# Wall Boiling Modeling and Model Validation in ANSYS CFD

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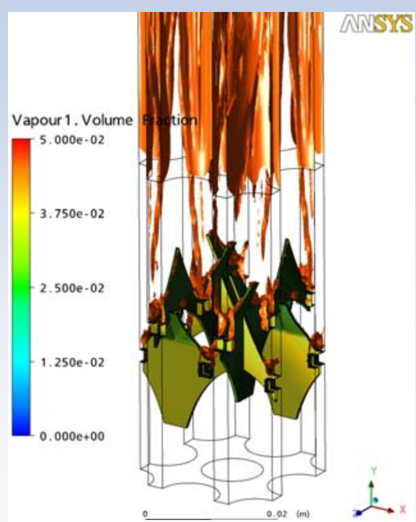
## Outline

- Introduction
- Wall boiling modeling in ANSYS CFD
- Bartolomej testcase (PWR)
- Lee testcase (BWR)
- Wall boiling with conjugate heat transfer
- Wall boiling in fuel assemblies
- Summary & Outlook

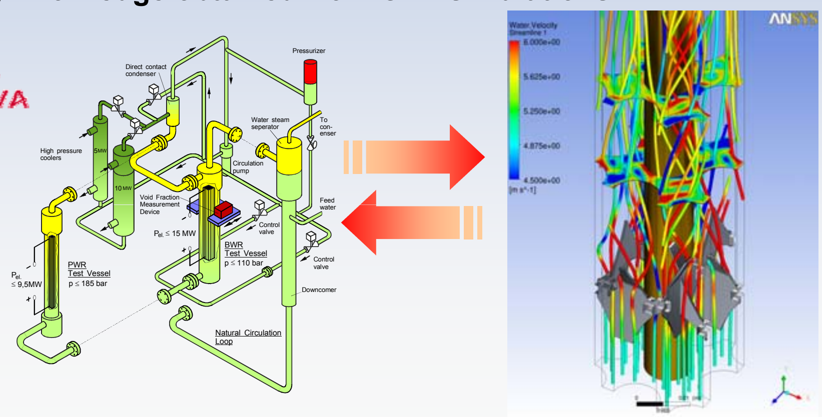


Courtesy by E. Krepper (FZD)

## Introduction – Towards CFD for Flows through Nuclear Fuel Assemblies

- Prediction of boiling flow through fuel assemblies
- Optimization of fuel assembly and spacer grid design
- Replacement/supplementation of very expensive experiments by knowledge obtained from CFD simulations



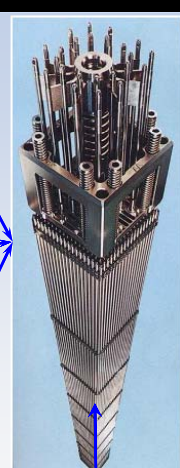

  

## CFD Simulation for Fuel Assemblies in Nuclear Reactors

Material Properties

Turbulence

Multiphase Flow Modeling



Wall Boiling & Bulk Condensation

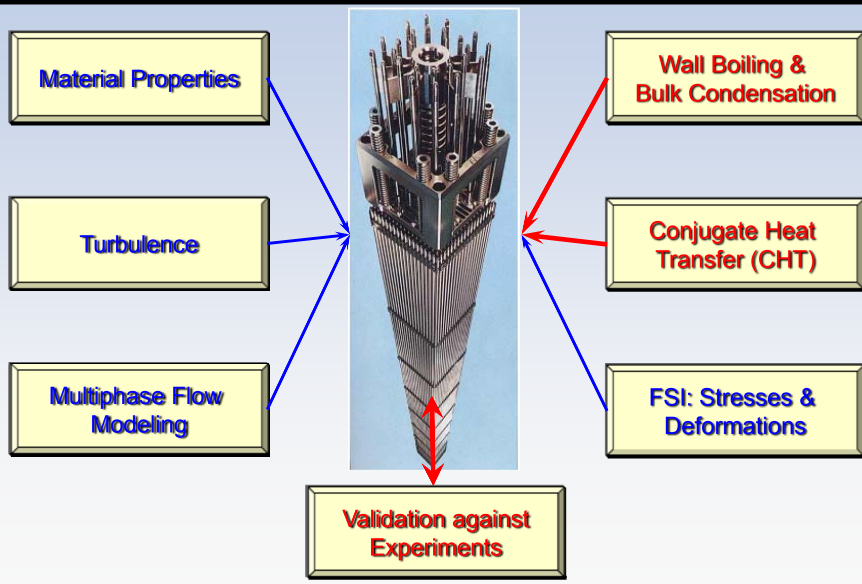
Conjugate Heat Transfer (CHT)

FSI: Stresses & Deformations

Validation against Experiments

## CFD Simulation for Fuel Assemblies in Nuclear Reactors







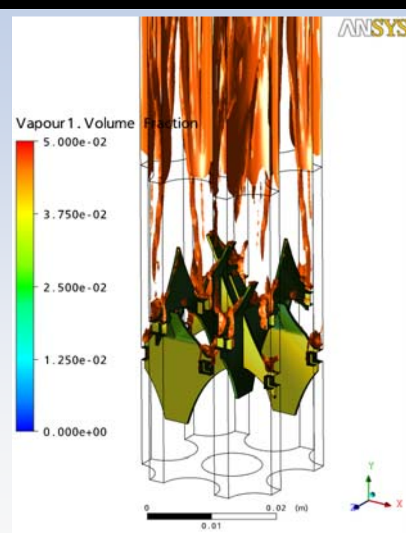

## Wall Boiling in Fuel Assemblies

### The applications:

- PWR: nuclear reactor safety scenarios
- BWR: normal regime of operation

### Model history:

- Original mechanistic model developed by Podowski et al. @ RPI
- 1st prototype for ANSYS CFX in EC project ECORA
- Release of the model in ANSYS CFX 12.0
- RPI wall boiling model available as UDF for ANSYS Fluent 12.0




Courtesy by E. Krepper (FZD)

## The RPI Wall Boiling Model

Why special modeling for wall boiling?

- For subcooled flows with superheated walls, standard thermal phase change models for bulk boiling/condensation will underpredict mass transfer rates
- Accounts for steam bubble growth on nucleation sites and bubble departure
- Mechanistic model for wall driven boiling

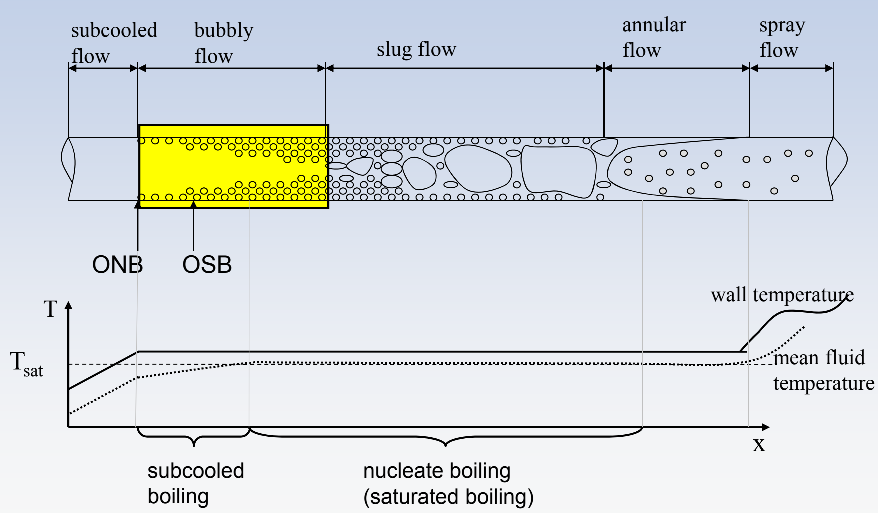
Model outline:

- Mechanistic wall heat flux splitting
  → convective heat transfer, evaporation, quenching
- Empirical submodels required for closure
- Available for different BC's: prescribed $T_{wall}$ or $q_{wall}$, CHT walls
- Activated per boundary patch with individual $T_{wall}$ or $q_{wall}$





## Multiphase Flow Regimes for Boiling Water Flow



## Flows with Subcooled Boiling (DNB) – RPI-Wall Boiling Model

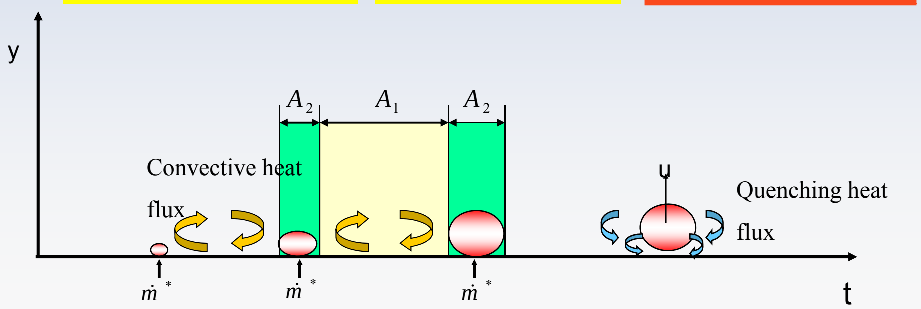
### Mechanistic wall heat partioning model:

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

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

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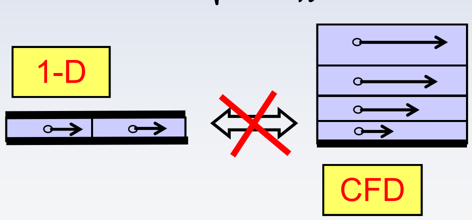
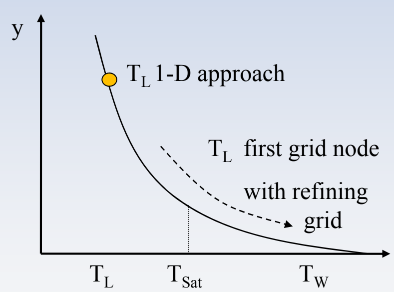
## Grid dependent correlations

- **Quenching heat flux**

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

$$h_Q = 2f\sqrt{\frac{t_W \rho_L C_{PL} \lambda_L}{\pi}}$$

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## Grid dependent correlations

- **Evaporation heat flux**

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

$$\dot{m} = \frac{\pi\, d_W^3}{6} \rho_G\, f\, n$$

$$d_W = \min\left\{1.4mm, 0.6\,\text{mm} \cdot \exp\left(-\frac{T_S[\text{K}] - T_L[\text{K}]}{45[\text{K}]}\right)\right\}$$

$d_W$ – bubble departure diameter

$n$ – nucleation site density per m²

$f$ – bubble departure frequency

**small quenching & overestimated evaporation on fine grids**

**wrong heat flux partitioning**

→ tends to film boiling on fine grids (due to $T_L \rightarrow T_W$)

