The role of High Fidelity Numerical Simulations for Nuclear Reactor Safety Analyses

SNETP FORUM, 2 - 4 Februari

Ed Komen

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Contents

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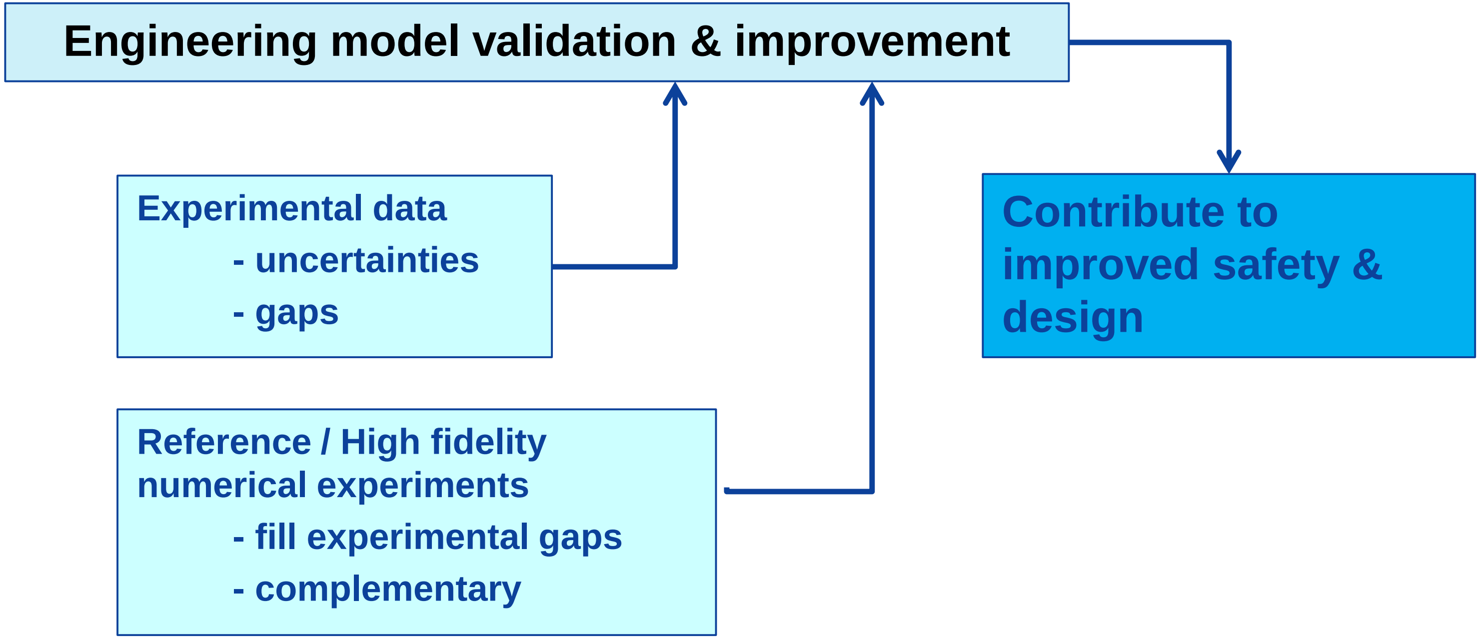
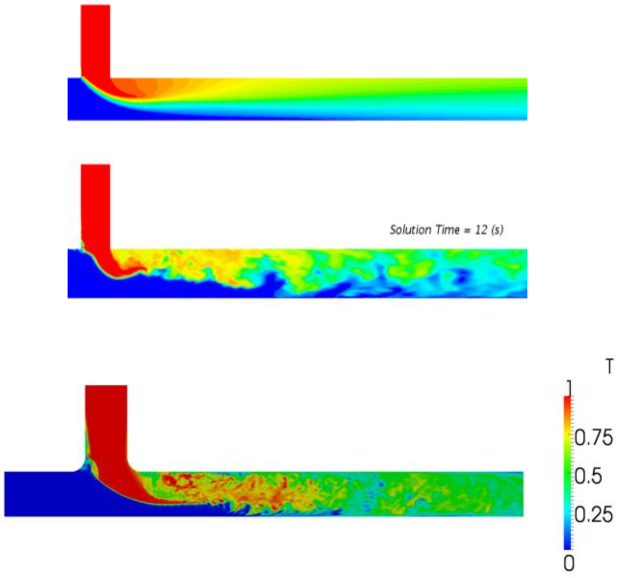
Introduction



