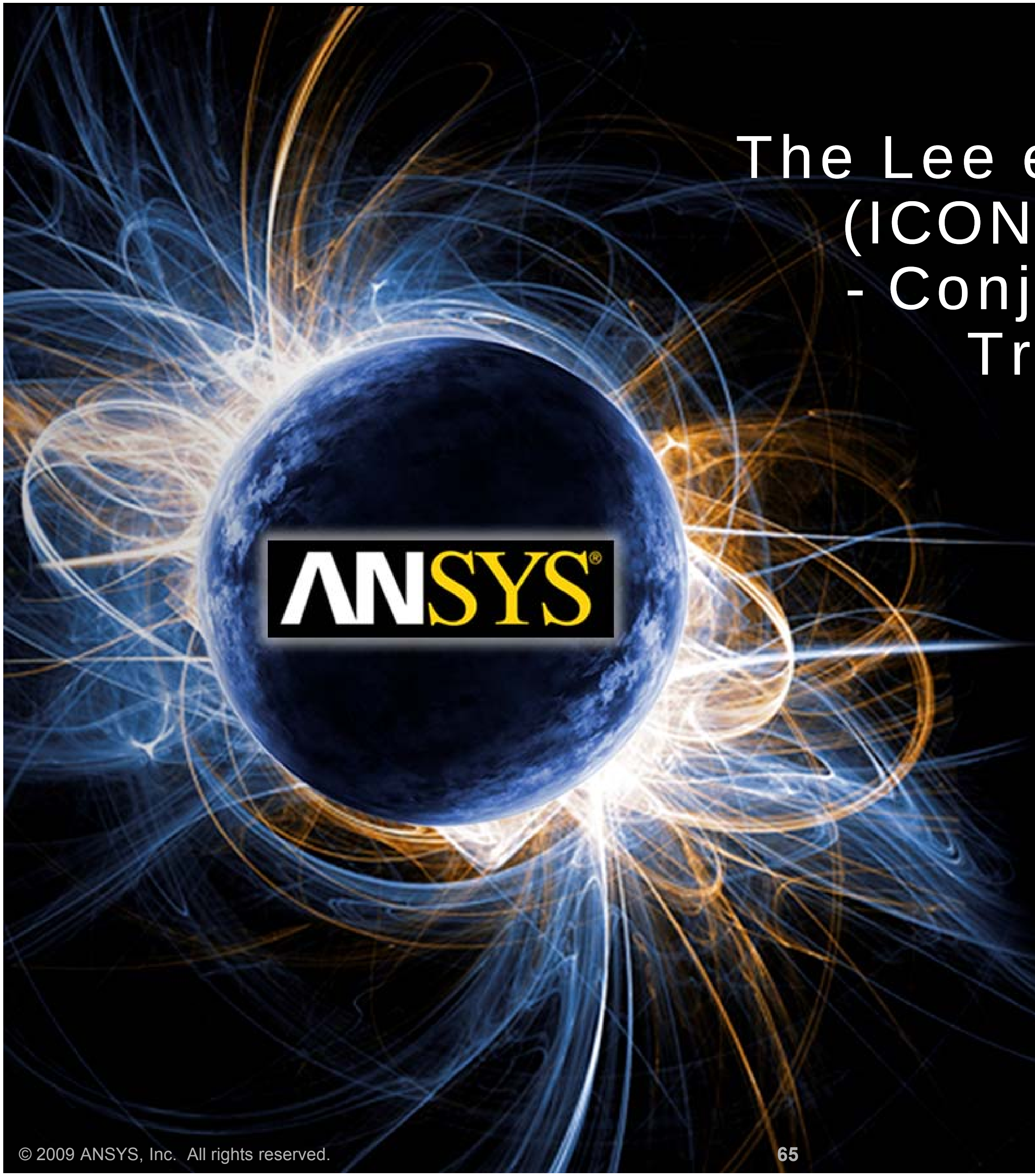


A_{2F} Limiter Modification: Results Set 25, Gas Volume Fraction @ z=1610[mm]



Grid Independency: Results Set 25, Gas Volume Fraction @ z = 1610 [mm]