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## Revisited RPI Boiling Model

- **Grid invariance of the model required**
- **determine $T_L$ from temperature wall function (Kader, 1981)**

$$T^+ = \Pr \cdot y^+ e^{(-\Gamma)} + \left[2.12 \cdot \ln(y^+) + \beta\right] \cdot e^{(-1/\Gamma)}$$

$$y^+ = \frac{\rho_L \cdot \Delta y \cdot u_\tau}{\mu}$$

- **from definition:**

$$T^+ = \frac{\rho \cdot c_{PL} \cdot u_\tau}{\dot{q}_W}(T_W - T_L)$$

→ **evaluating $T^+$ at 2 different locations**

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## Revisited RPI Boiling Model

- heat flux in boundary layer identical at both locations

$$\dot{q}_{W,\,y^+=\text{first cell}} = \frac{\rho \cdot c_{PL} \cdot u_\tau}{T^+_{y^+=\text{first cell}}} (T_W - T_L)_{y^+=\text{first cell}}$$

$$\dot{q}_{W,\,y^+=\text{const}} = \frac{\rho \cdot c_{PL} \cdot u_\tau}{T^+_{y^+=\text{const}}} (T_W - T_L)_{y^+=\text{const}}$$

heat fluxes are equal

$$(T_W - T_L)_{y^+=\text{const}} = \frac{T^+_{y^+=\text{const}}}{T^+_{y^+=\text{first cell}}} \cdot (T_W - T_L)_{y^+=\text{first cell}}$$

- additional factor in correlations for $d_W,\ \dot{q}_F,\ \dot{q}_Q$
- assumption of $y^+_{const}$=250; model parameter

## RPI-Wall Boiling Model – Submodels for Model Closure

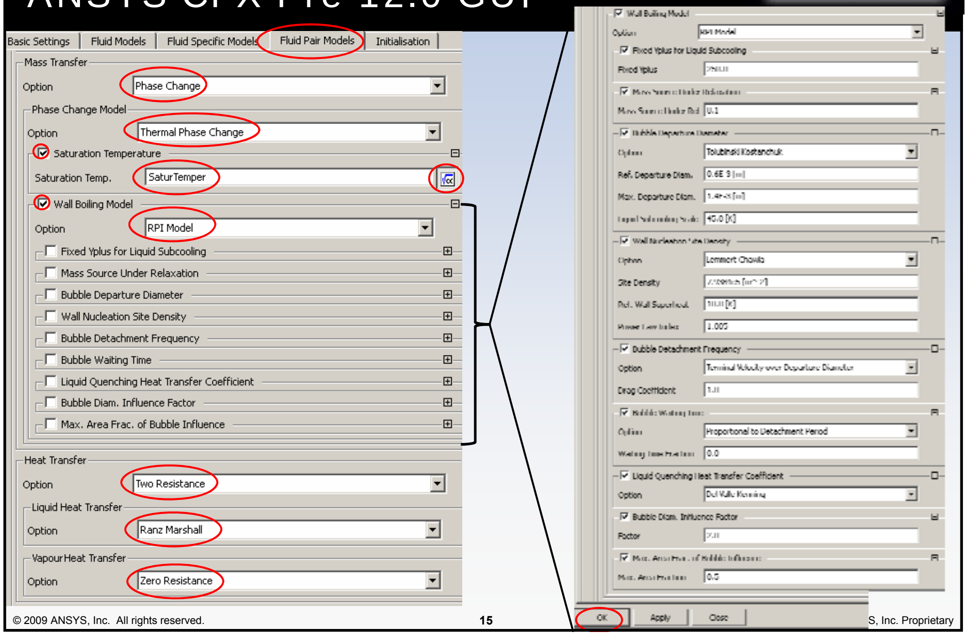
**Submodels for closure of RPI wall boiling model:**

- 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

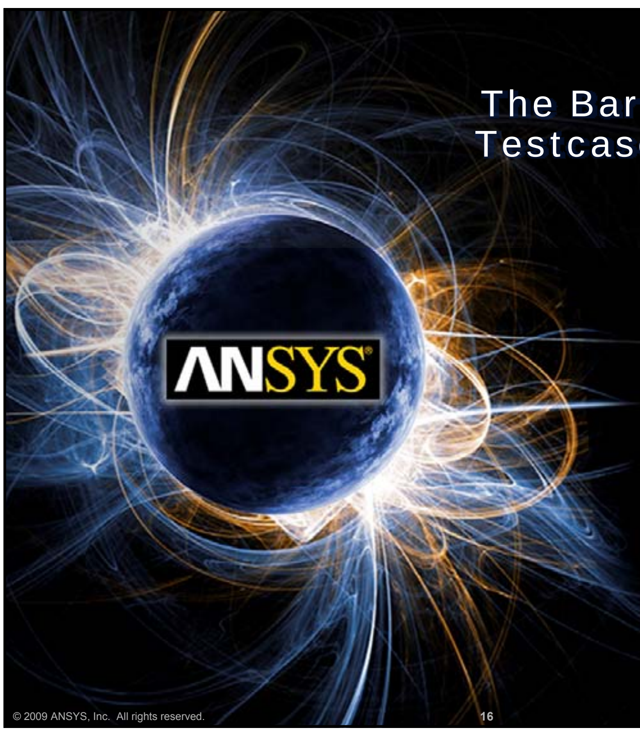
  

## RPI Wall Boiling Model in the ANSYS CFX-Pre 12.0 GUI



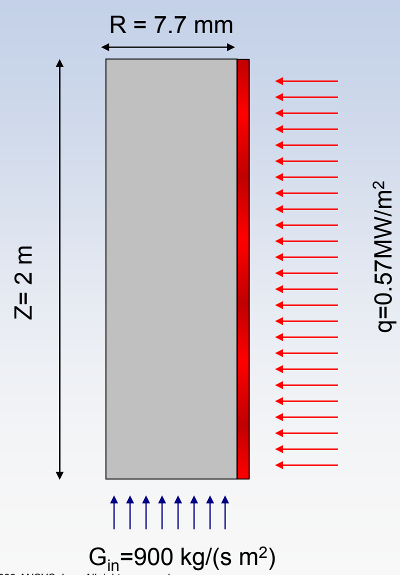






## The Bartolomej et al. Testcase (1967,1982)

## 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 |





## 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] | $10^{-2}$ | $10^{-3}$ | $5x10^{-4}$ |

## 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**
  - Accounting for higher volume fraction of the steam phase
- **Bubble bulk diameter**
  - Bubble diameter dependent on local fluid temperature (Kurul-Podowski)

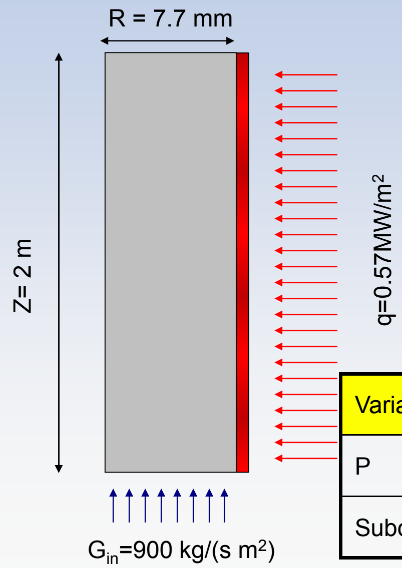
  

## Inter-Phase Mass, Momentum and Energy Transfer

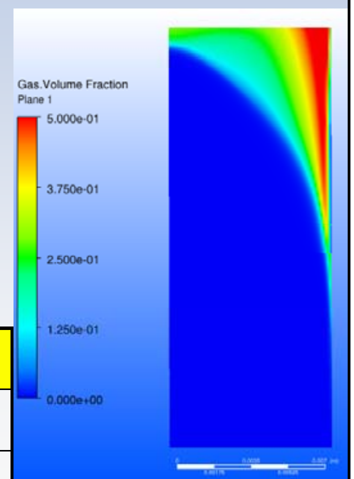
- **Mass transfer model**
  - CFX Thermal Phase Change Model
- **Momentum transfer models**
  - Grace drag
  - FAD turbulent dispersion force
  - Tomiyama lift force
  - Wall lubrication force (none, Antal, Tomiyama)
- **Heat transfer models**
  - Steam phase → set to local saturation temperature
  - Two resistance model
  - Ranz Marshall correlation for bubble heat transfer

