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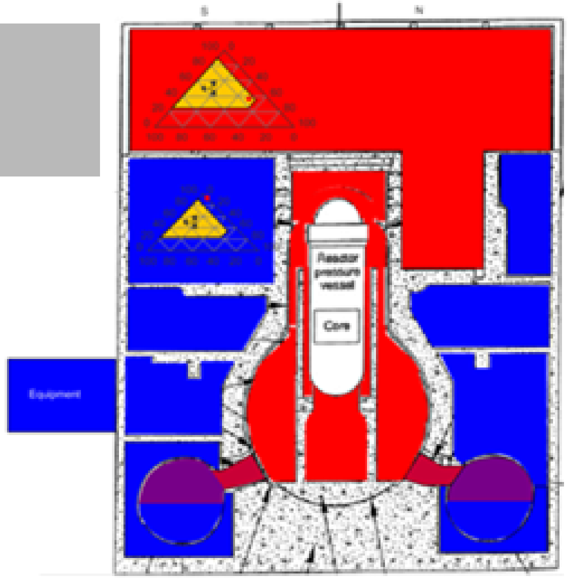
Horst-Michael Prasser

Labor of Thermal Hydraulics

NES Infotag, 18.10.2016

Important severe accident projects

Fukushima benchmark
(BSAF)



PSI work in Phase 2:

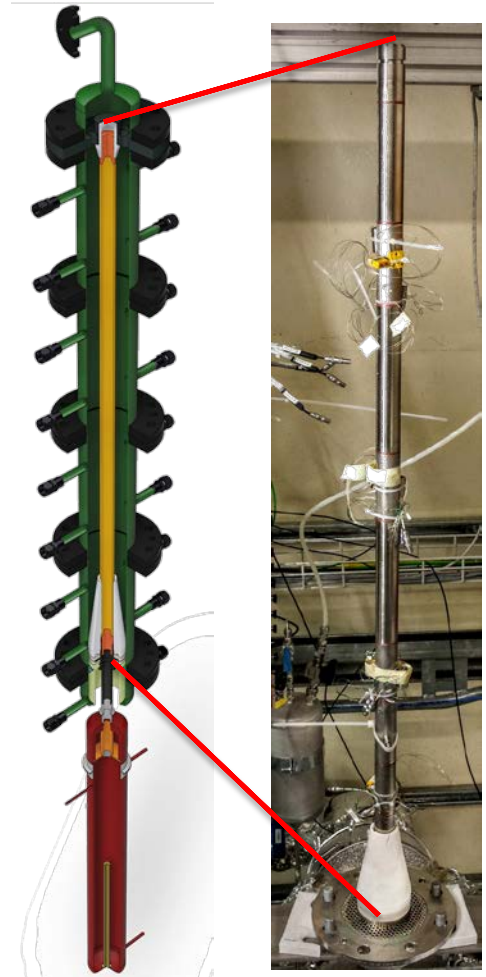
Unit 3

- Include fission product transport
- Different release paths

Phase 3 (?)

- PSA level 3

Reflux condensation
(PhD project F. Janasz)



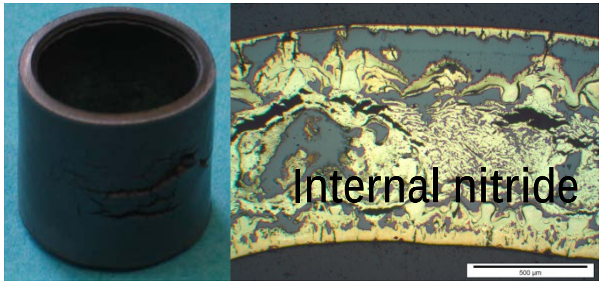
Continuation:

- Add aerosols
- Improve instrumentation

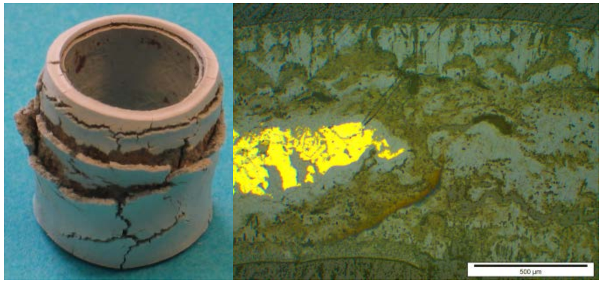
Cladding oxidation in air
(PhD project S. Park)

Pre-oxidation (O_2)

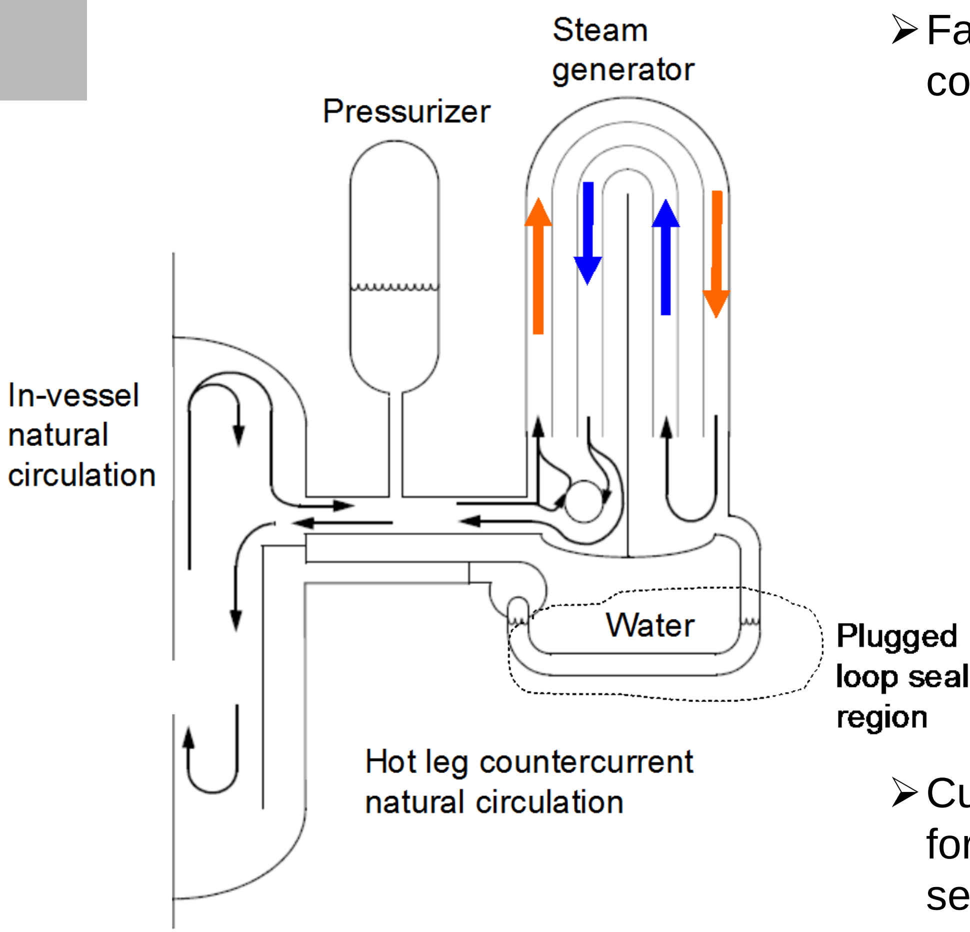
Nitriding (N_2)



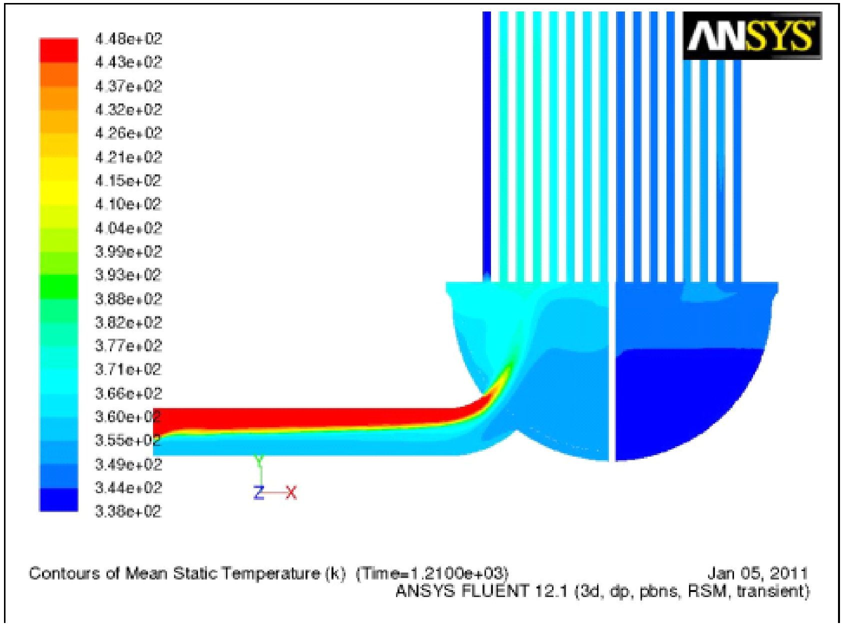
Re-oxidation (O_2)