CFD Methods



(U)RANS

Engineering

LES

High-fidelity

DNS

Computational demand

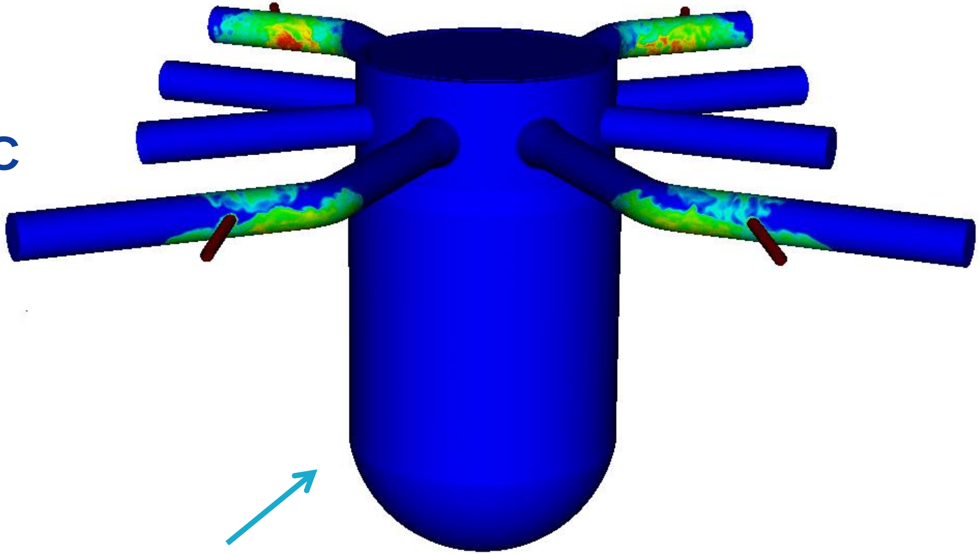
Accuracy

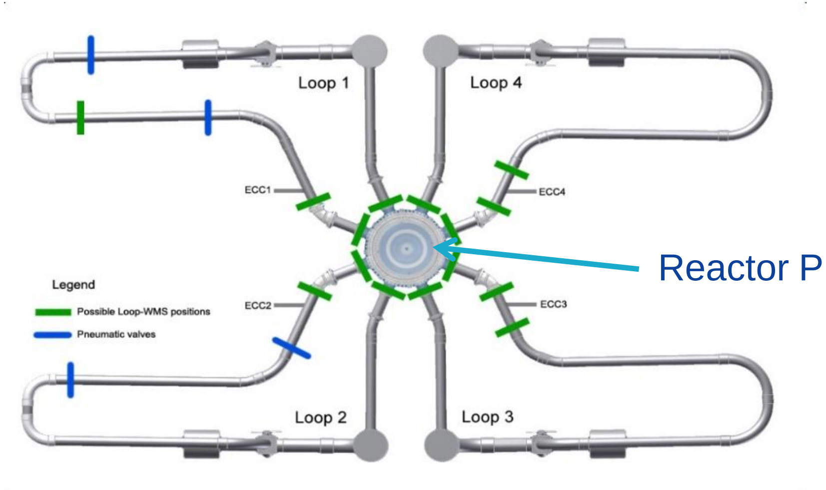
+

+

Example 1: Pressurized Thermal Shock

- Main issues for modelling PTS
  - **1. Turbulent mixing of the ECC water** → sufficient validation data exists





Reactor Pressure Vessel (RPV)

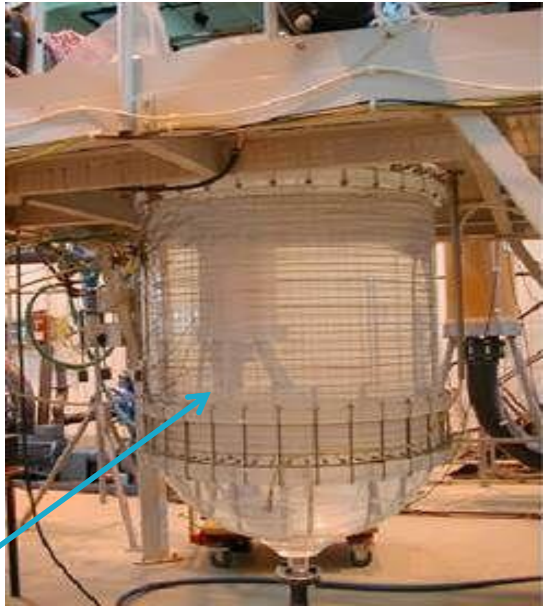
Top view 1:5 scale ROCOM test facility of 4 loops cooling system