## Validation for Test Case of Bartolomej et al. (1967, 1982)



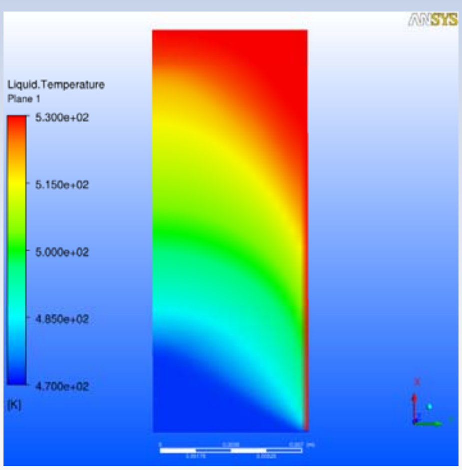

| Variable | Value |
|---|---|
| P | 4.5MPa |
| Subcooling | 58.2 K |

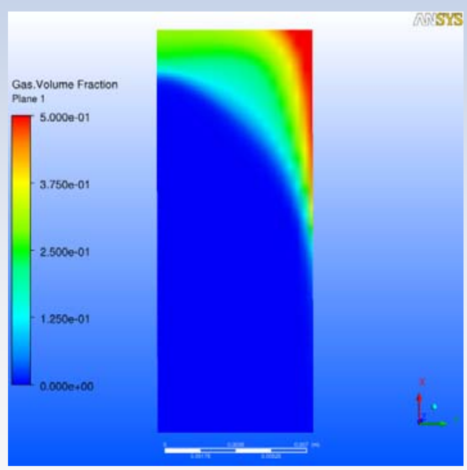




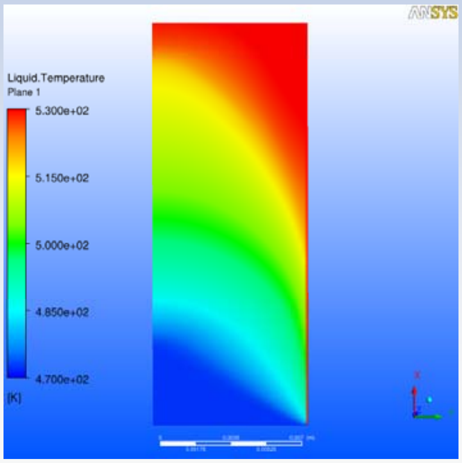



## Grid1

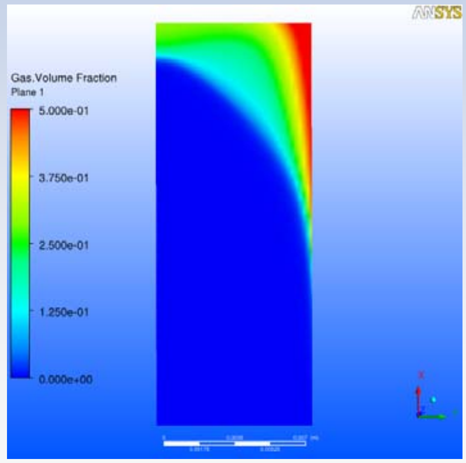


# Grid 2



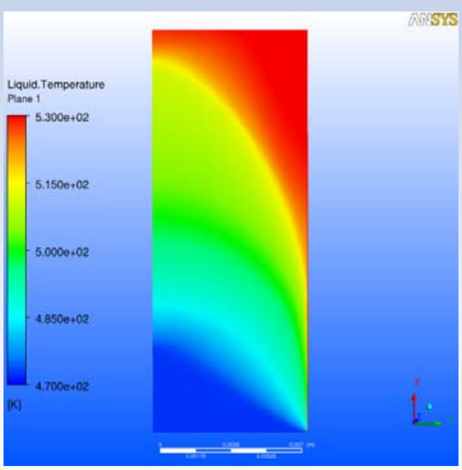
Liquid.Temperature
Plane 1
5.300e+02
5.150e+02
5.000e+02
4.850e+02
4.700e+02
[K]

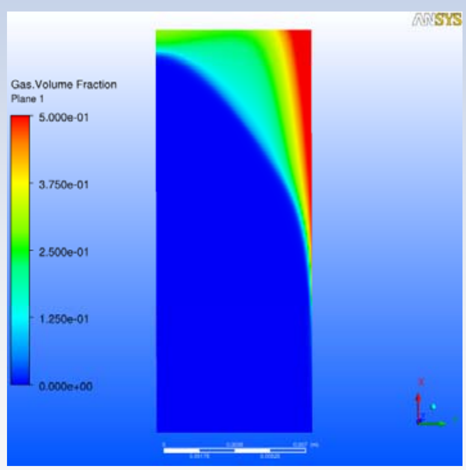
Gas.Volume Fraction
Plane 1
5.000e-01
3.750e-01
2.500e-01
1.250e-01
0.000e+00

# Grid 3



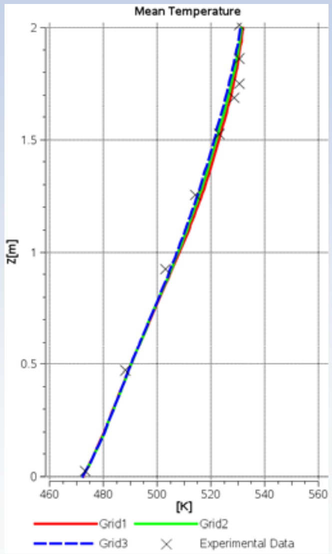
Liquid.Temperature
Plane 1
5.300e+02
5.150e+02
5.000e+02
4.850e+02
4.700e+02
[K]

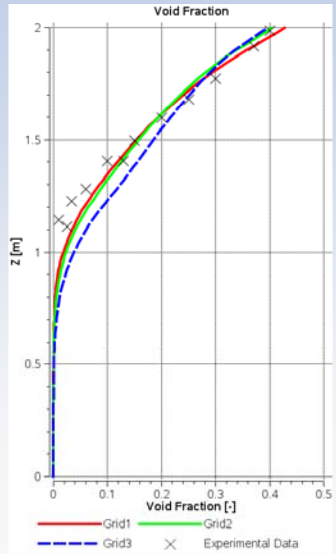



Gas.Volume Fraction
Plane 1
5.000e-01
3.750e-01
2.500e-01
1.250e-01
0.000e+00

# Comparison to Experimental Data



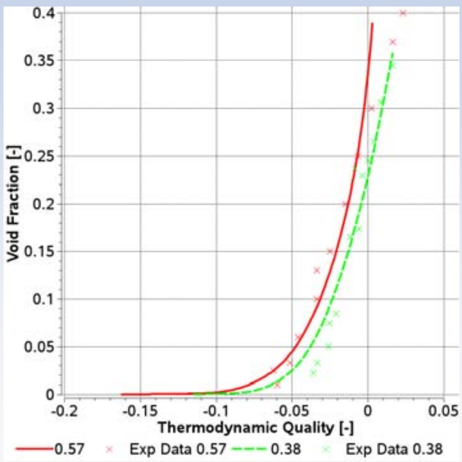
# Total Gas Content

| Grid | Gas Content |
|---|---|
| Grid1 | 0.0894 |
| Grid2 | 0.0892 |
| Grid3 | 0.0997 |

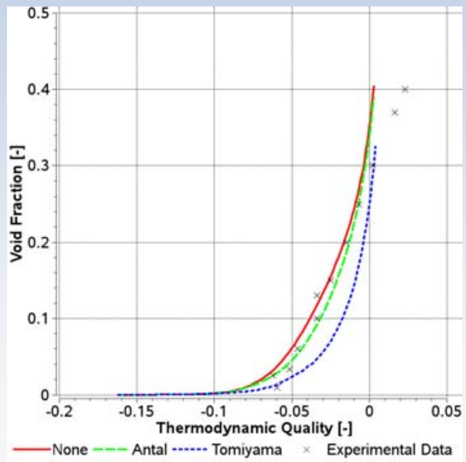
  

## Comparison to Experimental Data - Parameter & Model Variation

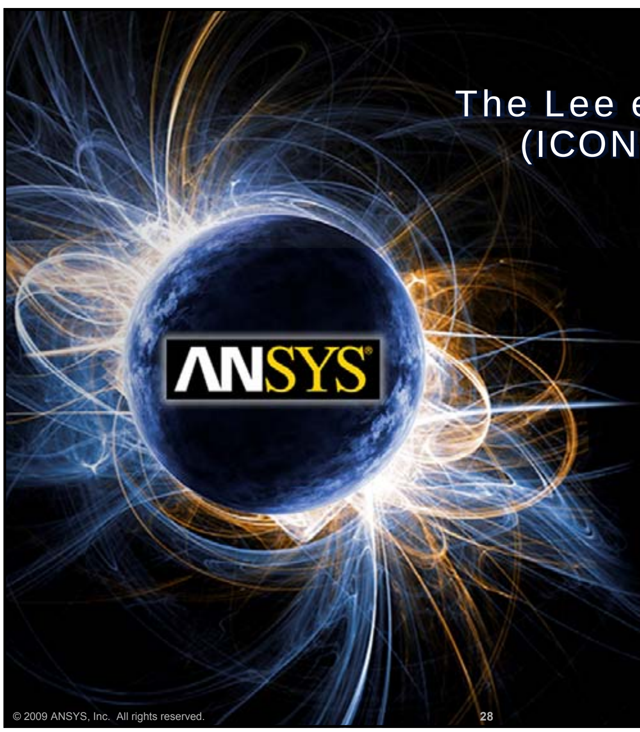
Influence of wall heat flux:




Influence of wall lubrication force model:





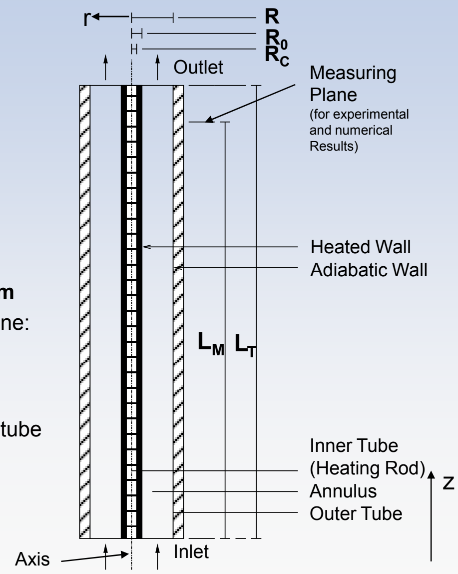
## The Lee et al. Testcase (ICONE-16, 2008)

# 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

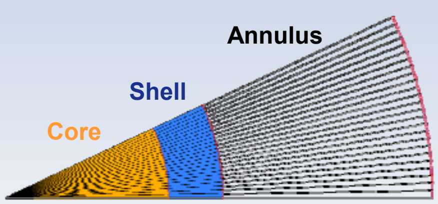



**Figure 2:** 1° simulated segment of the geometry

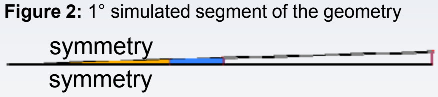
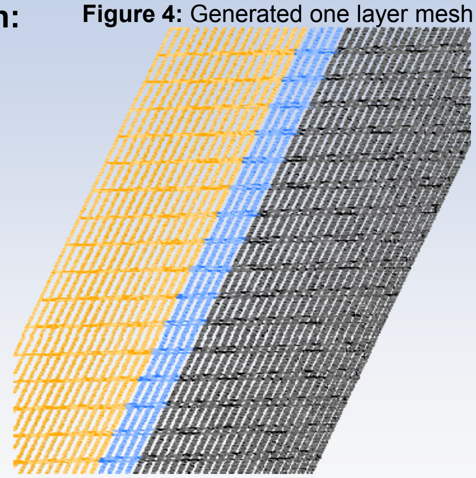


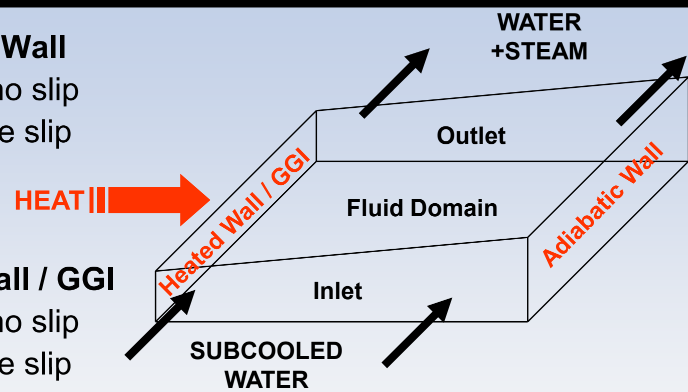

**Figure 3:** 1° segment with one-layer mesh example


**Figure 4:** Generated one layer mesh



## Boundary Conditions

- Adiabatic Wall
  - Liquid: no slip
  - Gas: free slip




- Heated Wall / GGI
  - Liquid: no slip
  - Gas: free slip
  - Thermal BC:
    - **HFO** → specified heat flux at wall
    - **CHT** → heat source in core / heat transfer in solid
  - RPI wall boiling model