Mixing in Hot Leg and Steam Generator Inlet Plenum



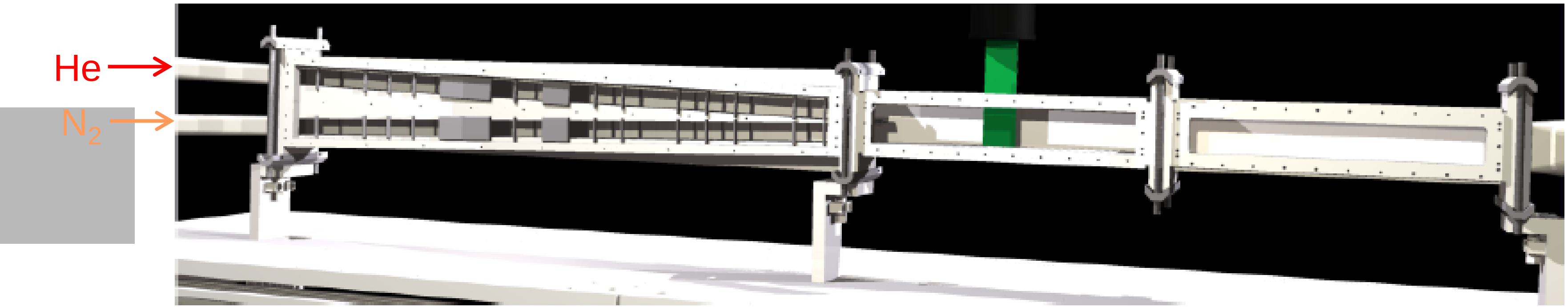
- ➢ Failure of SG tubes before Hot Leg → containment bypass scenario



- ➢ Current system codes: Failure time about *same* for hot-leg, surge line, SG tube: predictions very sensitive to BC → need in CFD + validation

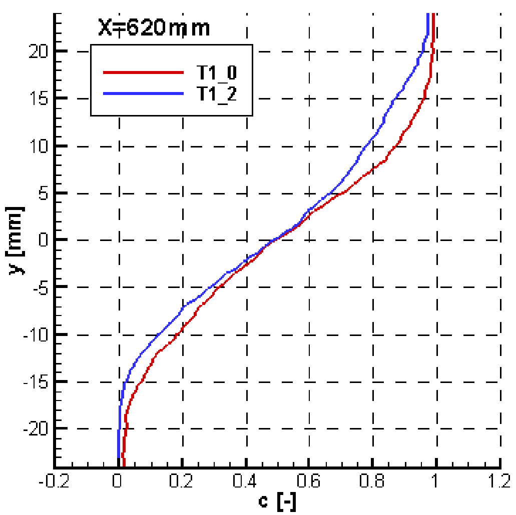
Status: Theoretical analyses by CFD simulations show relevance of the phenomenon

HOMER/GAMILO = non-Boussinesq mixing tests

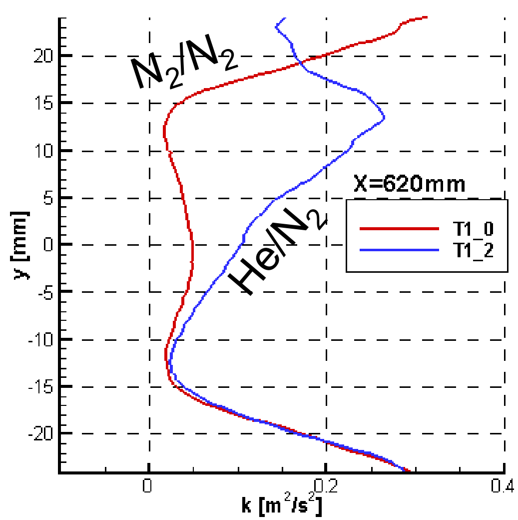


PIV and LIF of He/N_2 mixing (ρ_{N2}/ρ_{He} = 7) – contribution to **THINS (EU project)**

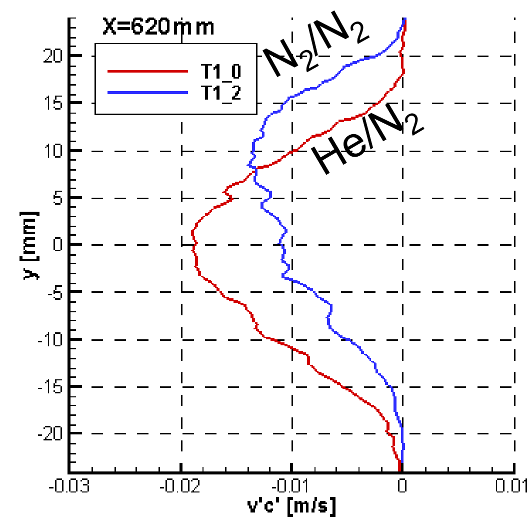
Concentration



Turbulent E_{kin}

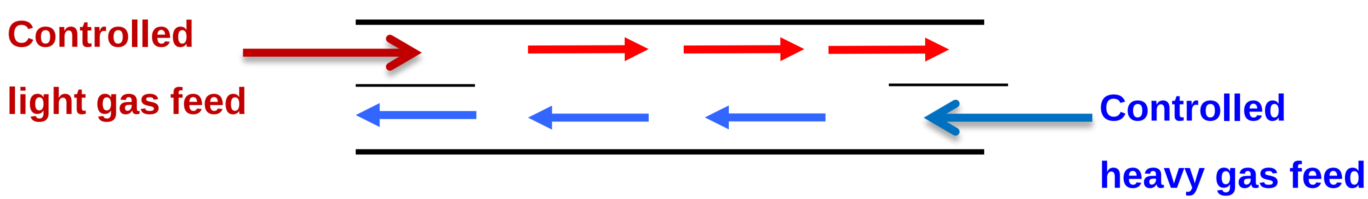


Turbulent conc. flux

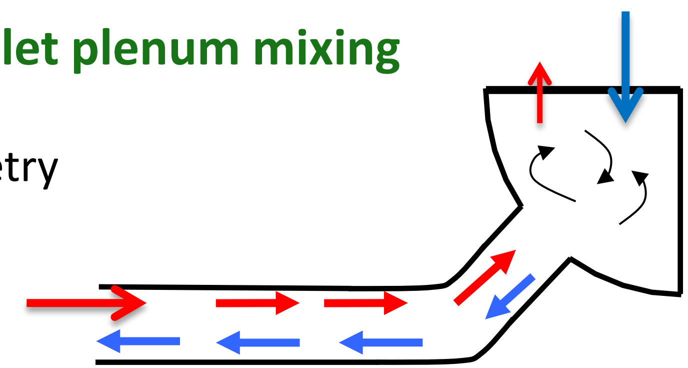


Temperature Induced SGTR - experimental

- **Phase 1: Co-current flow gas mixing**
  - Use of existing data from HOMER/GAMILO facility at PSI for analyses
  - Co-current flow
- **Phase 2: Hot leg counter-current flow**
  - Extension of present tests by new counter-current flow experiments



- **Phase 3: Steam generator inlet plenum mixing**
  - Introduce inlet plenum
  - Variable inlet plenum geometry



- **Phase 4: Large scale tests in ATLAS at KAERI (Scaling-up)**
  - Two tests for large scale validation of the codes
    - Natural circulation mixing of superheated steam cooled by secondary air
    - Effect of light gas (He) in SG – does natural circulation stop?

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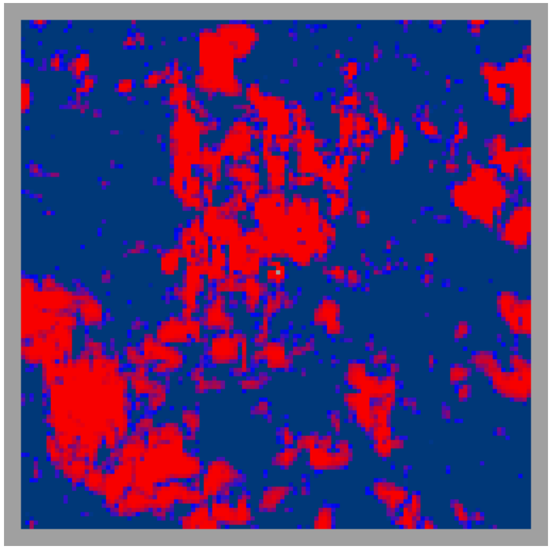
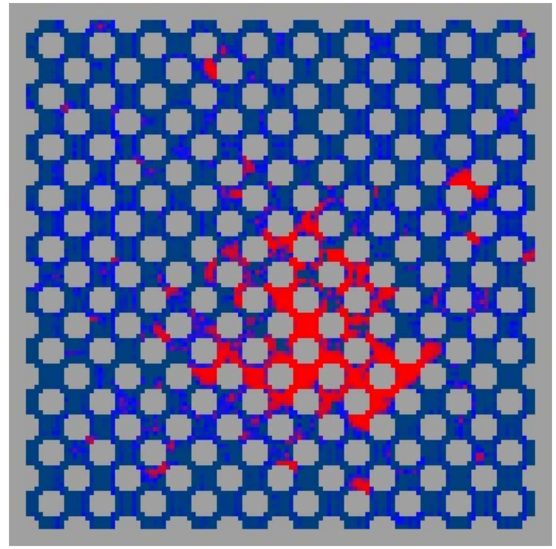
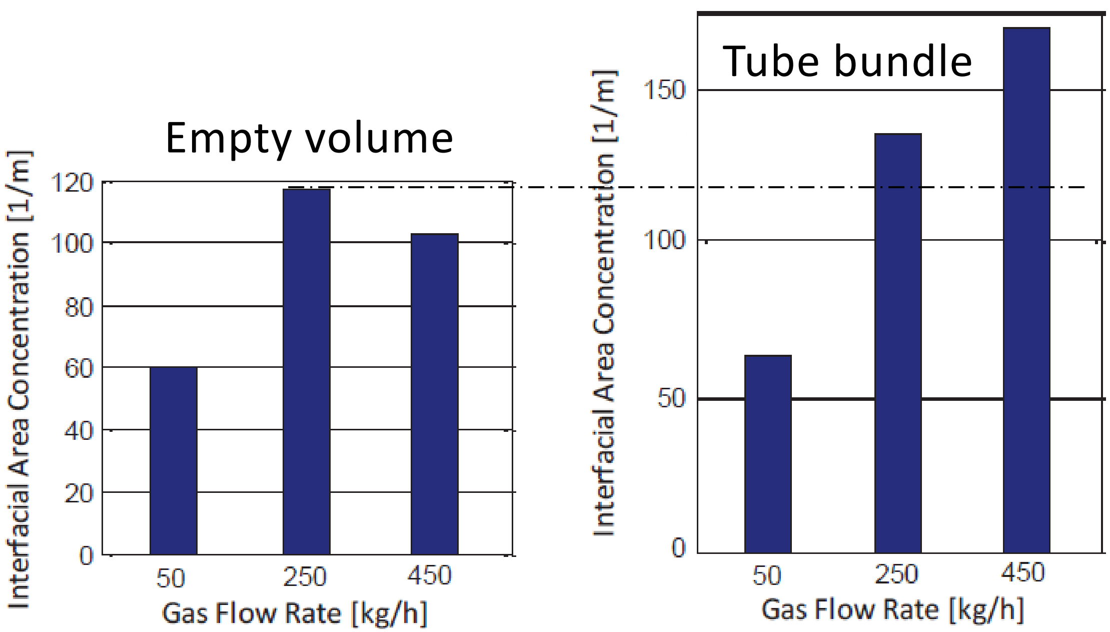
FCVS of (for?) Generation III