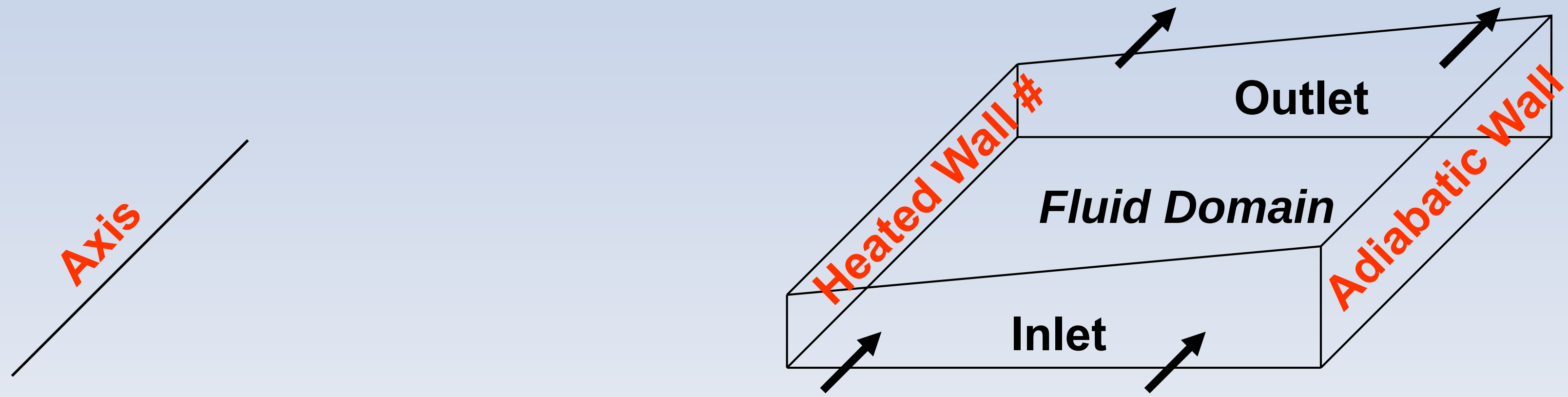




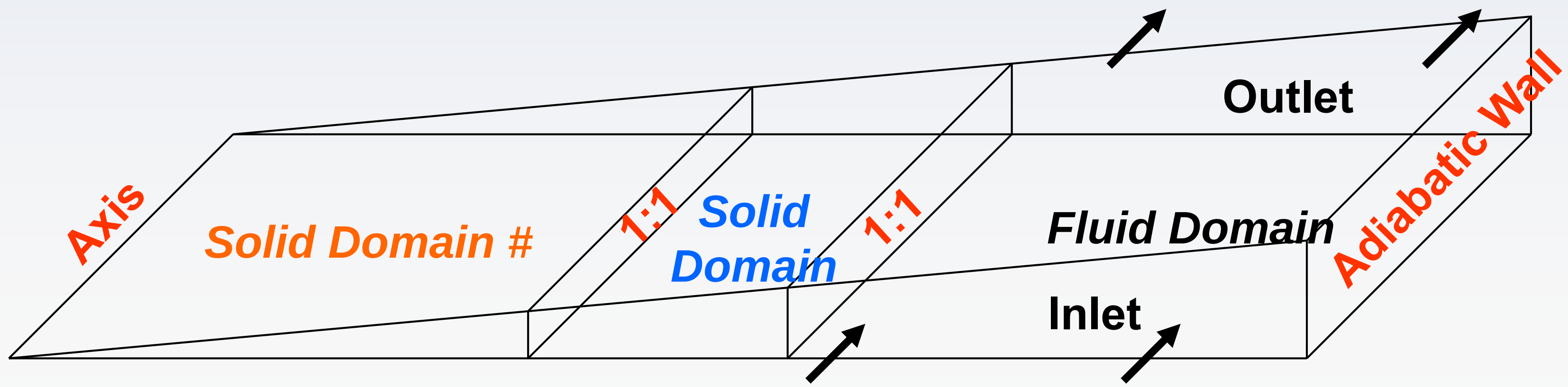
The Lee et al. Testcase (ICONE-16, 2008) - Conjugate Heat Transfer -

Heat Source in Solid Material & Conjugate Heat Transfer Prediction

HFO (Heat Flux Only): Fluid Domain (Annulus) ⟶ area specific heat flux boundary condition #



CHT (Conjugated Heat Transfer): Fluid Domain (Annulus) + ***Solid Domain (Non-Heated Rod Shell)*** +
+ ***Solid Domain (Heated Rod Core)*** ⟶ volume specific heat source #