## CFD Setup of the Lee et al. Testcase

1. **Material properties:**
   - IAPWS IF97 water-water steam property tables
2. **Liquid Phase:**
   - SST turbulence model
   - Thermal Energy equation
3. **Gaseous Phase:**
   - Particle model
   - Kurul & Podowski type bulk bubble diameter
   - Grace drag, Tomiyama lift, FAD turb. disp. force
   - 0-eq. disperse phase turbulence model
   - Sato bubble enhanced turbulence model
   - $T_{Steam}=T_{Sat}$

## CFD Setup of the Lee et al. Testcase (cont.)

### 4. Interfacial Heat & Mass Transfer

- RPI wall boiling model
- Bulk boiling model
- Two resistance interfacial heat transfer model
  - Water: Ranz Marshall
  - Steam: zero resistance





## 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<br>2: 12684 | | 1: 24682<br>2: 49364 | | 1: 97362<br>2: 194724 | |
| **No. of Elements** (hexahedra) | | 1: **20x150**<br>2: **40x150** | | 1: **40x300**<br>2: **80x300** | | 1: **80x600**<br>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

- **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., Koncar):**

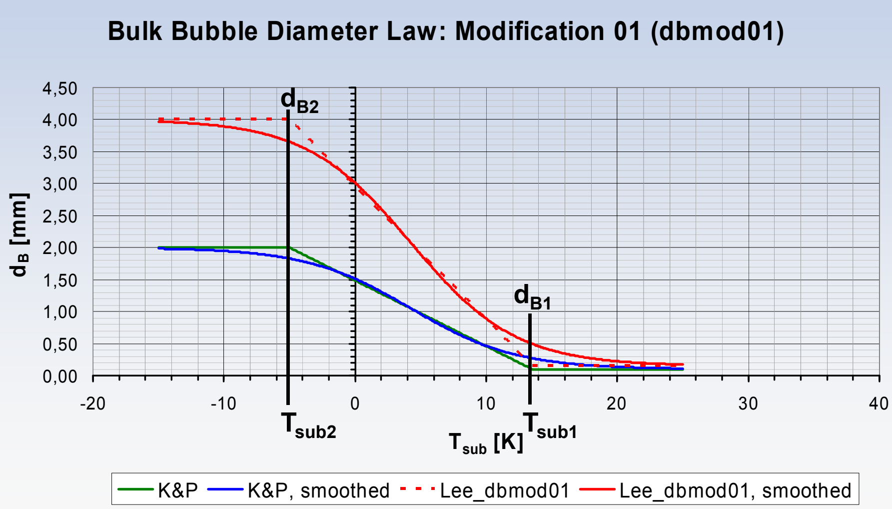
1. **Bulk bubble diameter (BBD)**
   **Kurul & Podowski → $d_{B,max}$~1.5mm @ wall**
   **modified $d_B$ law → $d_{B,max}$~4.0mm @ wall**
2. **Bubble departure diameter (BDD)**
   **Tolubinski & Kostanchuk → $d_W$ ~0.5mm max.**
   **const. bubble dept. diam. → $d_W$ =1mm - 3mm**
3. **$A_2$ - Wall area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

## BBD Modification Overview

| | $d_{B1}$ [mm] | $d_{B2}$ [mm] | $T_{sub1}$ [K] | $T_{sub2}$ [K] |
|---|---|---|---|---|
| K&P | 0.10 | 2.0 | 13.5 | -5.0 |
| dbmod01 | 0.15 | 4.0 | 13.5 | -5.0 |
| dbmod02 | 0.15 | 4.0 | 13.5 | 5.0 |
| dbmod03 | 0.15 | 4.0 | 25.0 | 5.0 |

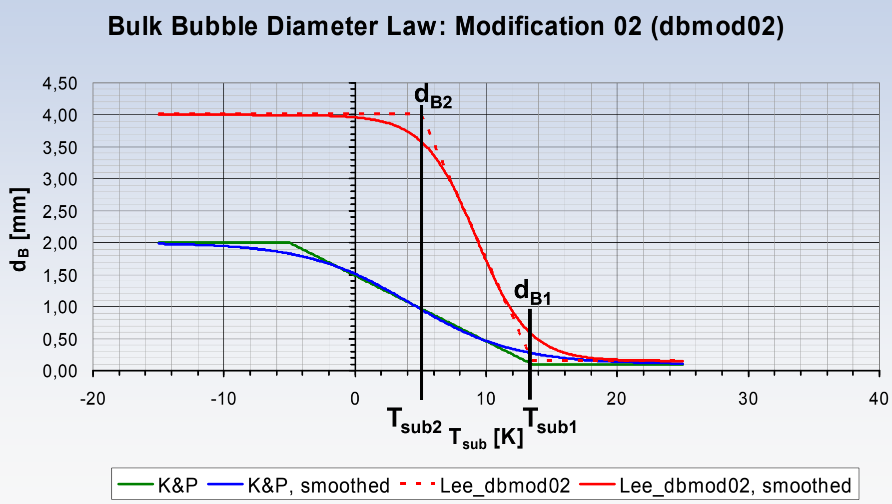
  

## BBD Modification dbmod01



## BBD Modification
## dbmod02

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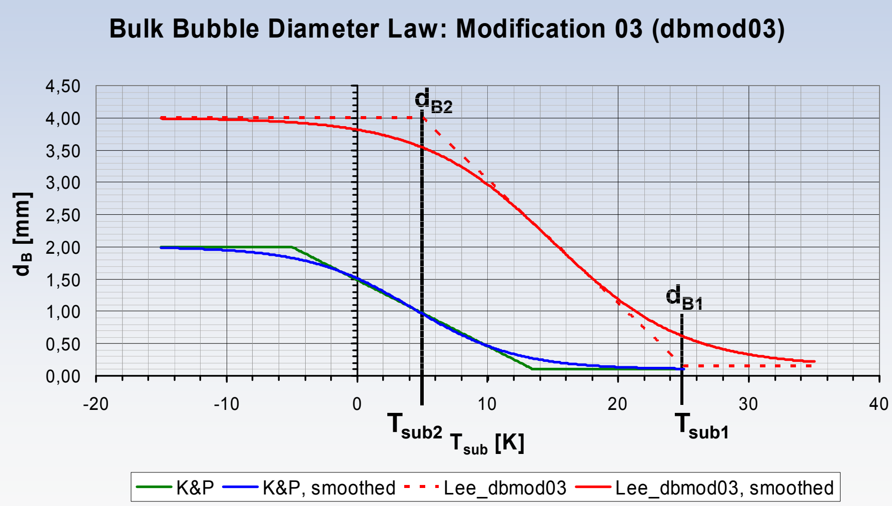
## BBD Modification
## dbmod03

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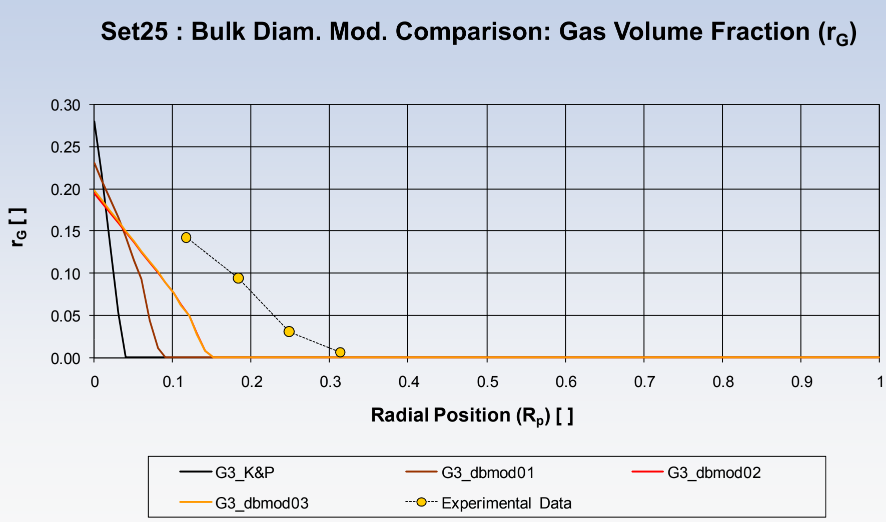
## BBD & BDD Modifications
## Test Matrix Overview

- **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 $d_{W.max}$ ≈ 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]

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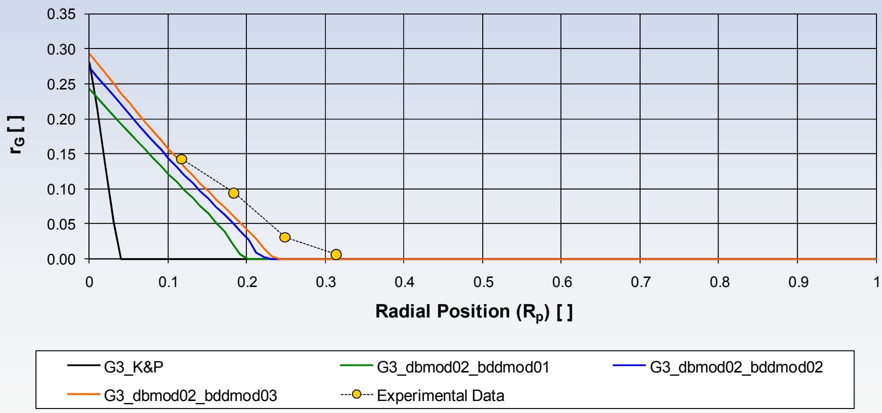
**Set25 Bubble Dept. Diam. Mod. Comparison: Gas Volume Fraction ($r_G$)**

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## BDD Modification / Set 25:
## Heat Flux to Vapor @ Heated Wall

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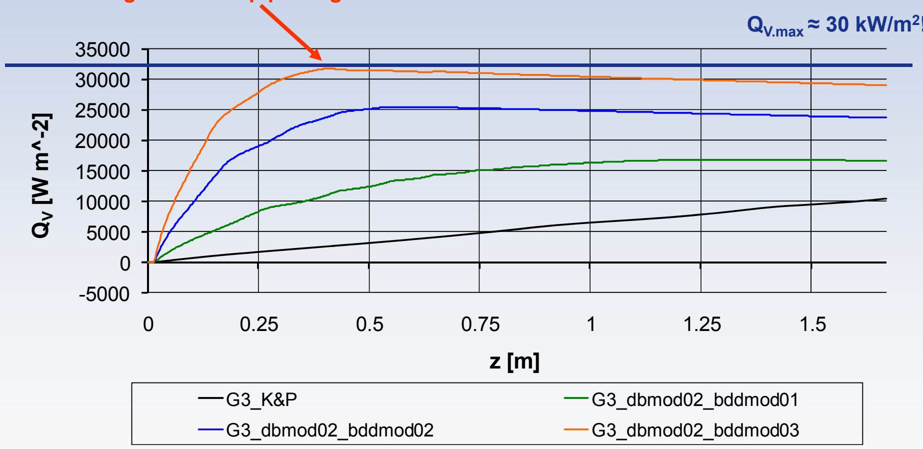
**Set25 Bubble Dept. Diam. Mod. Comparison: Heat Flux to Vapor ($Q_V$)**