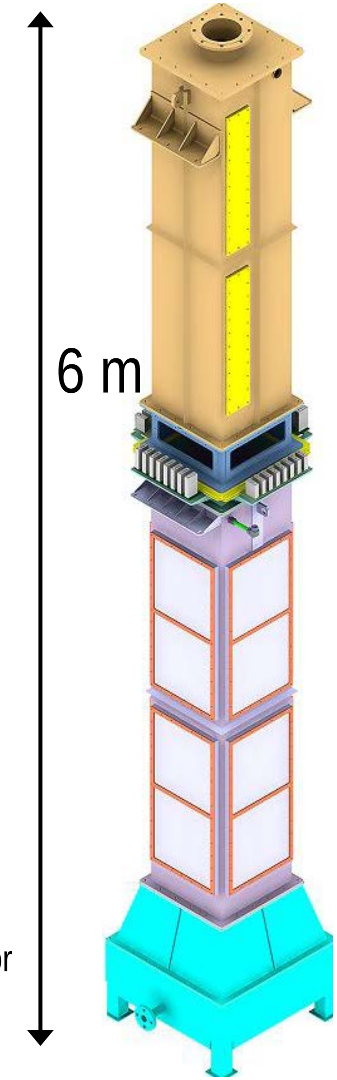
- **Optimization of the wet scrubbing process**
  - Design of injection nozzles / venturies (increase IAD and aerosol scrubbing)
  - Fluid-dynamic optimization of packings
- **New design of the flow control in the FCVS vessel**
  - Reorganize internal circulation
  - Passive decay heat removal
  - Reduce droplet entrainment by exhaust gas
  - Improve two-phase separation → mode compact filter size
- **Better chemistry**
  - New additives for retention of elementary iodine
  - New additives for retention of organic iodine
  - Exploring solid bed catalysts
- **Long term behavior** (both for wet scrubbers and dry filters)
  - Remobilization
  - Deterioration of chemicals during standby, operation and post-operation
  - Radiolysis studies
- **Deployment and decommissioning** (both for wet scrubbers and dry filters)
  - Treatment of activity laden retention material (liquids, solids)
  - Decontamination of structures, decontamination-friendly design

TRISTAN – Interfacial area concentration





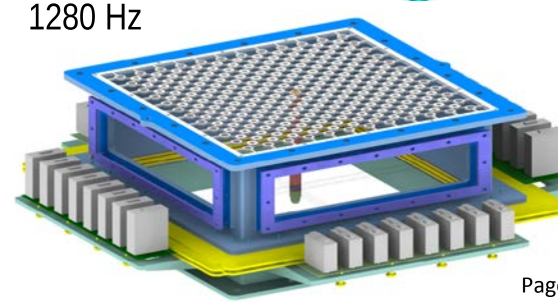




Wire-mesh sensor

120x120

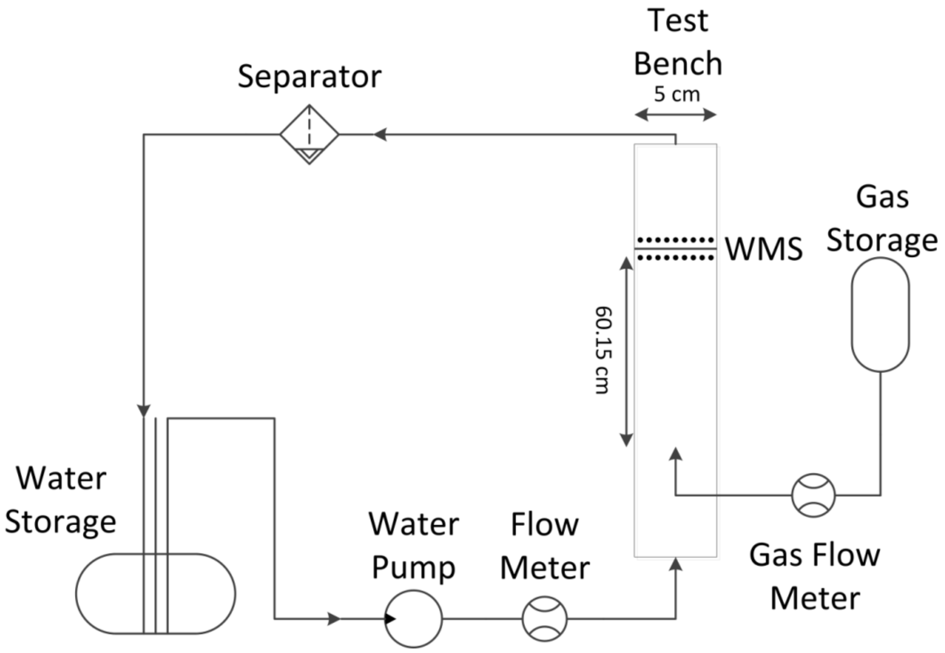
1280 Hz



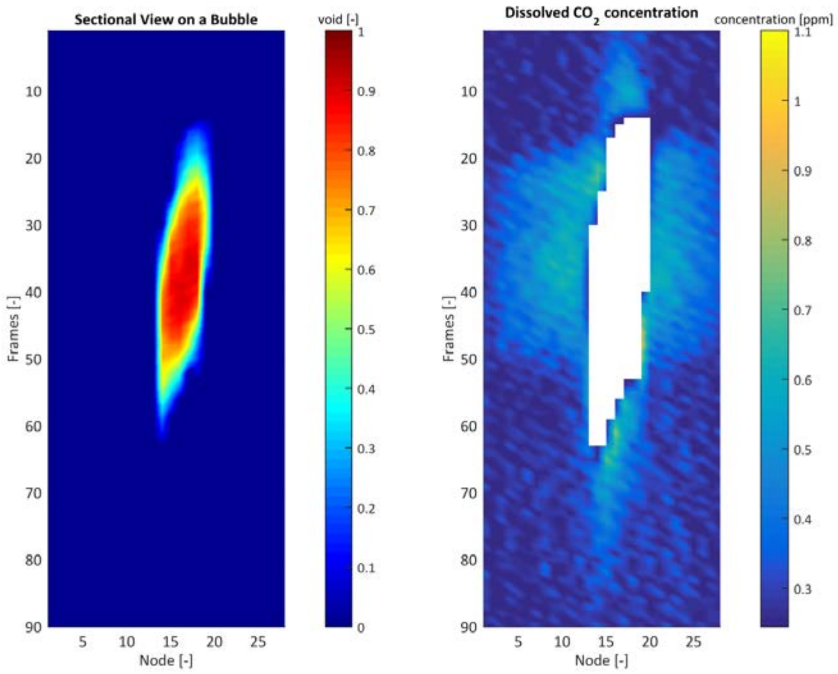
Next step: Mass transfer coefficient

$$\dot{m}_{transferred} = MTC \cdot IAD \cdot \nabla Conc$$

- Wire-mesh sensor used to detect bubbles & dissolved species simultaneously
- Model aerosol / model gas selected such that it increases electrical conductivity