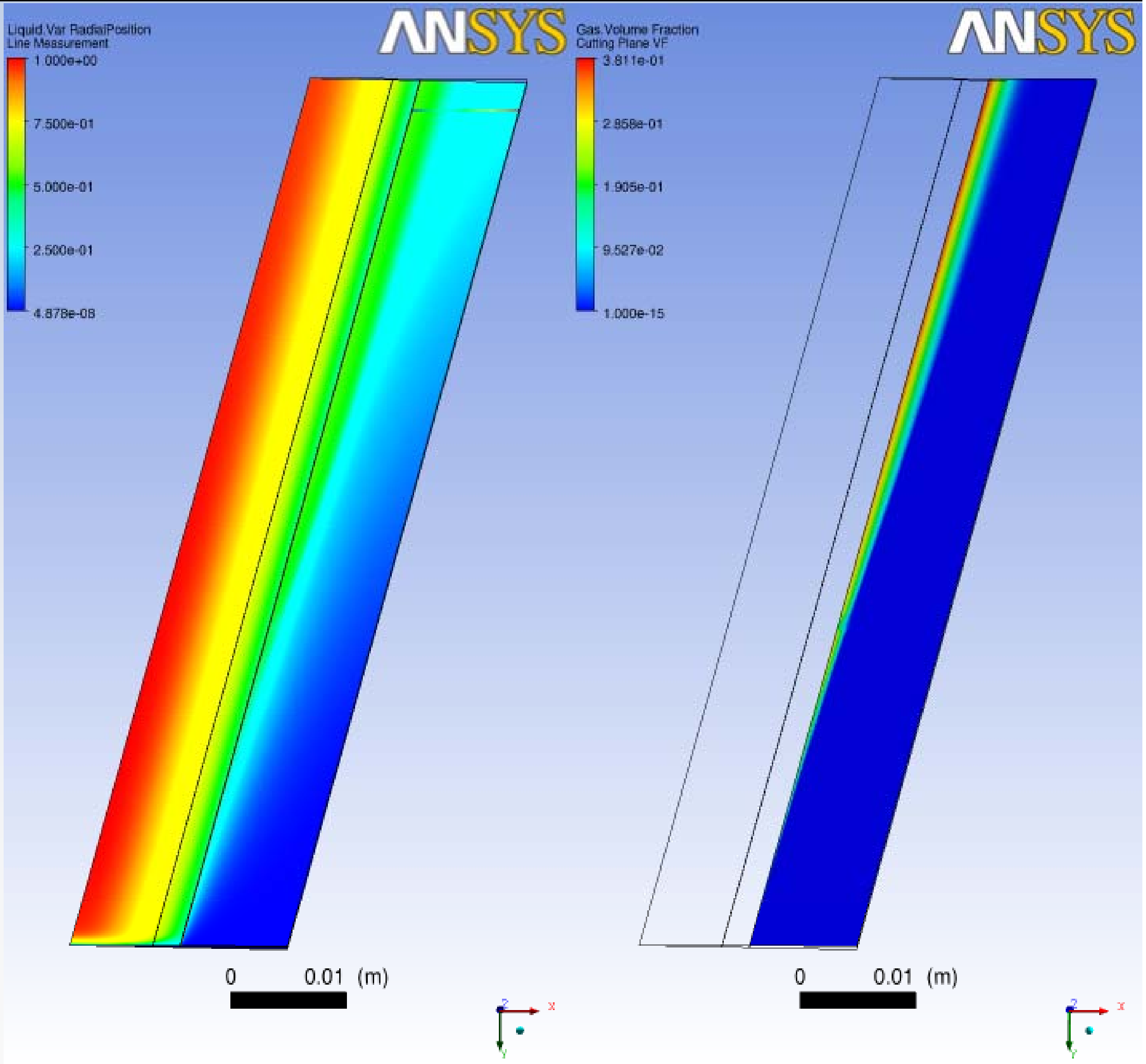


The RPI Wall Boiling Model: Lee et al. Testcase with CHT

- **Specific energy source in solid material, Set25 (equiv. to q_{Wall}):**