**Decreasing HFtV over pipe length indicates some limiter effect**

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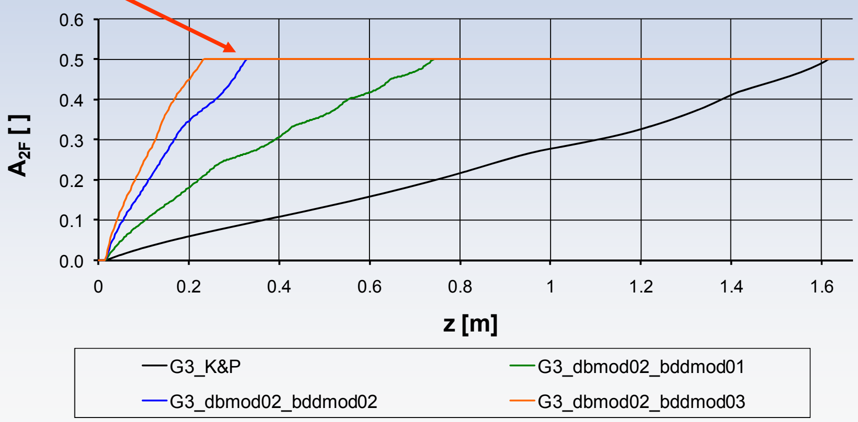
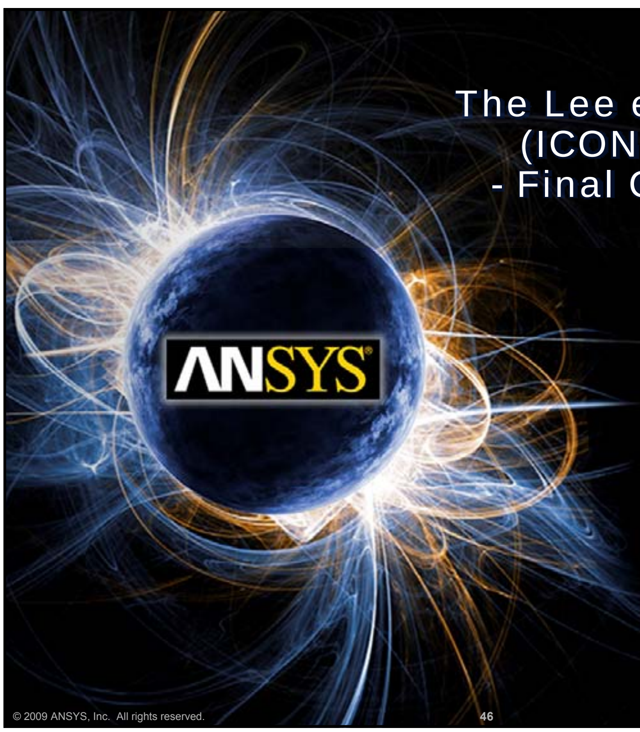
## BDD Modification: Bubble Influenced Area Fraction @ Heated Wall

**Set25 Bubble Dept. Diam. Mod.: Bubble Influenced Area Fraction ($A_{2F}$)**

$A_{2F}$ limiter becomes dominating factor with increased $d_W$ → raising this limitation




 45 



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

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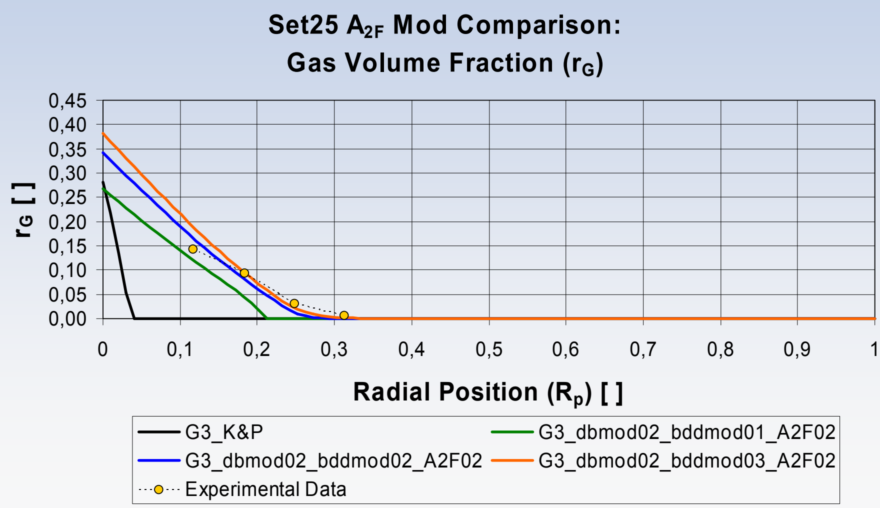
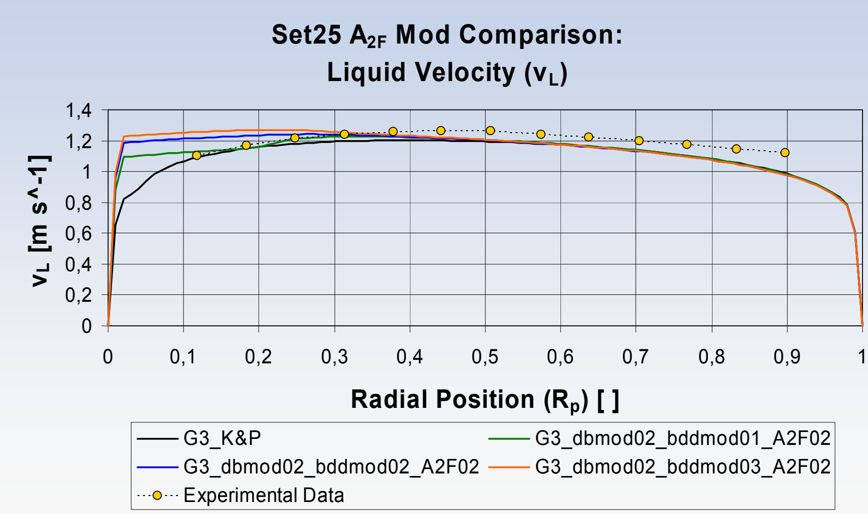
## $A_{2F}$ Limiter Modification: Results Set 25, Gas Volume Fraction @ z=1610[mm]





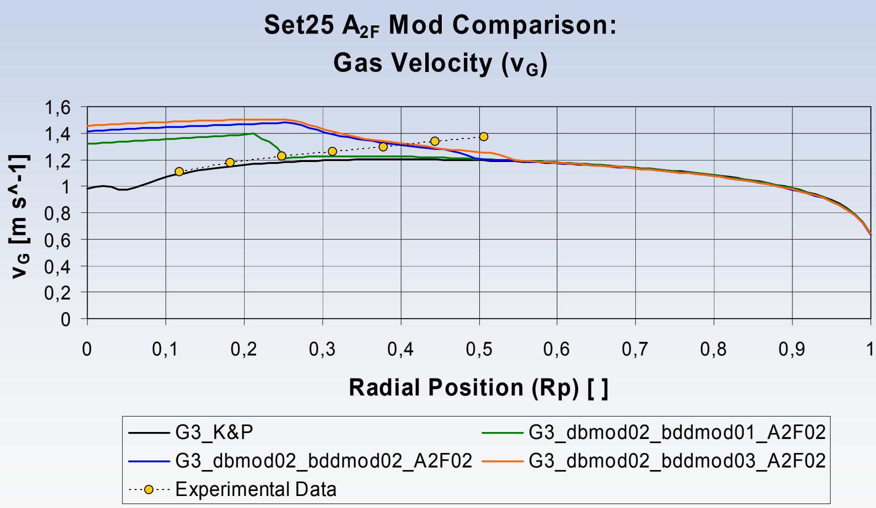



## $A_{2F}$ Limiter Modification: Results Set 25, Liquid Velocity @ z = 1610 [mm]



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

ANSYS

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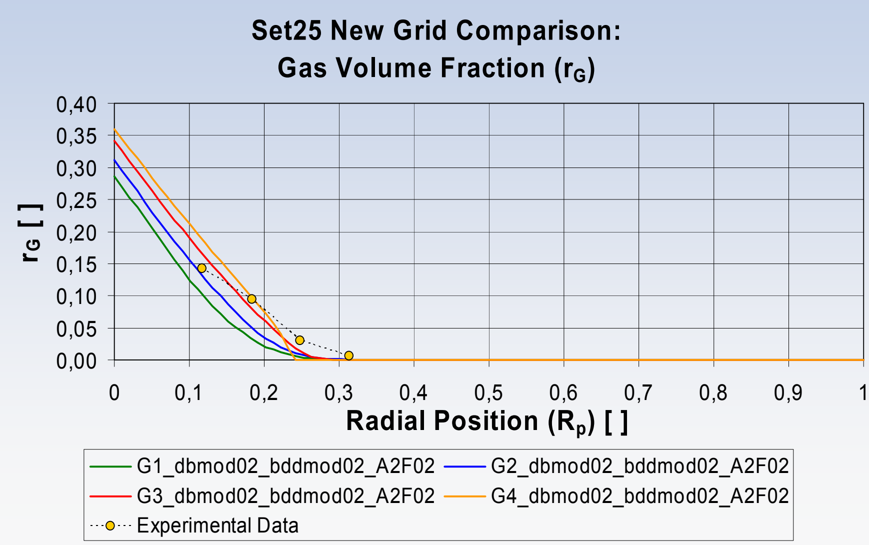
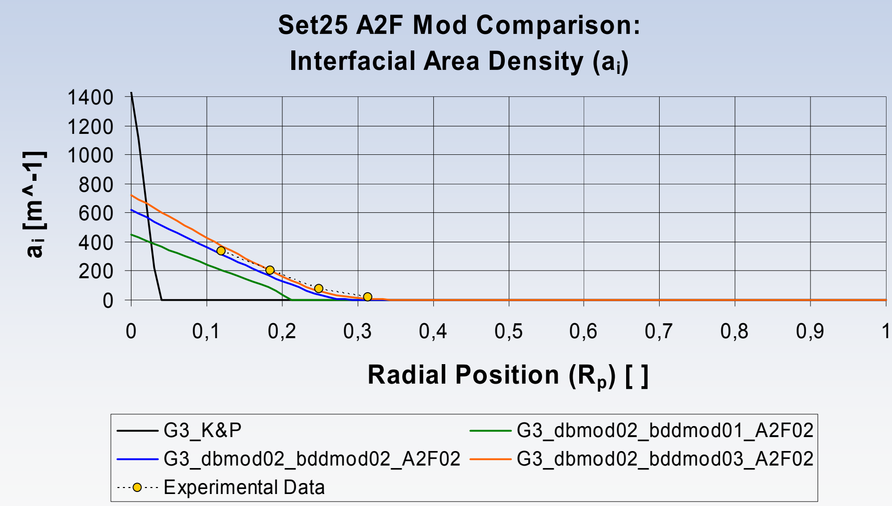
## Grid Independency: Results Set 25, Gas Volume Fraction @ z = 1610 [mm]