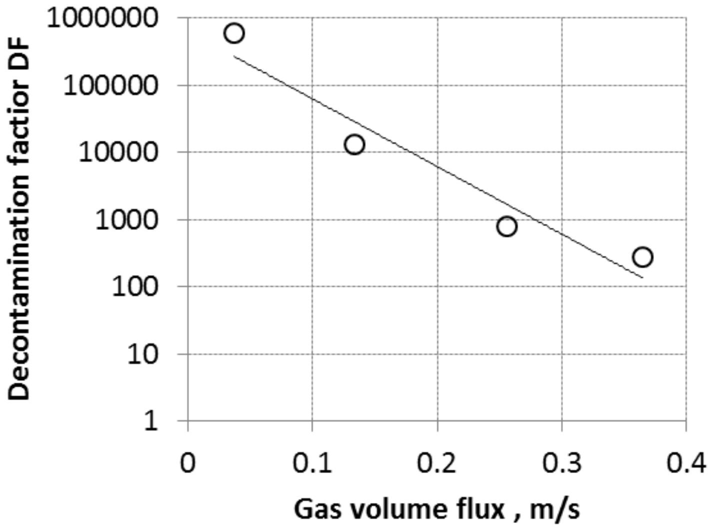
Test loop at ETH Zurich

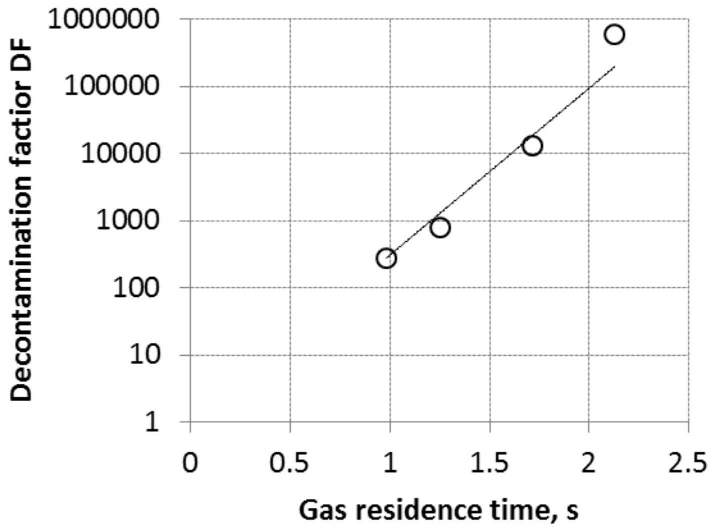


Sectional view on a CO_2 bubble in terms of void and dissolved CO_2

Petros Papadopoulos (PhD student)

Elementary Iodine tests -MiniVefita





Stagnant

Gas injection

Beghi, Lind, Suckow, Jäckel, Opilik, Krepelova

Condensation & re-evaporation at LINX

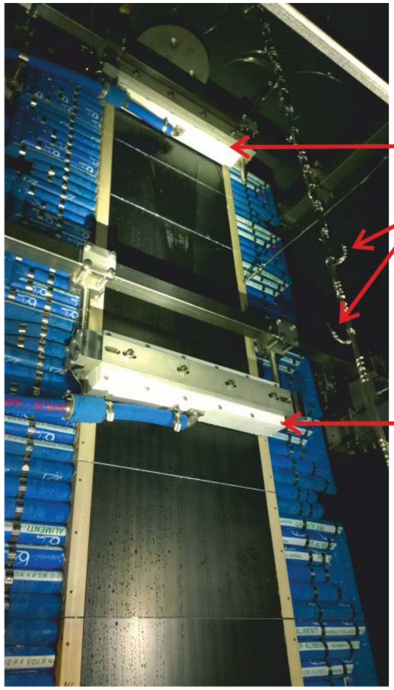


Plate heated, evaporation

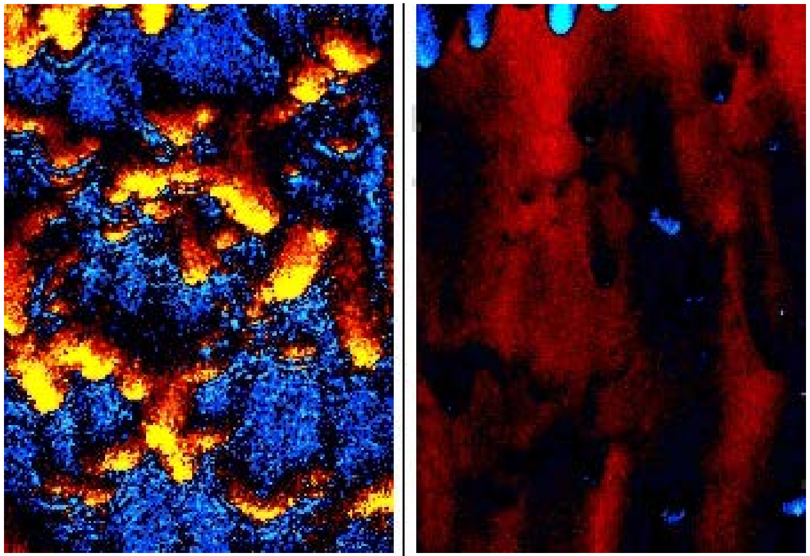
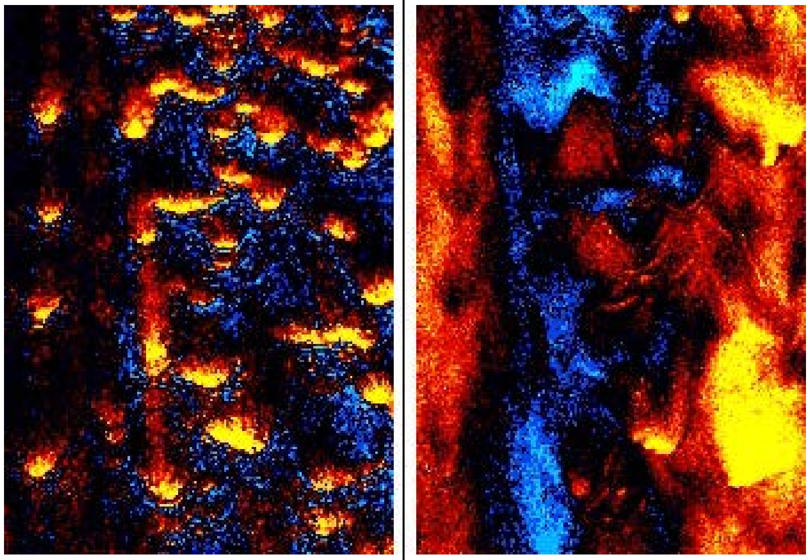


Plate cooled condensation



Film thickness by NIR (transmission)

Temp. by MWIR (fluctuating part)

Dupont, Guillaume

Film reconstruction

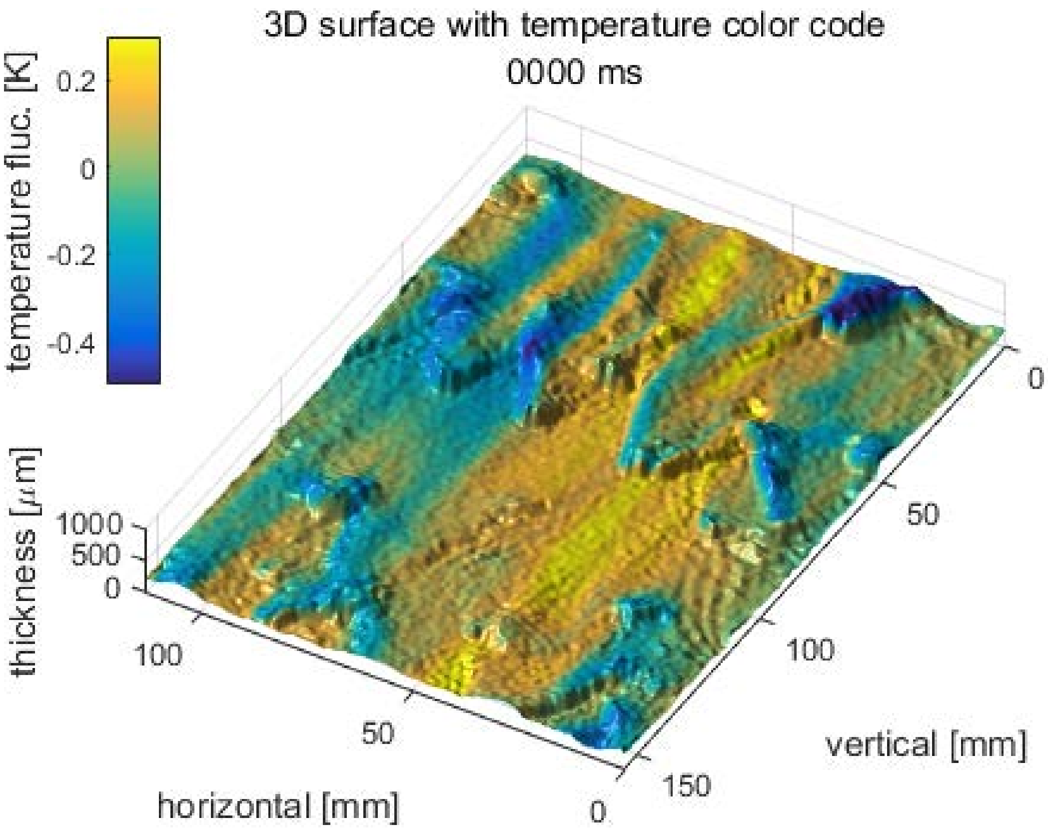
$$\dot{q}_{cond} = \frac{\lambda}{\delta} \cdot \Delta T = \alpha \cdot \Delta T$$

$$\overline{\dot{q}_{cond}} = \bar{\alpha} \cdot \overline{\Delta T} + \alpha' \cdot \Delta T'$$

$$\alpha' = \left(\frac{\lambda}{\delta}\right)' = -\frac{\lambda}{\delta^2}\delta'$$

$$\Delta T' = T'_{film}$$

Film temperature fluctuates because of presence of non-condensable gas



Color: Temperature

Height: Film Thickness

Dupont → defended PhD, Mignot

Next steps – LINX-2

Extensive test series
- Vary thermodynamic parameters
- Combine condensation and evaporation on the same test plate