  E_{Core}**=8.23·10^{7} [W/m^{3}]**

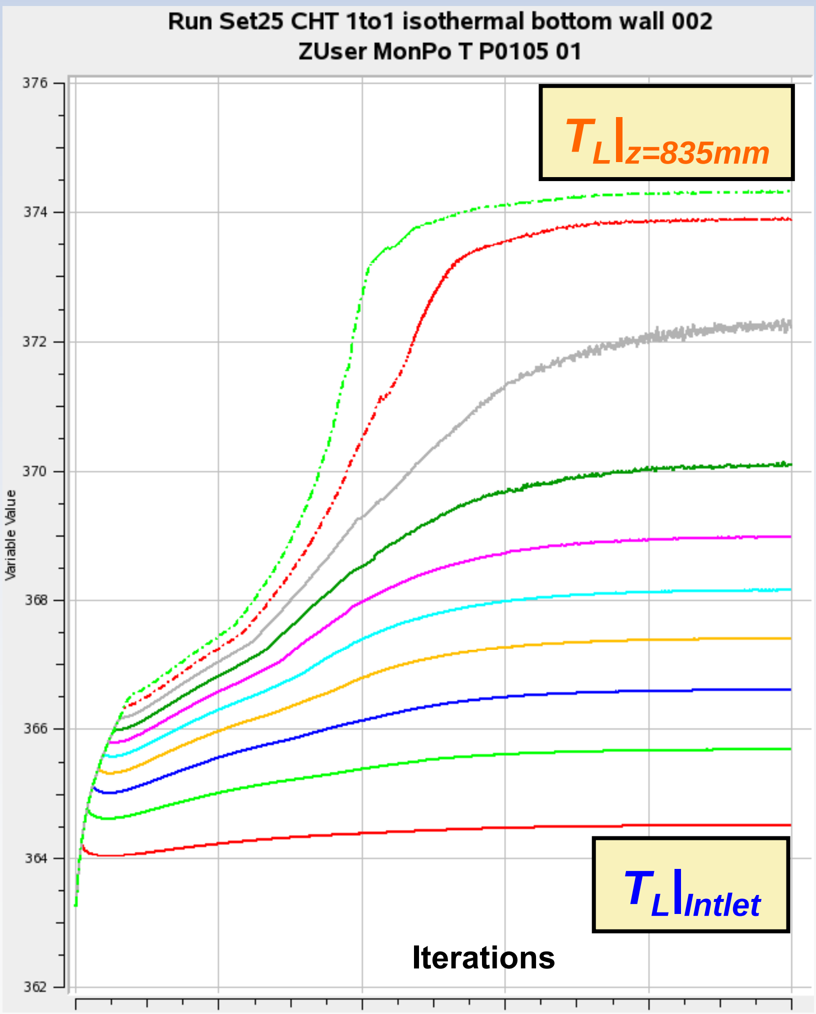
- **Temperature and Steam VF distribution in vertical plane**