Example 1: Pressurized Thermal Shock

- Main issues for modelling PTS

  - **2. Heat transfer coolant – RPV walls**
    → *open issue*

    - No CFD-grade experimental data
    - Alternative: high fidelity numeral experiments (DNS)

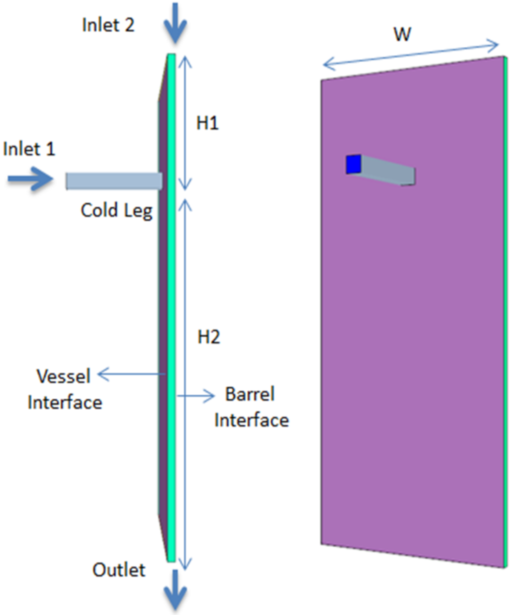


Plexiglas RPV (adiabatic)

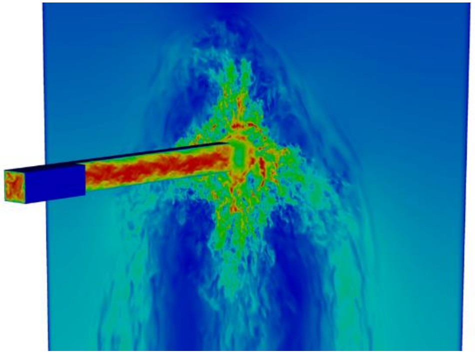
Need: DNS of a *PTS 'numerical experiments'* for further development and validation of engineering CFD models

Example 1: Pressurized Thermal Shock

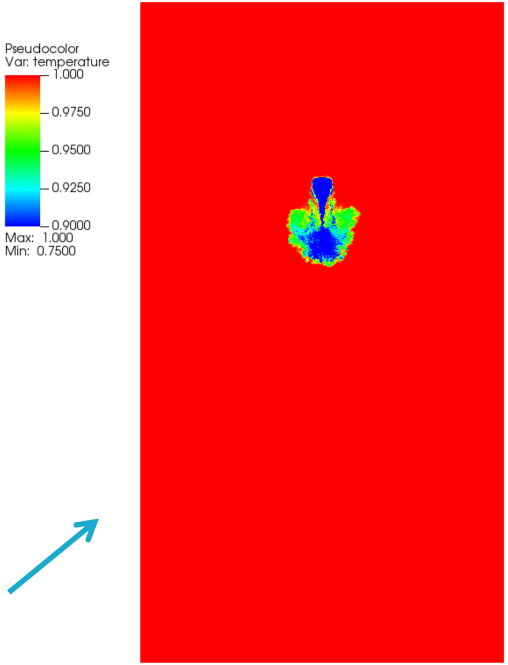
- High fidelity simplified PTS numerical experiments



ROCOM based simplified geometry



Case without buoyancy – velocity



Case with buoyancy – temperature

Example 2: Liquid metal fuel assemblies

Experiments for model validation:

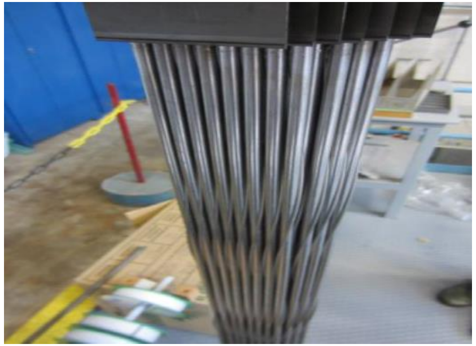
Simulant coolant

- Accurate measurements, but scaling issues

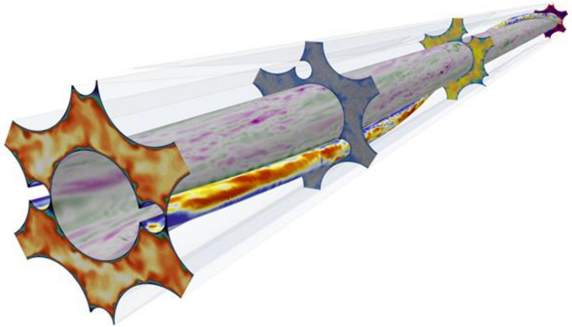
Liquid metal coolant

- Opaque, local flow field measurements difficult

→ Need for complementary reference 'numerical experiments'



Wire wrapped fuel assembly



DNS of infinite periodic wire wrapped fuel assembly

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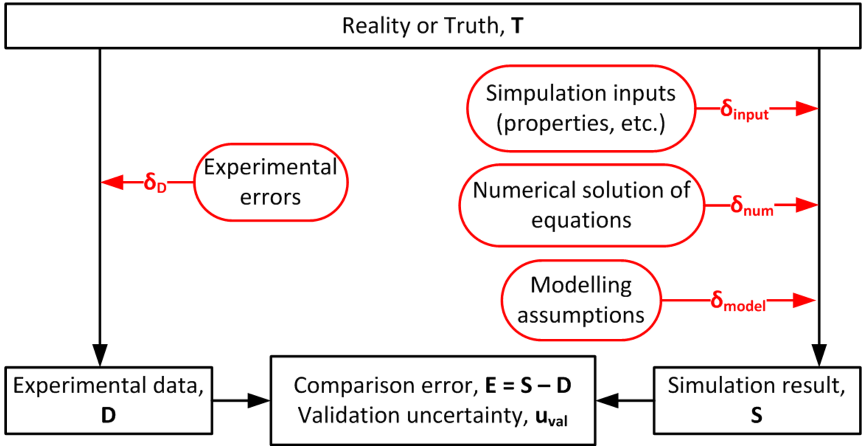
Validation – UQ methodolgy

ASME VV-UQ: determination of engineering model uncertainty

Validation against experiments:

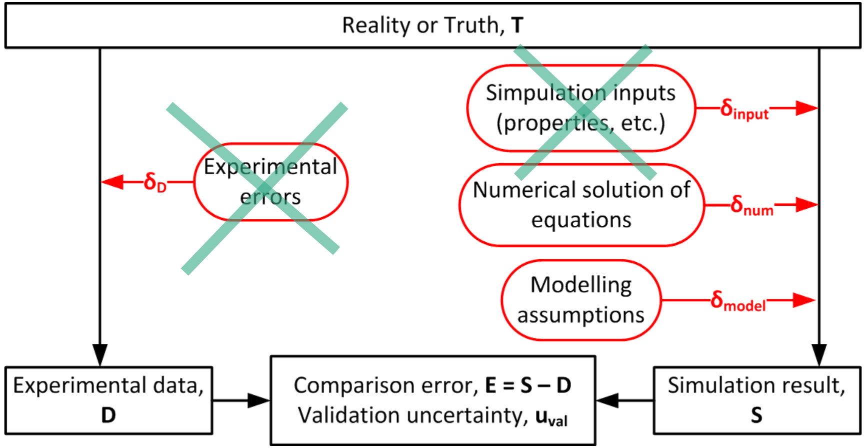


$$\boldsymbol{\delta_{model}} = E - (\delta_{input} + \delta_{num} - \delta_D) = \boldsymbol{E - \delta_{val}}$$

Validation – UQ methodolgy

ASME VV-UQ: determination of engineering model uncertainty

Validation against high fidelity numerical experiments – single phase flows



$$\boldsymbol{\delta_{model}} = E - \left(\delta_{input} + \delta_{num} - \delta_D\right) = \boldsymbol{E - \delta_{val}}$$

→ Smaller engineering model uncertainties possible!