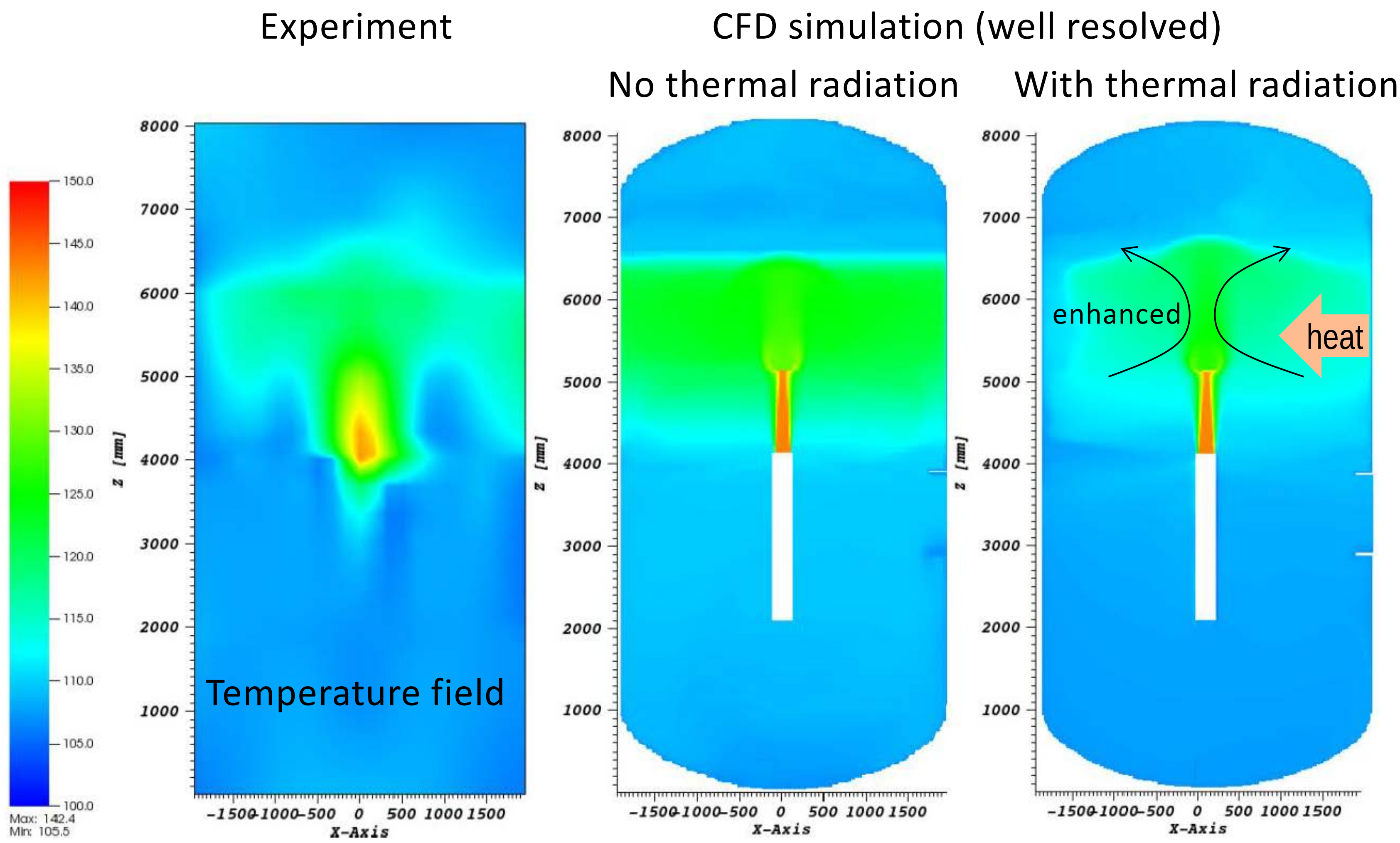
Vary wall properties
- Change wettability
- Different paints and covering materials
- Effect of thermal conductivity of covering material (?)

Aerosol deposition on condensate film
- Introduce soluble and insoluble aerosols
- Measure deposition (scrubbing) on condensate film

Analytical work
- System and CFD code validation (ASTEC, GOTHIC, FLUENT)
- High-resolution CFD modeling (e.g. LES + IT + LPT)

Alternative application of the IR instrumentation
- AP1000 internal and external water film on containment wall
- Film flows in passive coolers or similar

HYMERES: Relevance of thermal radiation



- Walls heat eroding vapor plume and enhance buoyancy → faster layer erosion
- Thermal radiation has feedback on velocity field due to IR absorption in vapor

Sharabi, PANDA team

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HYMERES-2

- Current HYMERES project to be completed by end of 2016 according to schedule

New proposal:

- PSI and CEA have proposed (PRG6-November 2015 and PRG7- June 2016), to continue with a phase 2.

Research topics:

- ***Topic 1: extend the database on flow impacting obstructions and containment internals***
- ***Topic 2: thermal radiation***
- ***Topic 3: extend the database on suppression pressure pool and BWR systems***
- ***Topic 4: extend the database on safety components performed operation***

Project period:

- 2017-2020

Project costs:

- Total: 6.1 MEURO
- PANDA: 4.6 MEURO (24 tests). **i.e. external contribution to PANDA, about 550 KEURO/YEAR**
- MISTRA (CEA): 1.5 MEURO (10 tests)

NEST Pilot Project Concept

- *Option I - Practical Training Courses*

Practical training courses related to HYMERES-II – 1-2 weeks

focused on experiments and be an experimental training course

focused on computation/simulation

- *Option II. HYMERES-II activities related to NEST*

Development tasks for groups of NEST Participants

Self-dependent work of NEST Participants under the guidance of Mentors

Discussions of problems and results of NEST Participants' work at meetings.

- *Option III. NEST Fellows*

PSI and CEA would each host few advanced students, post docs or young professionals, designated as NEST Fellows (for a period of 6 months or more)

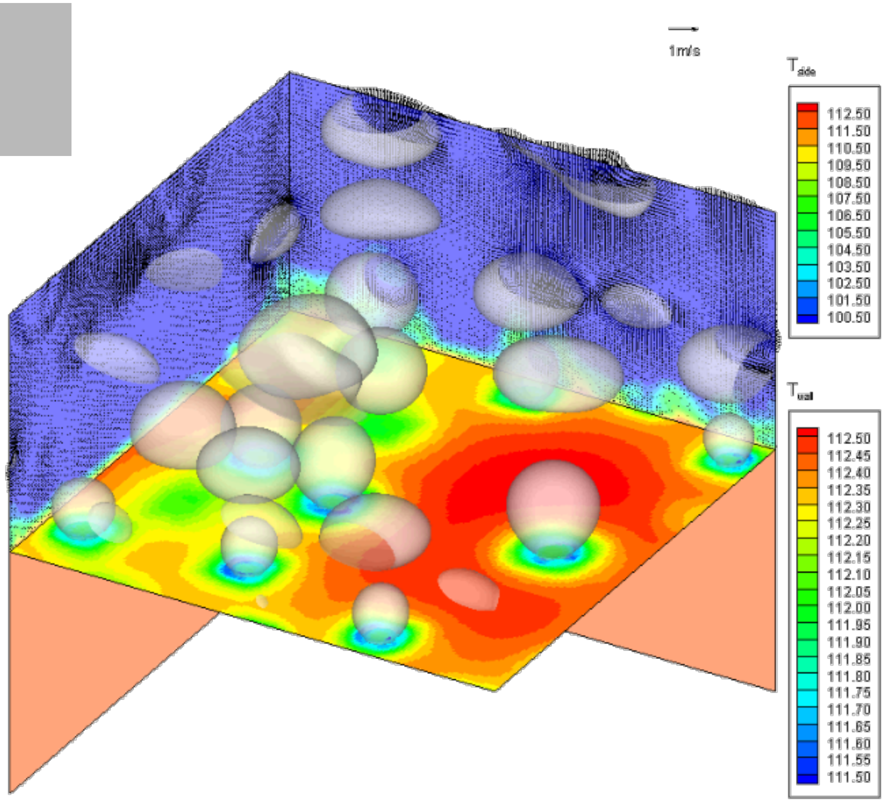
Project/work descriptions drafted by the operating agents of HYMERES-2

- *Added value: Multidisciplinary Activities*

Participants get some exposure to other fields of research and education beyond the containment hydrogen question (e.g. using opportunities of the ETH NE master program)

Fundamental boiling simulations

Progress to date: Flow boiling LES + IT with multiple nucleation sites (HPC)



- Micro-layer model
- Pool and flow boiling studies
- Conjugate heat transfer
- Stochastic nucleation site distribution
- Multi-scale approach down to molecular dynamics

Next steps:

- Compressive flows (condensation hammers)
- Forced evaporation

Strategic goal:

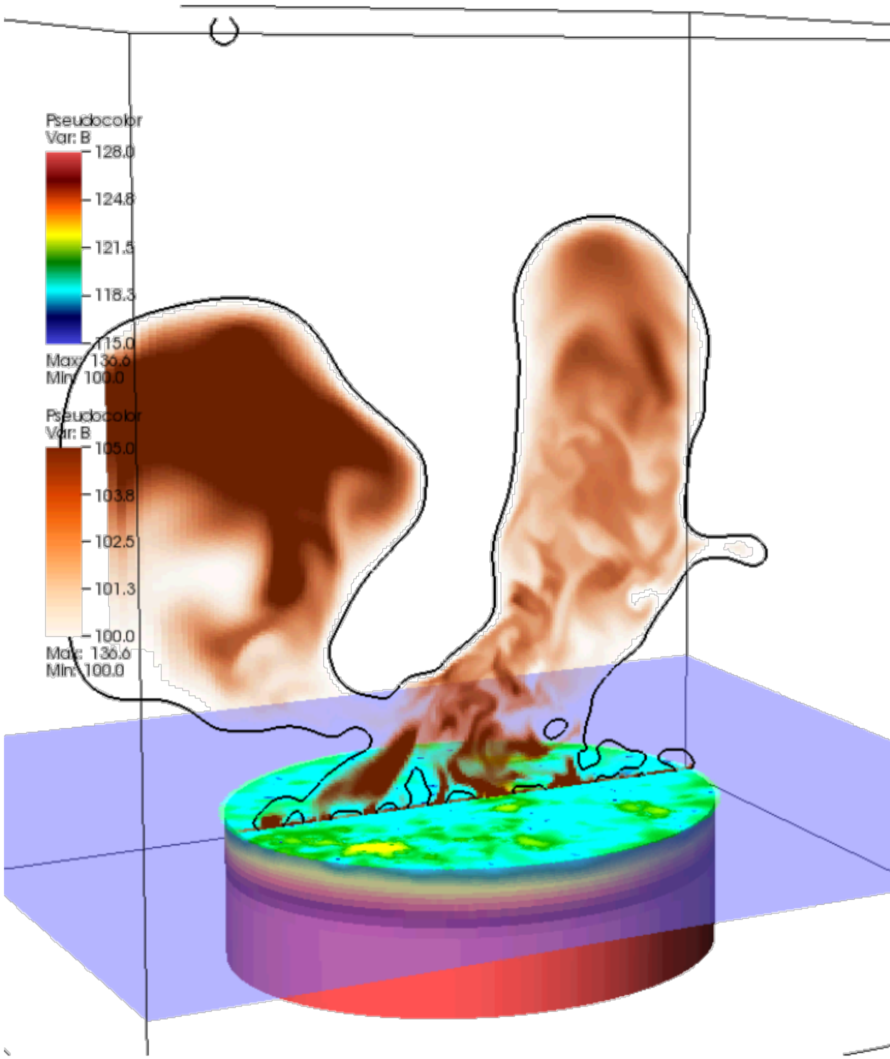
- Fundamental simulation of Departure from Nucleate Boiling (DNB)

Goal:

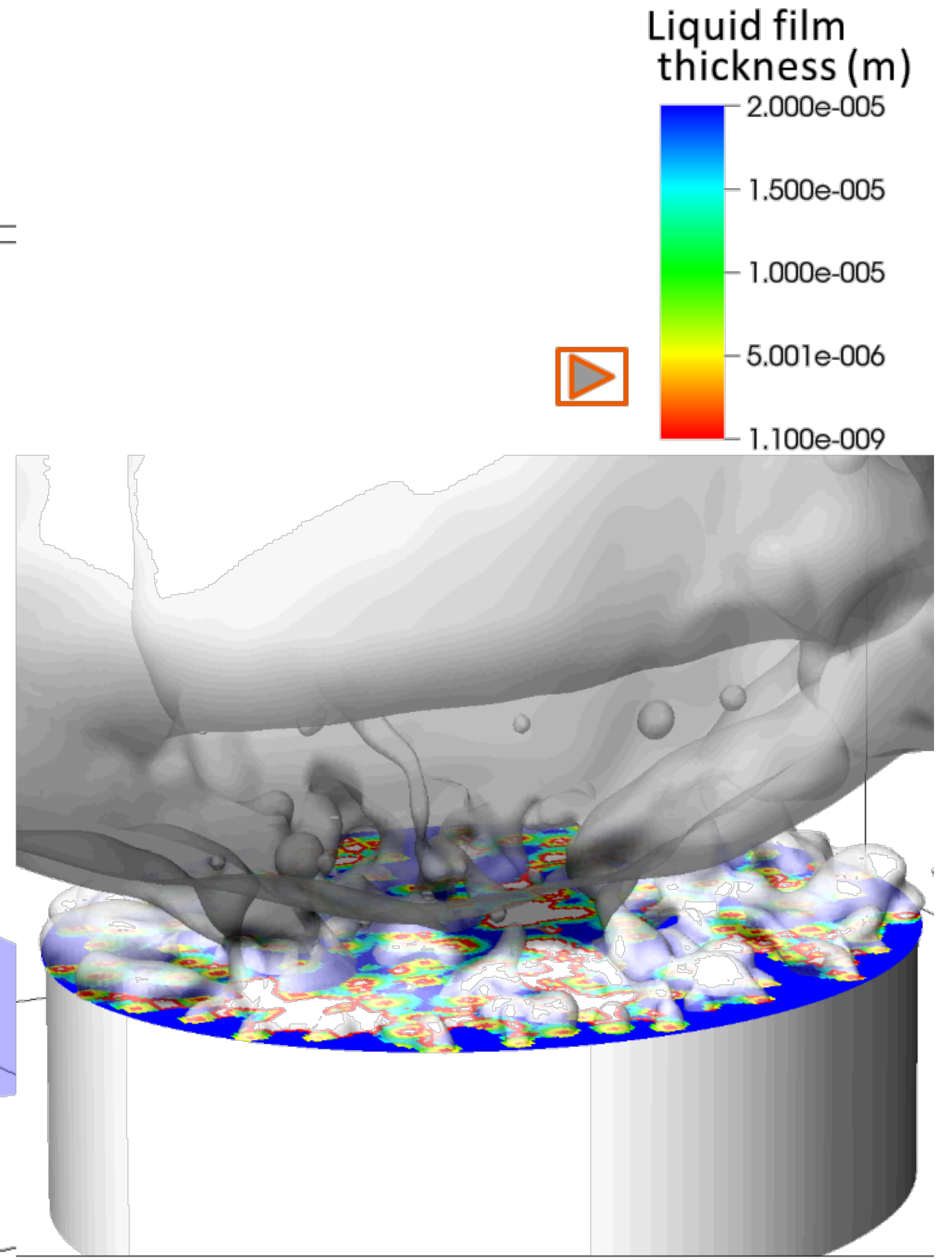
Prediction of DNB

Yohei Sato & Bojan Niceno

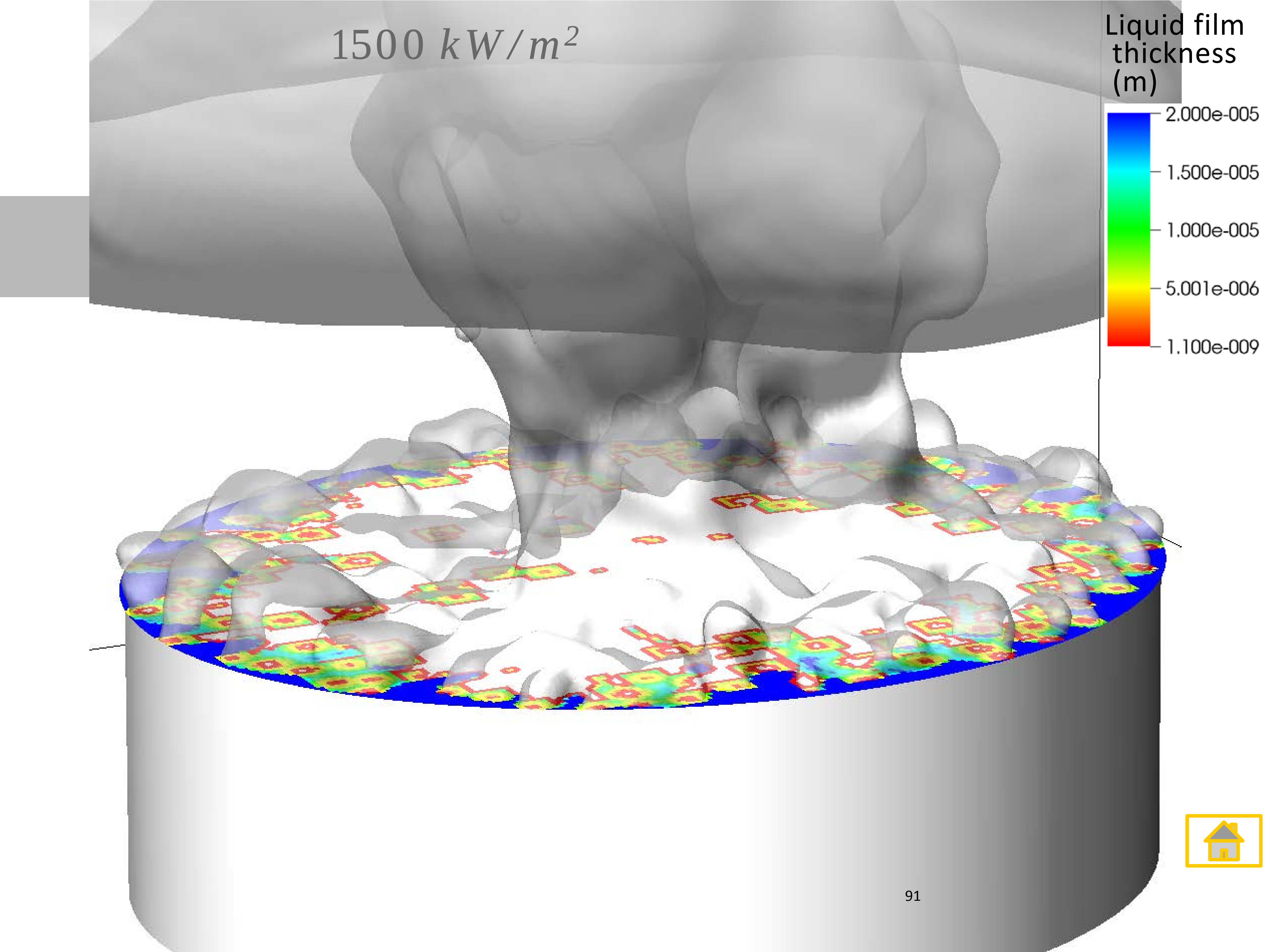
$1200\ kW/m^2$



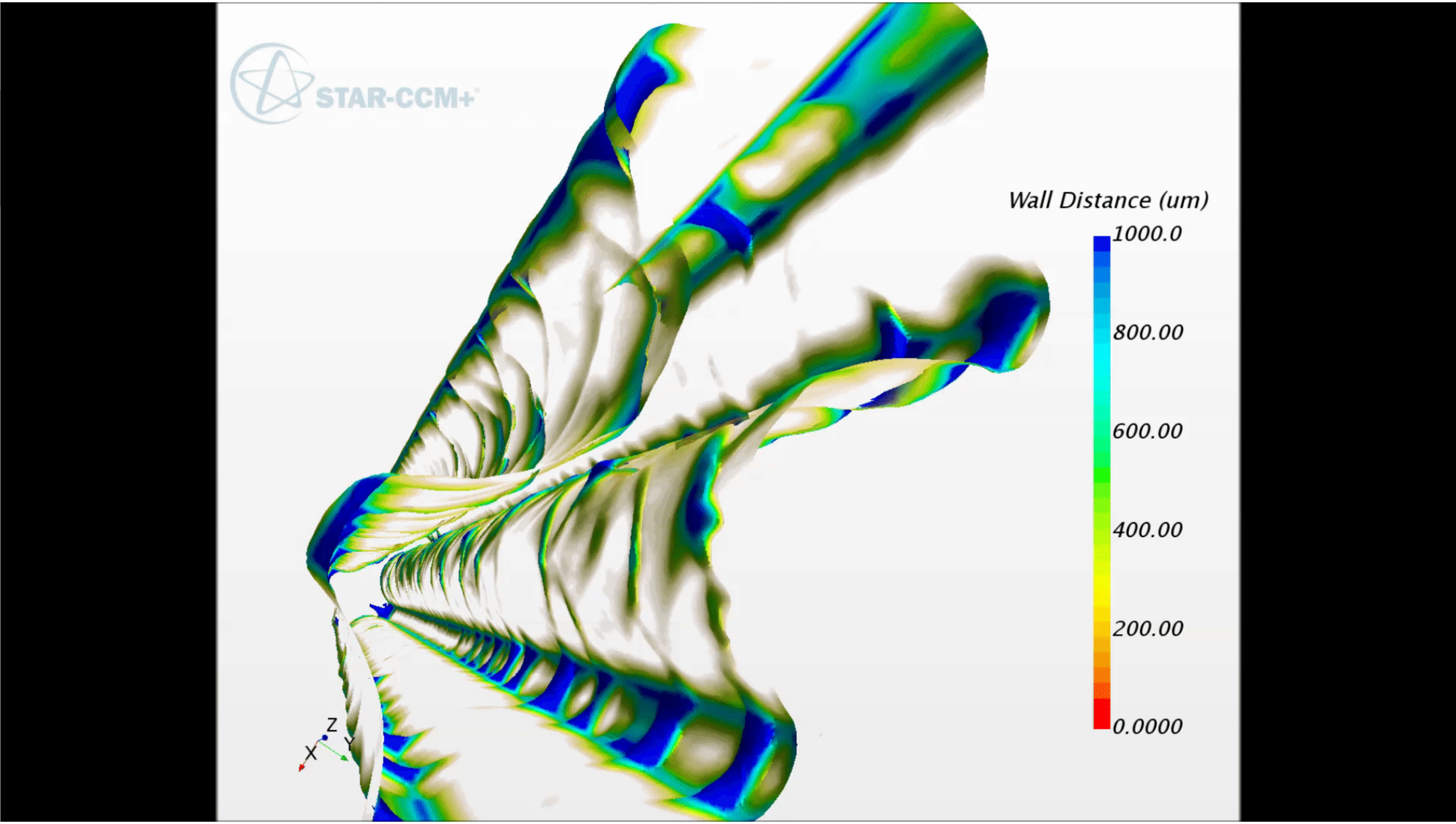
Temperature distribution



Liquid film thickness


1500 kW/m²
Liquid film thickness (m)
2.000e-005
1.500e-005
1.000e-005
5.001e-006
1.100e-009

URANS of film flow in subchannel (adiabatic)



Abhishek Saxena

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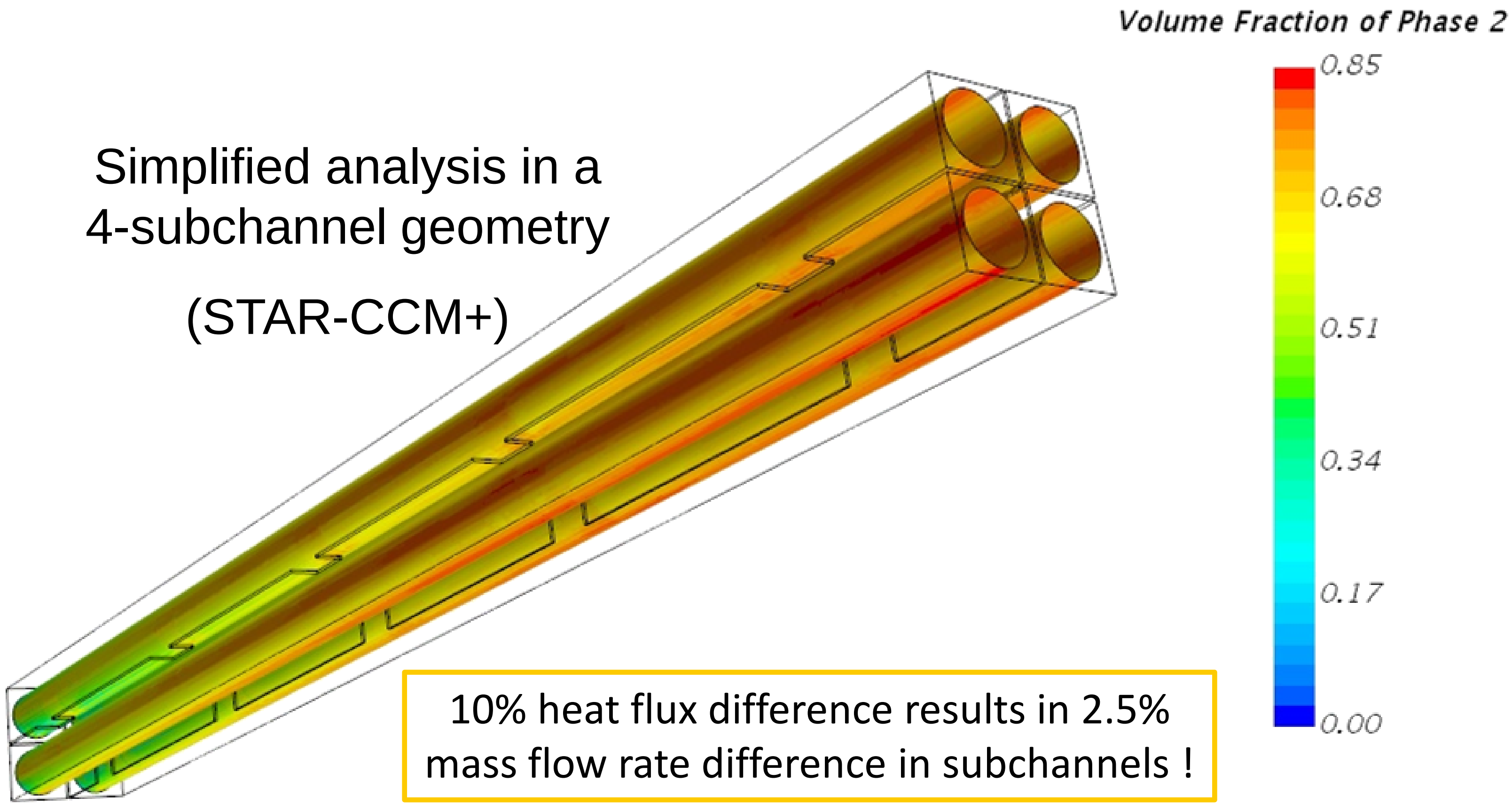
Feasibility of full two-phase fuel element studies

Simplified analysis in a 4-subchannel geometry

(STAR-CCM+)