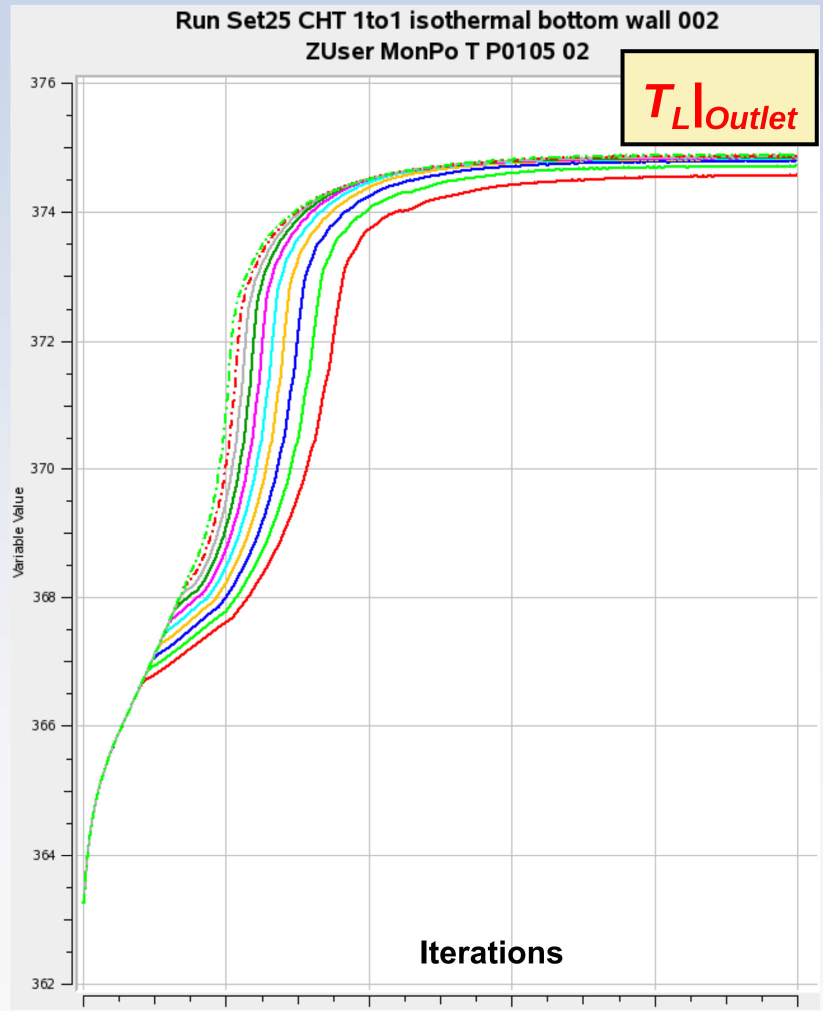


The RPI Wall Boiling Model: Lee et al. Testcase with CHT

ANSYS

Set25 & CHT: Water temperature monitors Δx_W=1.5mm, Δz=83.5mm,

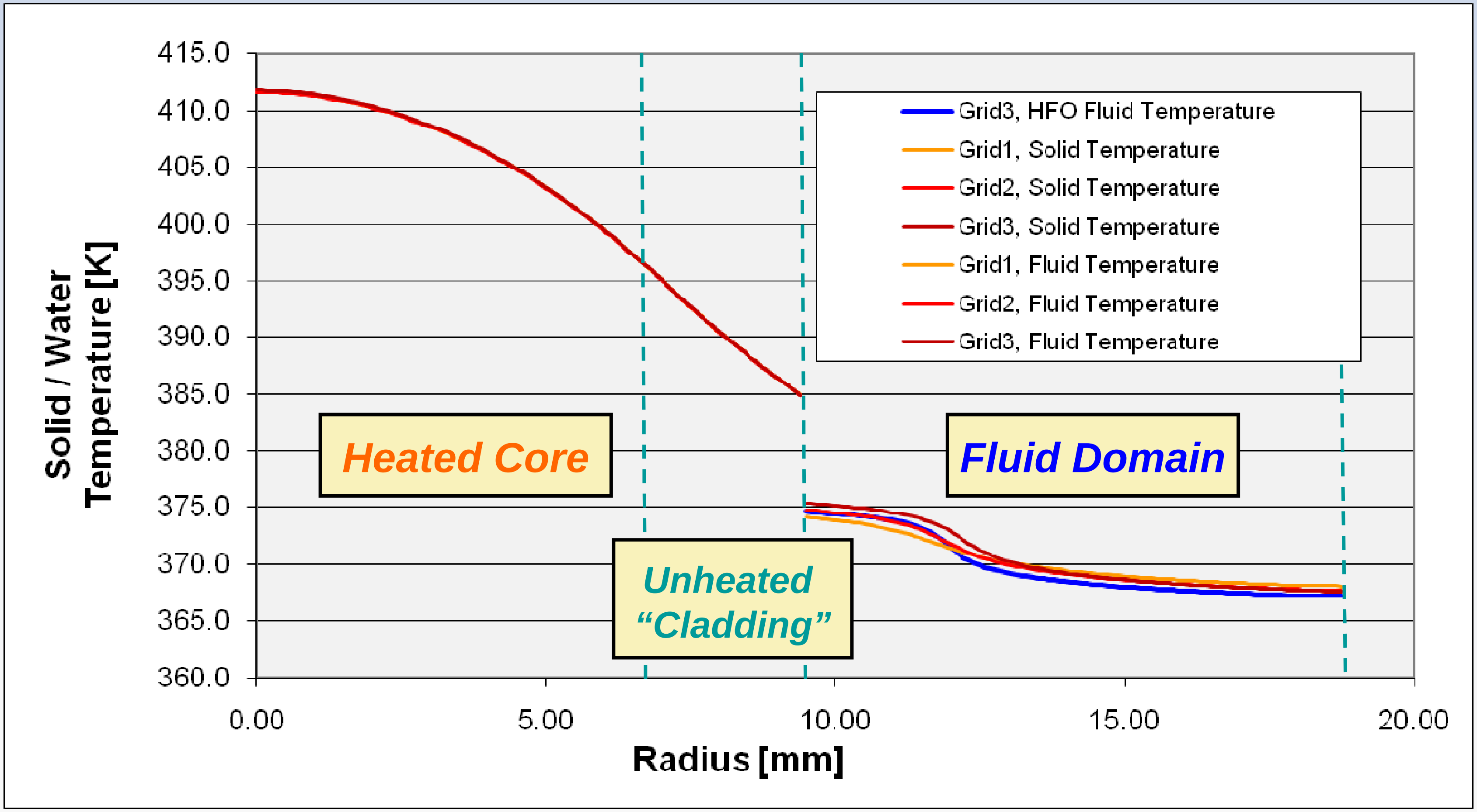