ANSYS




 50 

## $A_{2F}$ Limiter Modification: Results Set 25, Interfacial Area Density @ z=1610[mm]

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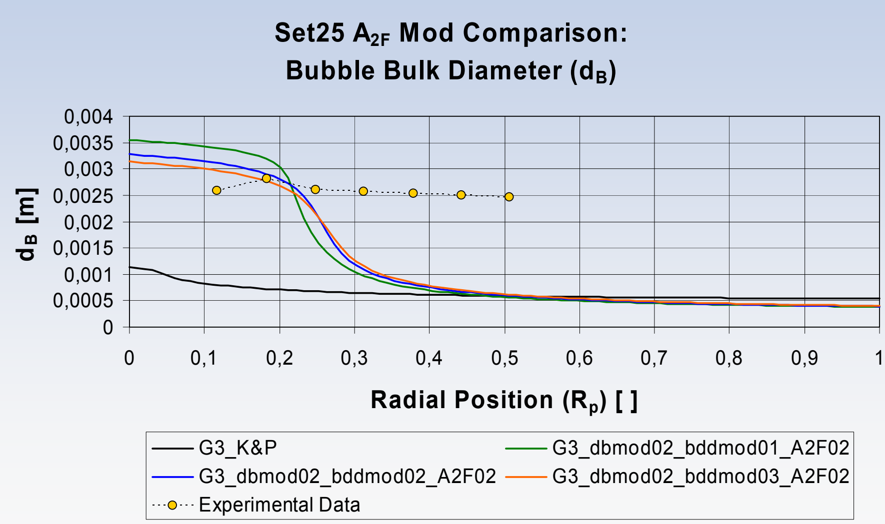
## $A_{2F}$ Limiter Modification: Results Set 25, Bulk Bubble Diameter @ z=1610[mm]

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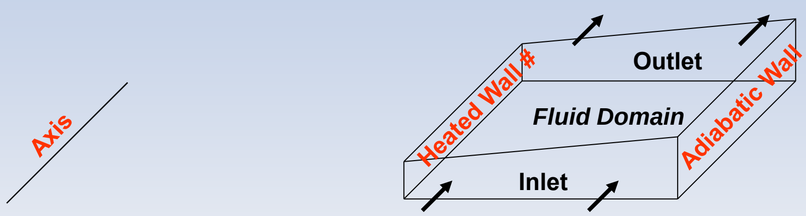
# The Lee et al. Testcase (ICONE-16, 2008) - Conjugate Heat Transfer -

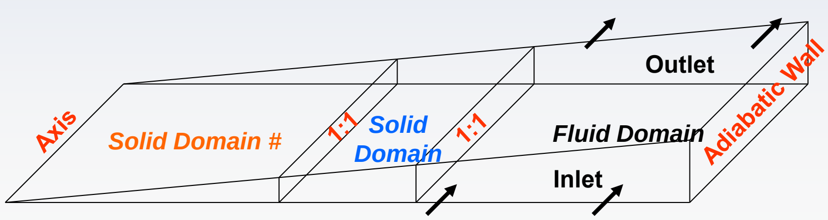
  

# Heat Source in Solid Material & Conjugate Heat Transfer Prediction

**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 #



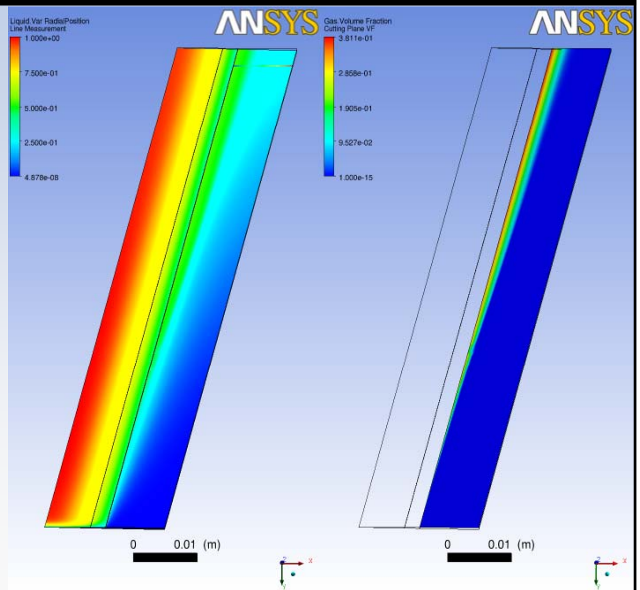

  

## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

- **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**



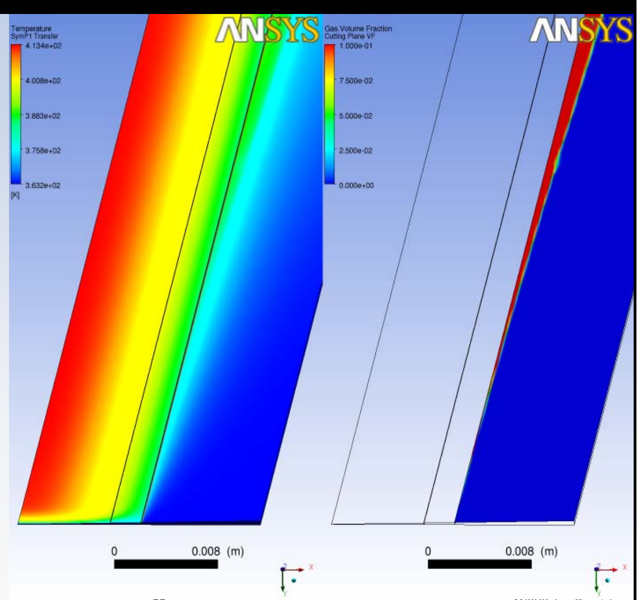





## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

- **Temperature and Steam VF distribution @ Inlet**

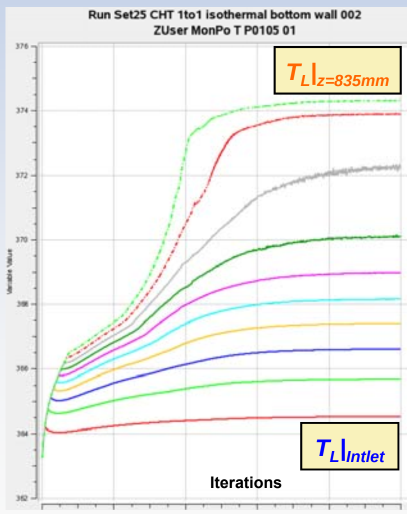
- **Isothermal BC for solid core bottom wall: $T_{Wall}$=$T_{Water, Inlet}$**

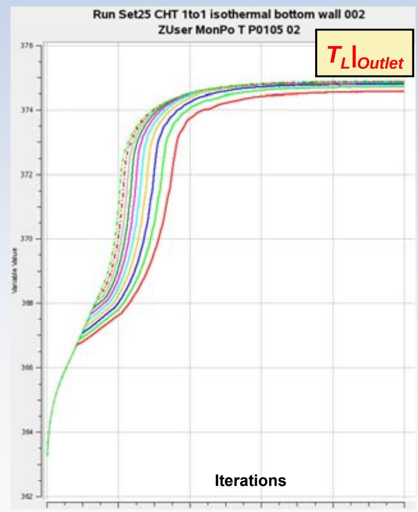


## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

ANSYS

**Set25 & CHT: Water temperature monitors $\Delta x_W$=1.5mm, $\Delta z$=83.5mm,**



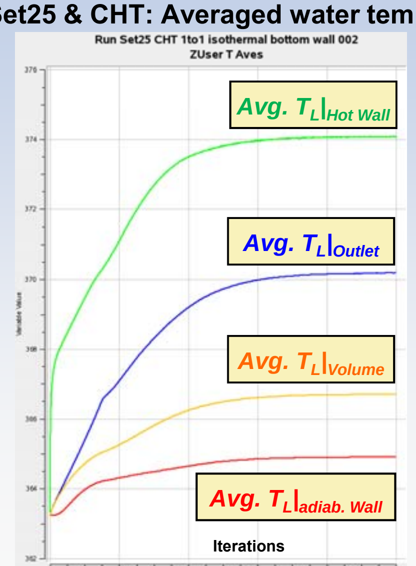


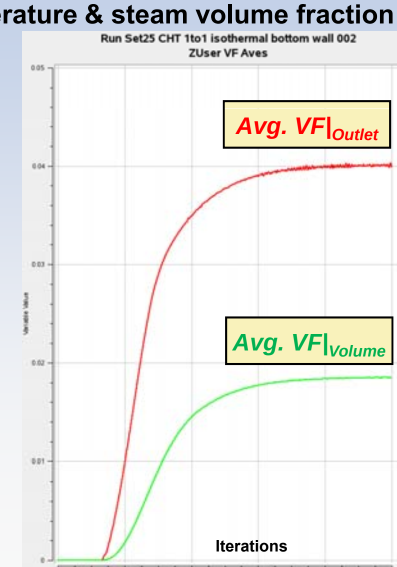



## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

ANSYS

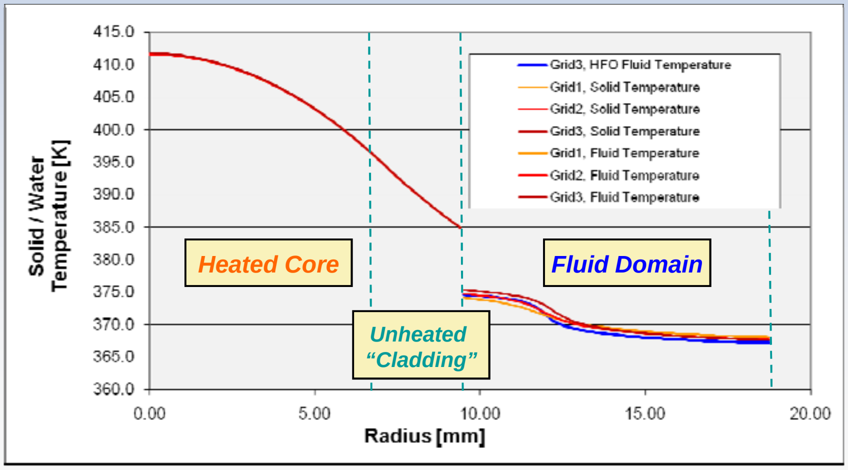
**Set25 & CHT: Averaged water temperature & steam volume fraction**