Main idea for *single-phase* flows

High fidelity numerical experiments
- application oriented
- fill experimental gaps

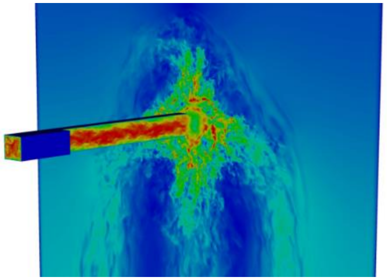
Uncertainty quantification

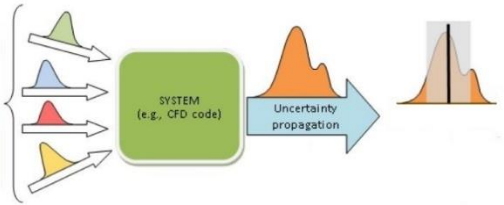
Engineering model validation

Machine learning

Engineering model improvement

Contribute to improved safety & design



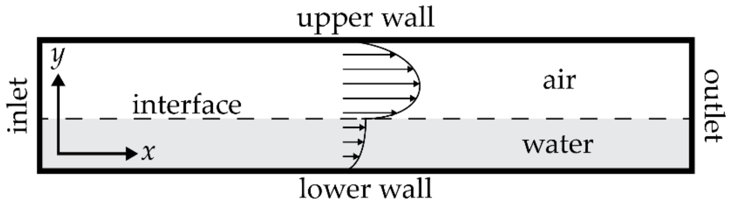


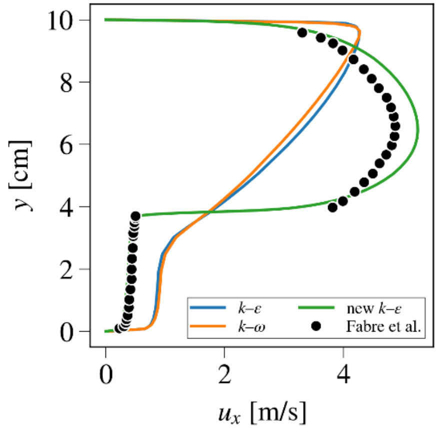
- Improved engineering models
- Smaller engineering model uncertainties

High fidelity simulations for *two-phase* flows

Illustration of the need, example

Horizontal co-current channel flow of Fabre et al, 1987



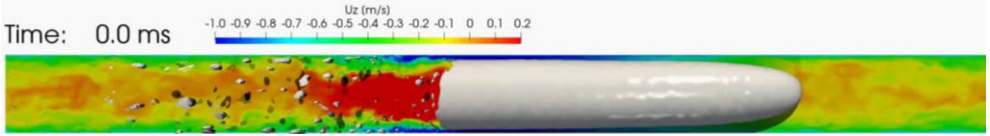


- Standard engineering models fail
- Further engineering model development needed

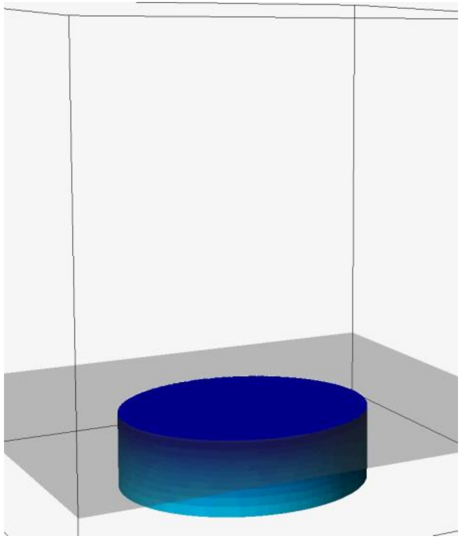
→ Need for complementary high fidelity two-phase flow ‘numerical experiments’

High fidelity simulations for *two-phase* flows

Two examples



LES Co-current Taylor bubble flow:
E. Frederix et al, FTAC 2020



DNS saturated pool boiling,
Y. Sato, B. Niceno, IJHMT 2018

- Currently, uncertainties in two-phase flow high fidelity simulations are generally (much) larger those in single-phase flow simulations
- Reasons: unresolved interfacial phenomena like coalescence, break-up, ….and numerics more complex

→ Need for further development of high fidelity two-phase flow simulations

Research project idea for *two-phase* flows

Interested?

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1. Experiments
   - support development of HiFi interfacial sub-grid scale modelling

2. Improvement of two-phase flow HiFi simulations
   - improved sub-grid scale modelling
   - improved numerics

Uncertainty quantification

3. Engineering model validation

Machine learning

4. Engineering model improvement
   - n-field all flow regime modelling (n=2,3,…)

- Improved engineering models
- Smaller engineering model uncertainties

Contribute to improved safety & design

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Questions?

EU DuC = N