The RPI Wall Boiling Model: Lee et al. Testcase with CHT

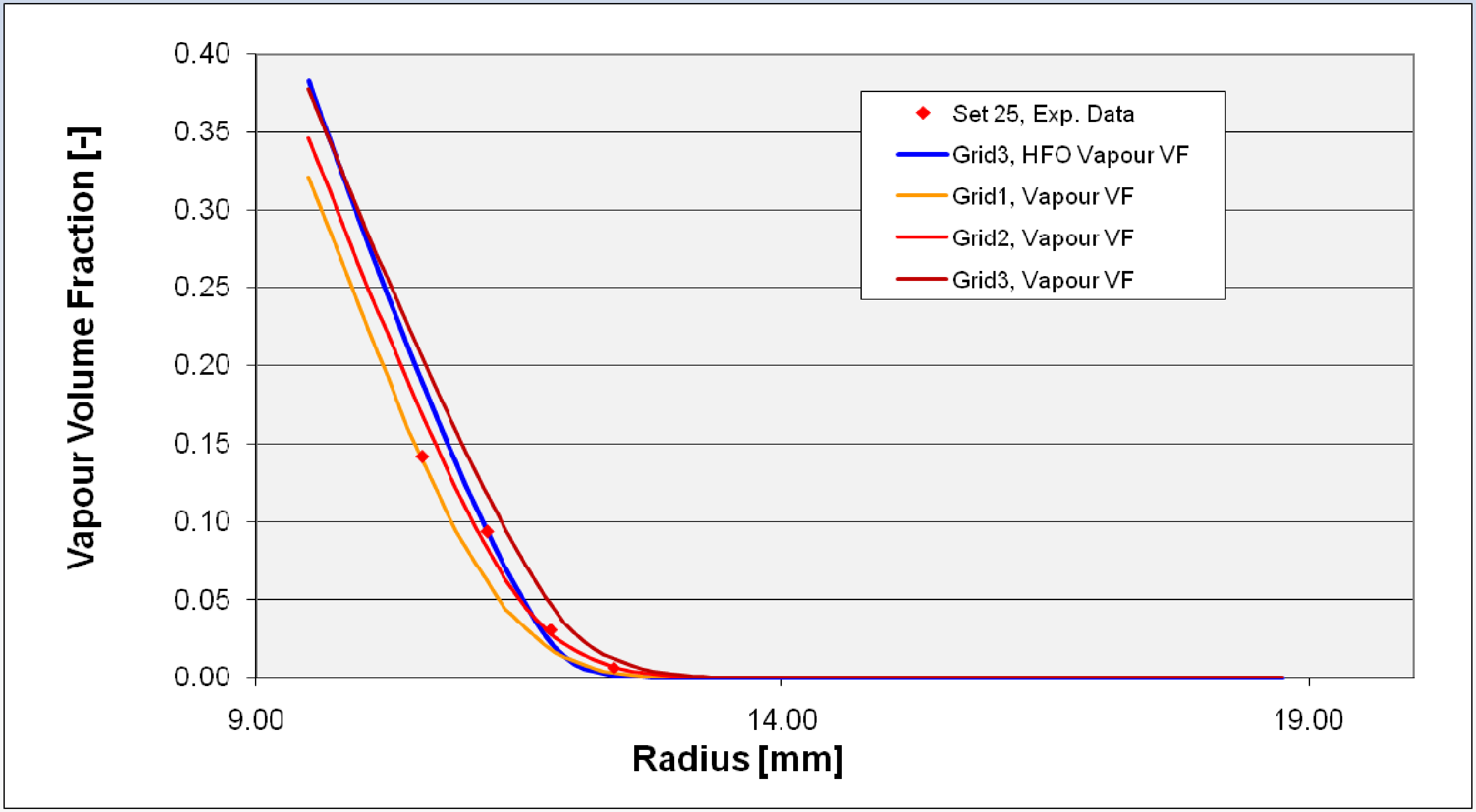
ANSYS

Set25 & CHT: Grid independence for temperature distribution @ z=1610[mm]