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

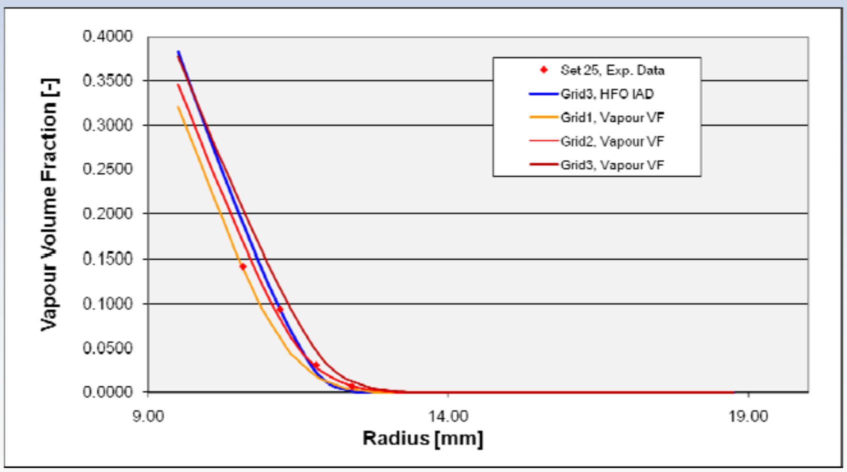
**Set25 & CHT: Grid independence for temperature distribution @ z=1610[mm]**




 59 ANSYS, Inc. Proprietary

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

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

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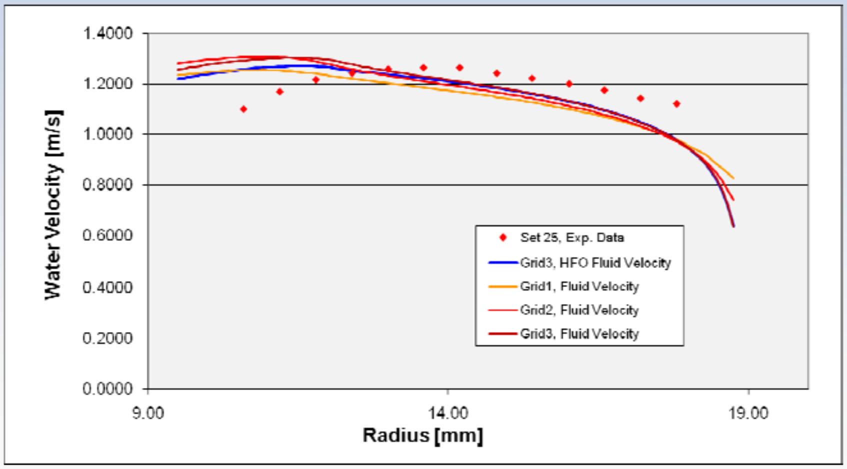
## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

ANSYS

### Set25 & CHT: Water velocity distribution @ z=1610[mm]

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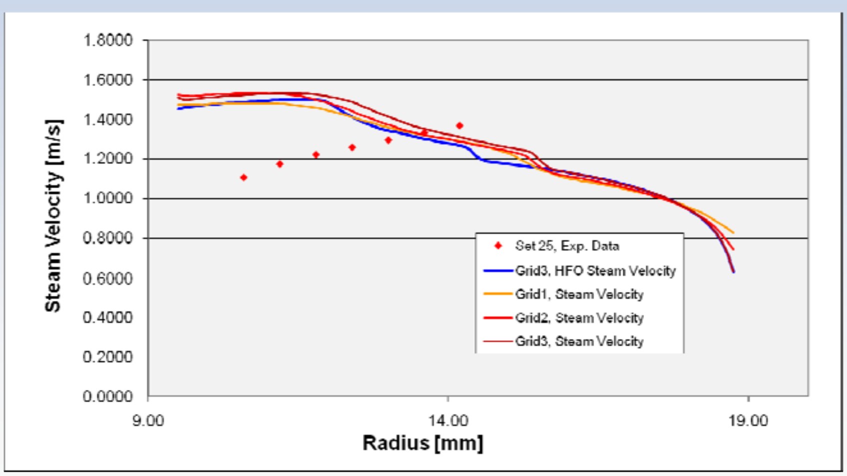
## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

ANSYS

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

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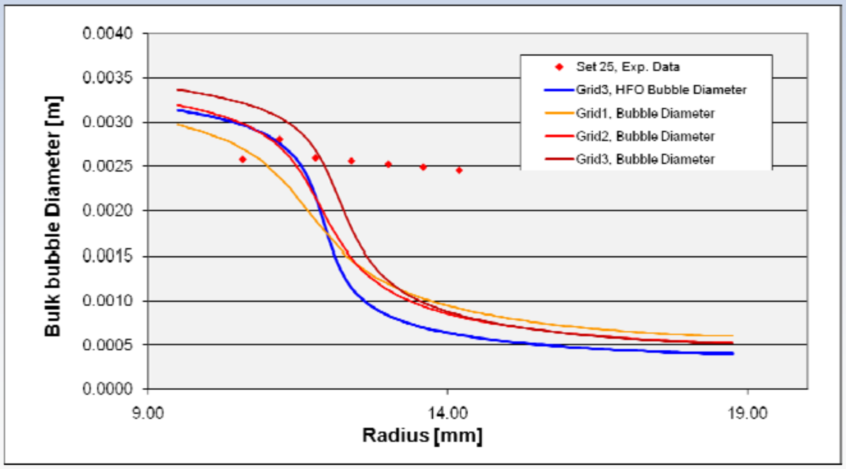
## The RPI Wall Boiling Model: Lee et al. Testcase with CHT

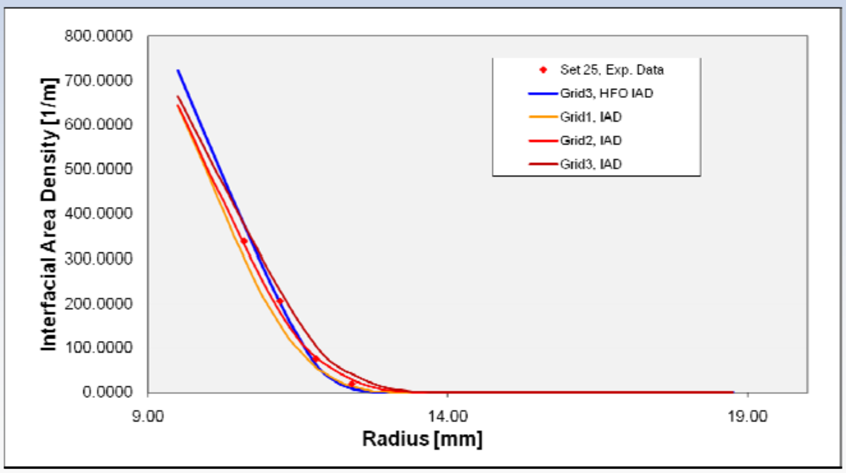
**Set25 & CHT: Bulk bubble diameter distribution @ z=1610[mm]**



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

**Set25 & CHT: IAD distribution @ z=1610[mm]**



## Wall Boiling in a 3x3 Fuel Rod Bundle with Periodic BC's

## Wall Boiling in a 3x3 Periodic Fuel Rod Bundle

- 3×3 rod periodic section from a nuclear reactor fuel assembly with guide vanes
- **Periodic BC's at all sides**
- Wall heat flux of

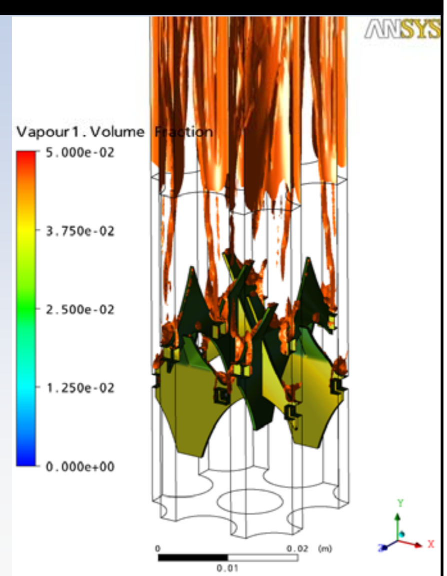
  $q_{wall} = 5 \cdot 10^5\ W/m^2$
- Reference Pressure

  p = 15.7 MPa
- Water inlet velocity

  $v_{Inlet}$=5.0m/s
- Water inlet temperature

  $T_{Inlet}$ = 607K

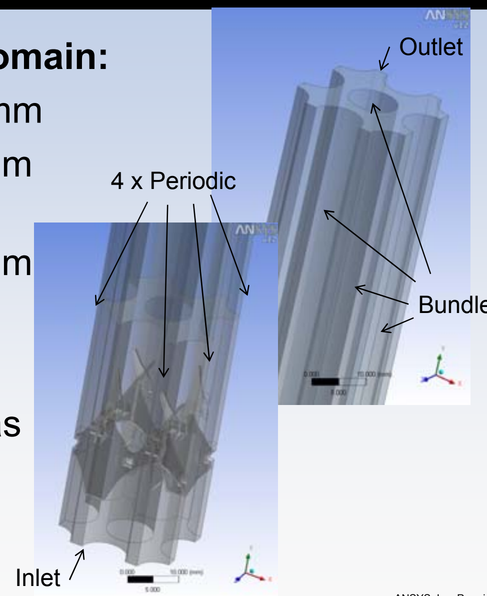
  (= 12K water subcooling)



## Wall Boiling in a 3x3 Periodic Geometry & Meshing

- **Dimensions of flow domain:**
  - Length = 530 mm
  - Tube diam. = 9.4 mm
  - Subchannel width = 2.6 mm
  - Heated rod walls
  - Spacer grid treated as adiabatic walls

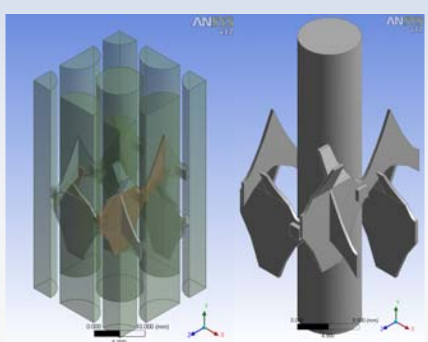


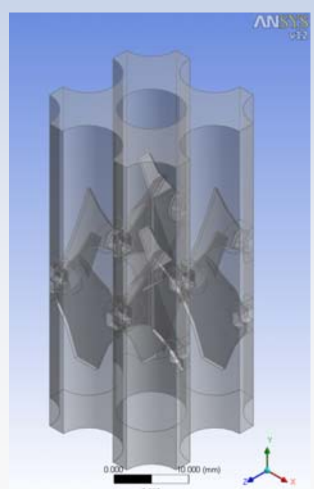




## Wall Boiling in a 3x3 Periodic Geometry & Meshing

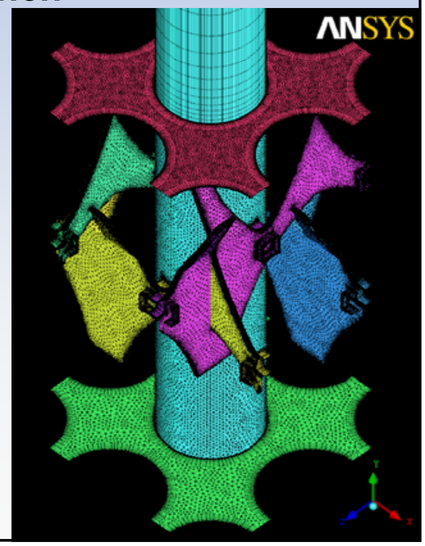
- **Geometry preparation in ANSYS Design Modeler**
- **Extraction of periodic fluid domain**





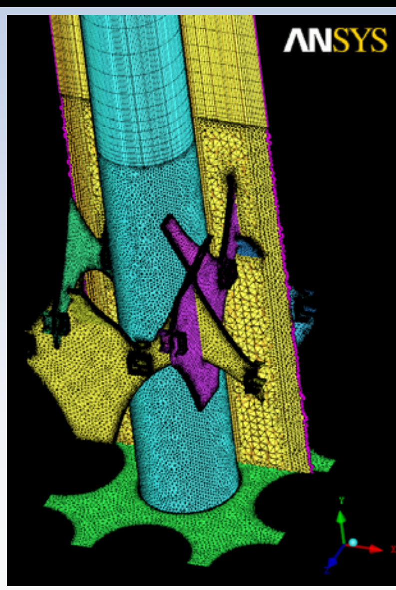
## Wall Boiling in a 3x3 Periodic Geometry & Meshing

- **Meshing in ANSYS Workbench**
- **Tet/Prism in lower part**
- **Extruded prism mesh in upper part**
- **Mesh statistic**
  - Tetra: 1,752,320
  - Hexa: 838,800
  - Prism: 2,088,820
- **Quality**
  - Quality > 0.25
  - Min Angle > 10 deg






## Wall Boiling in a 3x3 Periodic Geometry & Meshing



## Wall Boiling in a 3x3 Periodic Fuel Rod Bundle

### 1. Material:
- IAPWS IF97 water-water steam property tables

### 2. Liquid Phase:
- BSL RSM turbulence model
- Thermal Energy equation

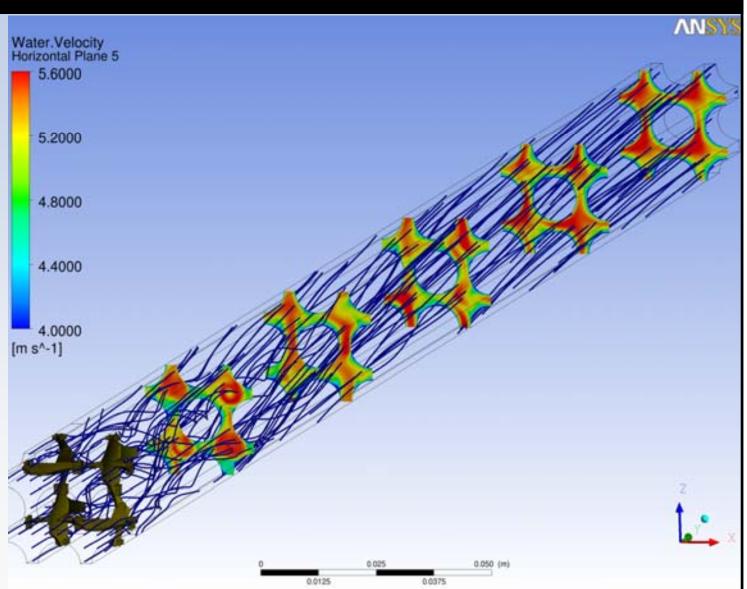
### 3. Gaseous Phase:
- Particle model (Kurul-Podowski model)
- Grace drag & non-drag forces
- 0-eq. disperse phase turbulence model & Sato
- $T_{Steam}=T_{sat}$

### 4. Interfacial Heat & Mass Transfer
- RPI wall boiling model & bulk boiling model

## Wall Boiling in a 3x3 Periodic Fuel Rod Bundle

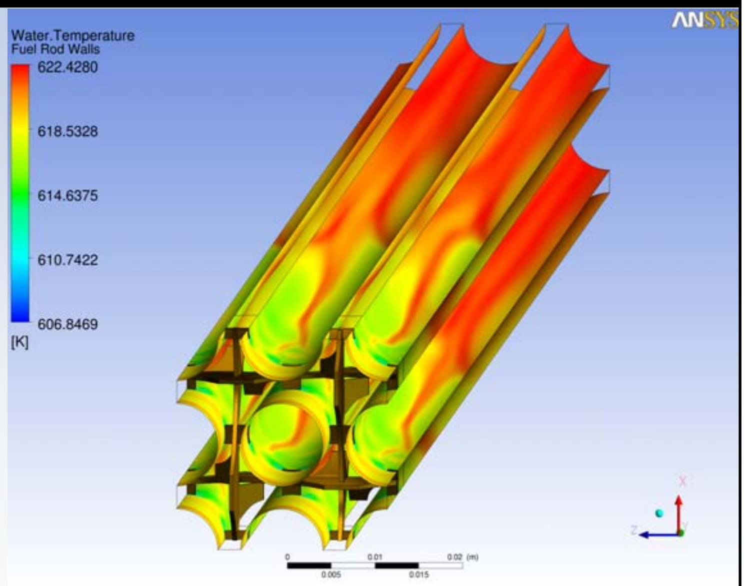
**Streamlines & water velocity in horizontal planes**



## Wall Boiling in a 3x3 Periodic Fuel Rod Bundle

**Near wall water temperature**

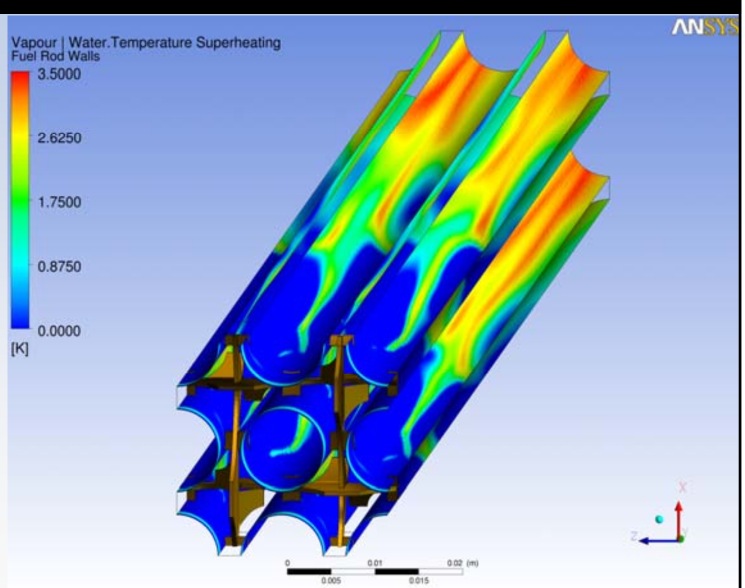







## Wall Boiling in a 3x3 Periodic Fuel Rod Bundle

**Wall superheat**

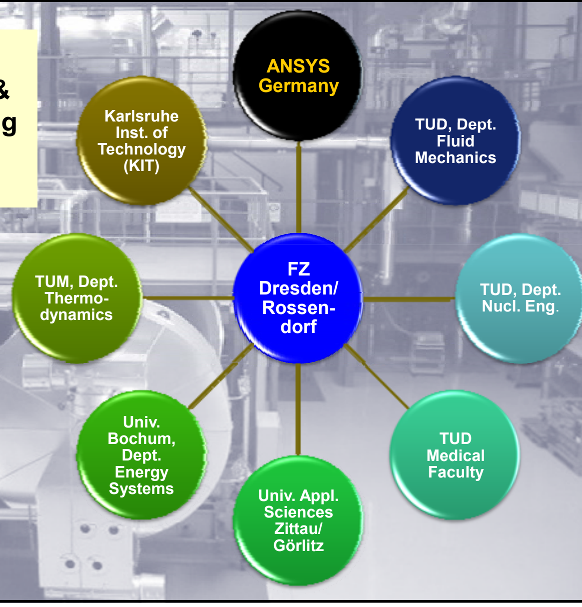


# Coming next…

ANSYS

**R&D Initiative:**

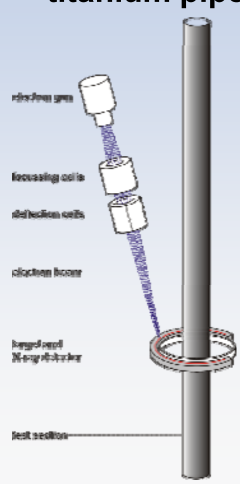
"Modeling, Simulation & Experiments for Boiling Processes in Fuel Assemblies of PWR"




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

ANSYS

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




Images by courtesy of U. Hampel, FZD

## Conclusions & Final Remarks

- ANSYS CFD 12.0 provides set of CFD models for boiling simulation in fuel assemblies
- Wall boiling model validation has shown good agreement for Bartolomej & Lee testcases
  → for PWR & BWR flow conditions
- Modified RPI wall boiling model delivers almost grid independent results
- Model compatibility with CHT (Conjugate Heat Transfer) in solid material
  → CFD simulation with prescribed volumetric energy source in the Uranium core of fuel rods
- Identification of submodel parameters for PWR & BWR flow conditions





## Future Work

- ANSYS follows customer driven CFD software & model development
- Coupling of wall boiling model to inhomogeneous MUSIG / population balance
  → account for bubble size distribution changes
- Extension of the wall boiling model towards superheated steam, film boiling, CHF
- Multiphase flow regime transition
- Coupling of CFD with Neutron kinetics
- Continued & extended model validation

ANSYS

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CFX

ANSYS FLUENT

ICEM CFD

# Thank You!