The RPI Wall Boiling Model: Lee et al. Testcase with CHT

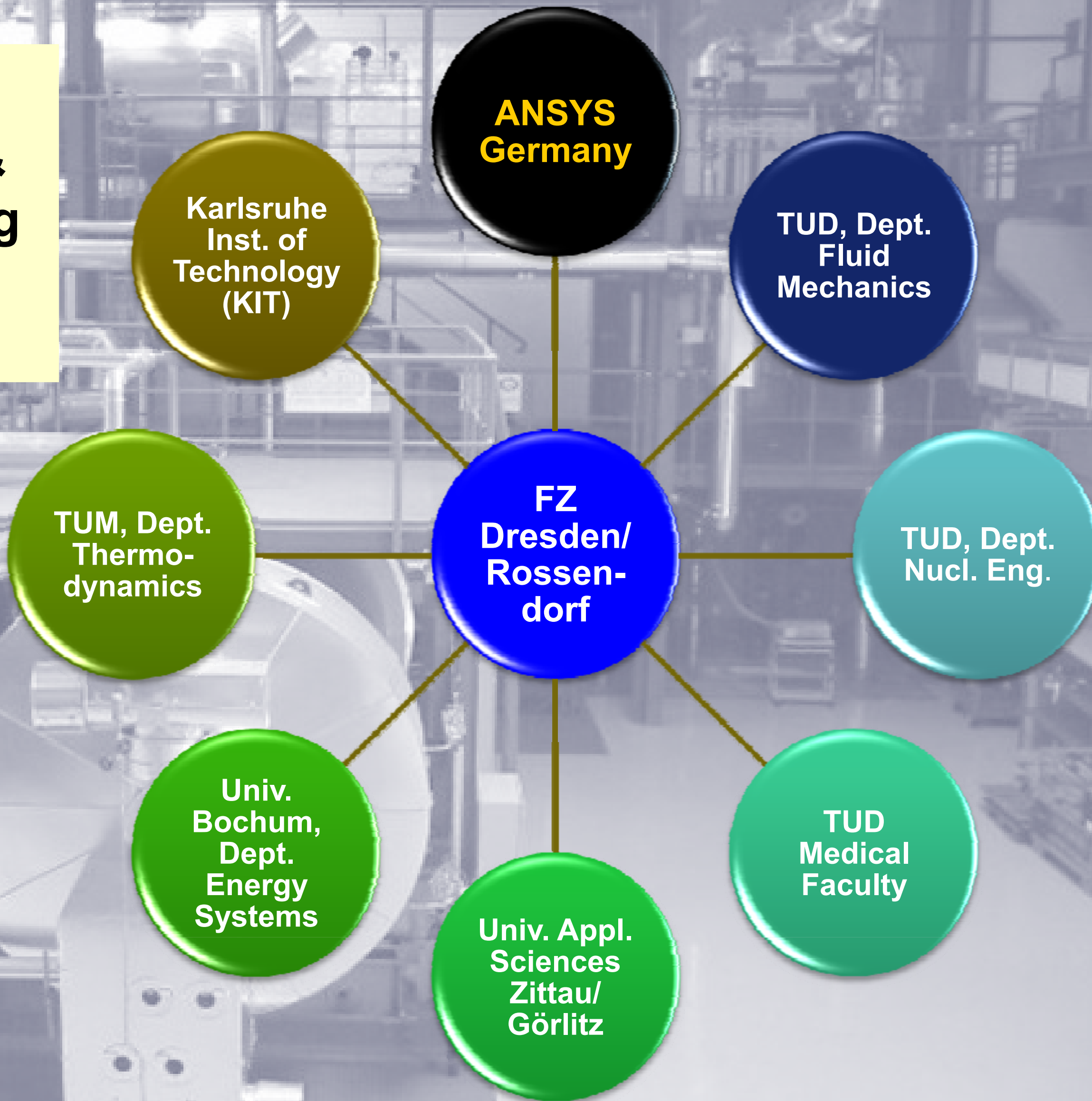
Set25 & CHT: Vapour VF distribution @ z=1610[mm]



New R&D Consortium

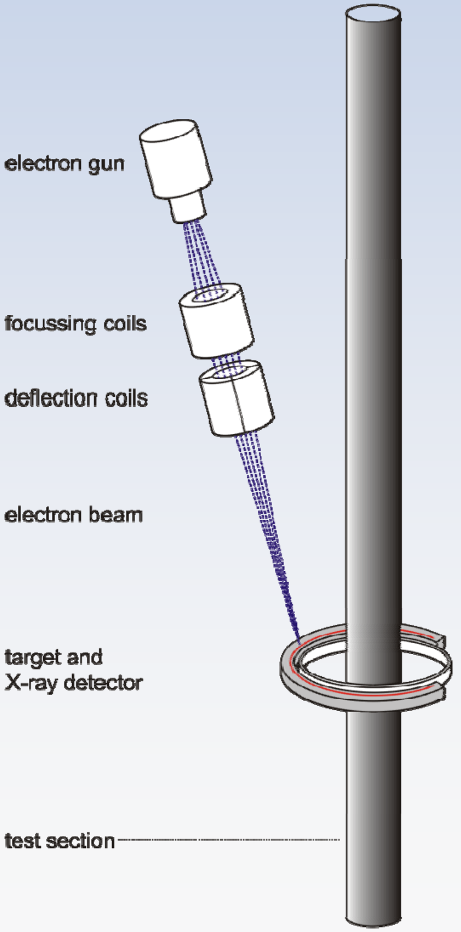
R&D Initiative:

"Modeling, Simulation & Experiments for Boiling Processes in Fuel Assemblies of PWR"



Modeling, Simulation & Experiments for Boiling Processes in Fuel Assemblies of PWR

- **Ultrafast electron beam X-ray CT of fuel rod bundle in titanium pipe on TOPFLOW @ FZD:**

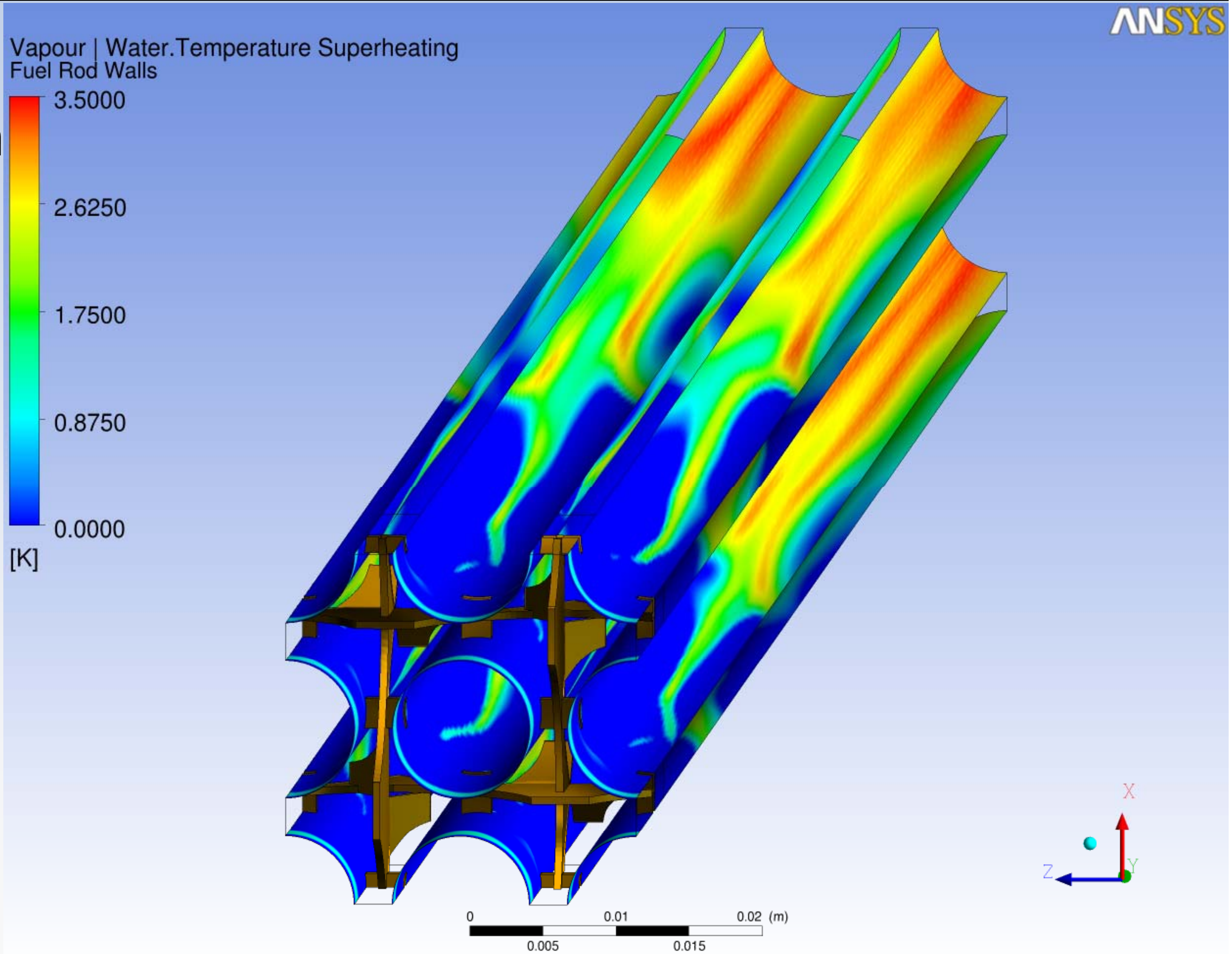


Images by courtesy of U. Hampel, FZD

Modeling, Simulation & Experiments for Boiling Processes in Fuel Assemblies of PWR

Wall boiling simulation in a 3x3 rod bundle with spacer grid:

Wall superheat T_W-T_{Sat}



Summary & Outlook

- **Overview on ANSYS CFD multiphase flow model development and validation**
- **Continuous effort in model improvement, R&D**
- **Emphasis in validation on BPG, comparison to data, geometry & grid independent modeling**
- **High interoperability of physical models**
- **Outlook:**
  - Ongoing & customer driven CFD model development
  - Research cooperation with Industry & Academia
  - More & more complex MPF phenomena
  - Coupling of wall boiling model to inhomogeneous MUSIG
  - Extension of the wall heat partitioning in wall boiling model

Thank You!