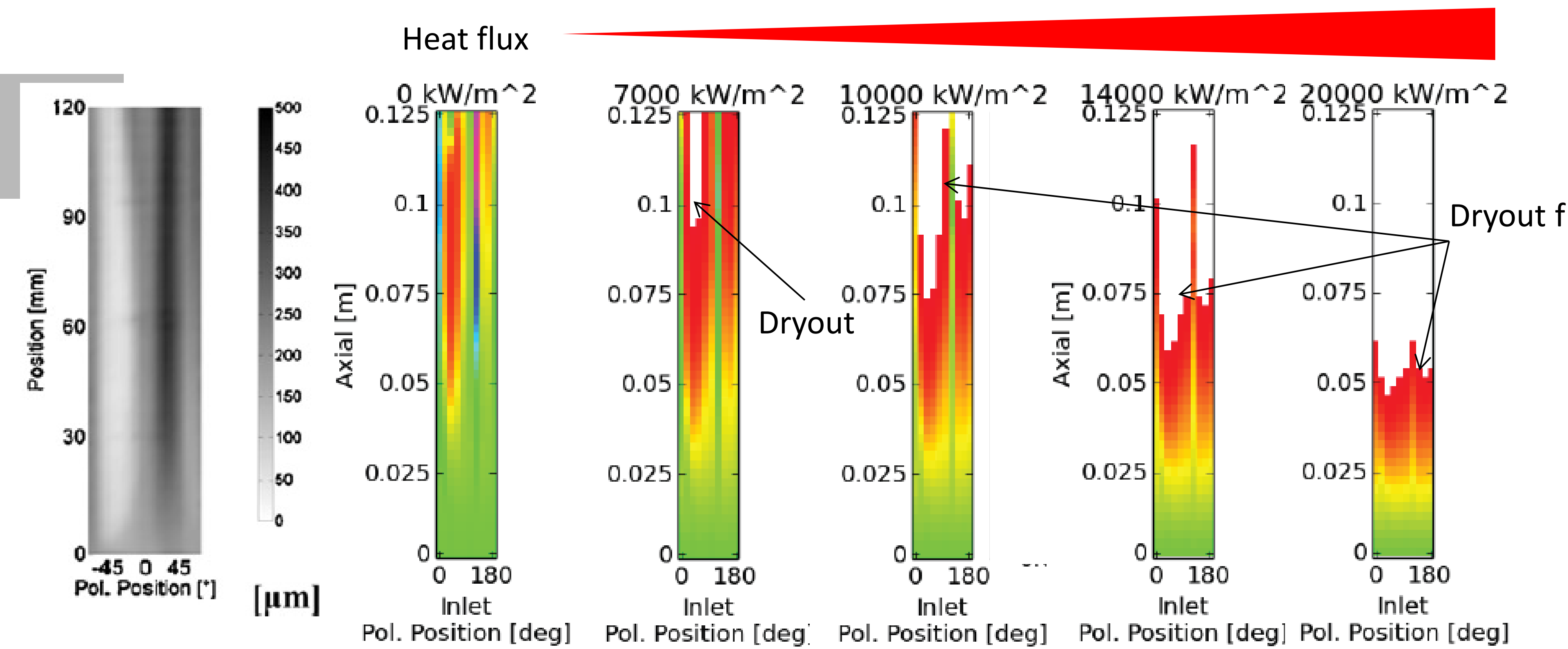


10% heat flux difference results in 2.5% mass flow rate difference in subchannels !

- Original plant parameter (BWR)
- Euler-Euler two-fluid model with k-eps turbulence

	⇨	
• 4 full length subchannels ~ 9 Mio Cells • Solver time → ~ 8 days on 32 CPUs • 1 node = 24 CPUs used on EULER cluster	⇨	• Full BWR fuel element ~ 250 Mio Cells • Solver time → ~ 30 days on 216 CPUs • 9 nodes = 216 CPUs = 72 kCHF + OH

RANS: 3D gas + 2D liquid



Adiabatic air-water test

Adiabatic chloroform case

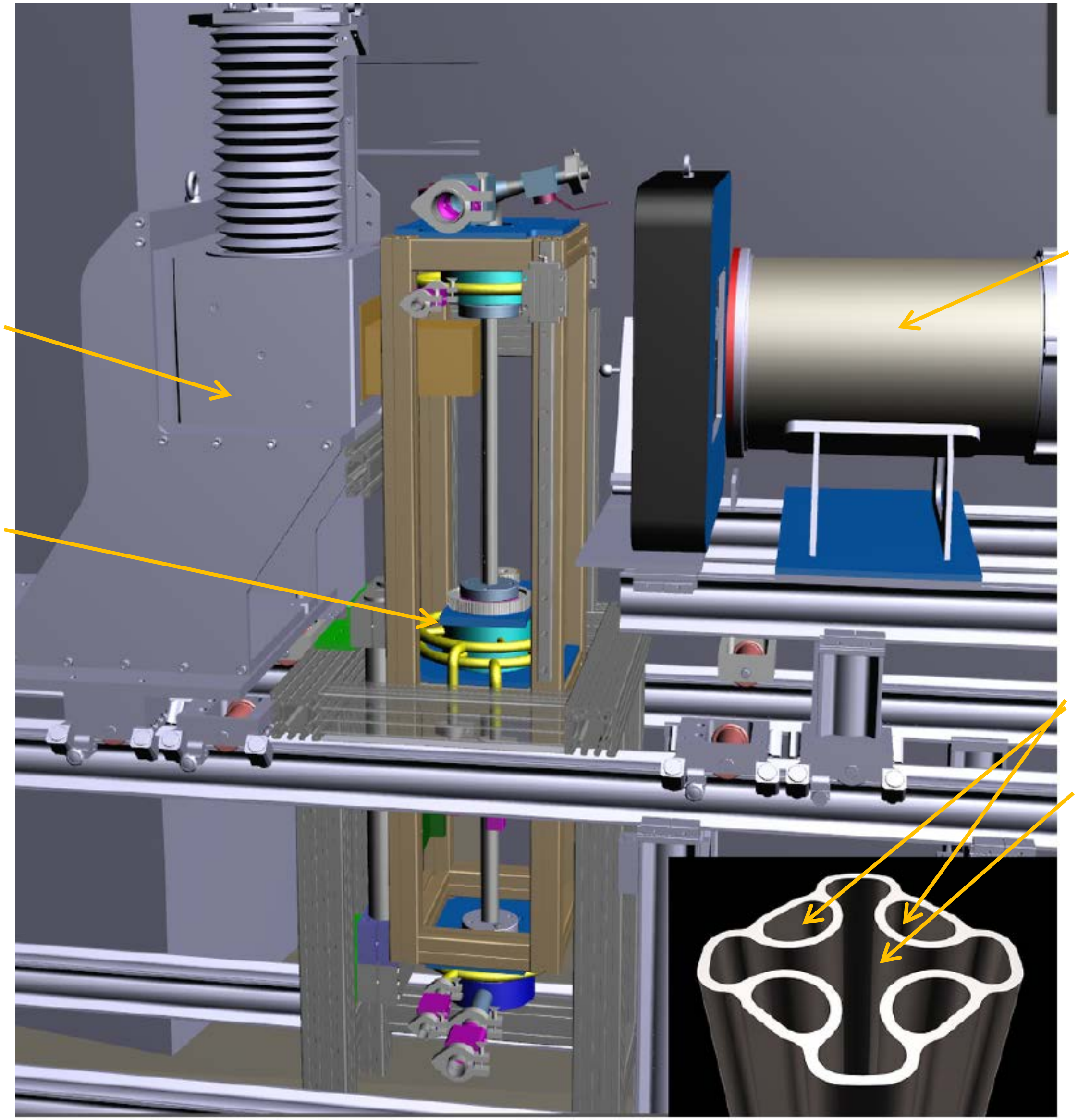
Uniformly heated chloroform cases

No mass transfer

Mass sink term due to evaporation implemented in 2D film model

PhD Student: Abhishek Saxena, Master student: Kerstin Cramer

Boiling & dryout in subchannels



Neutron camera

Rotating mechanism

Beam line of cold neutrons

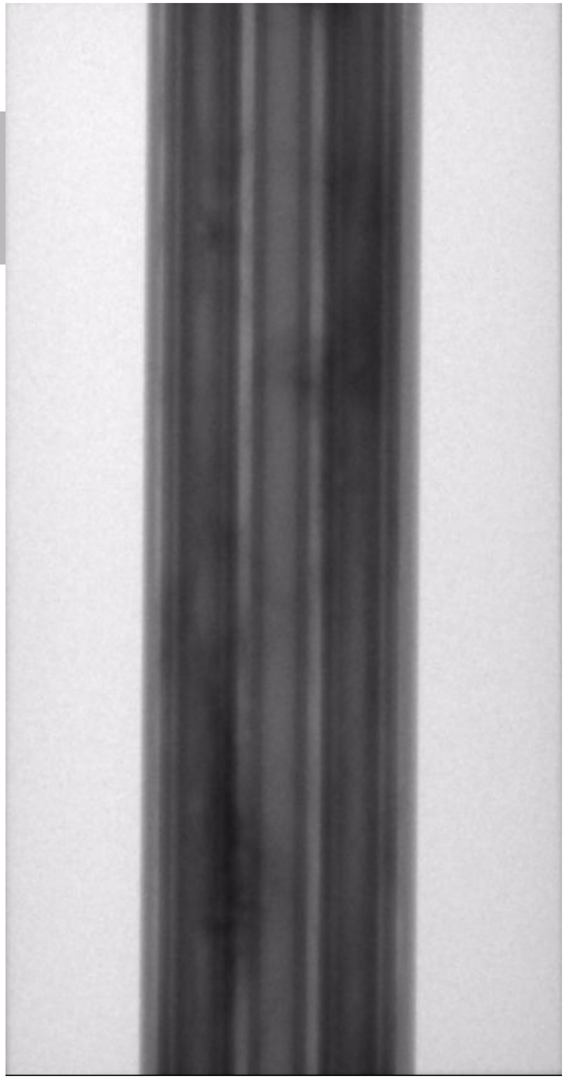
Test subchannel

Heating fluid D_2O

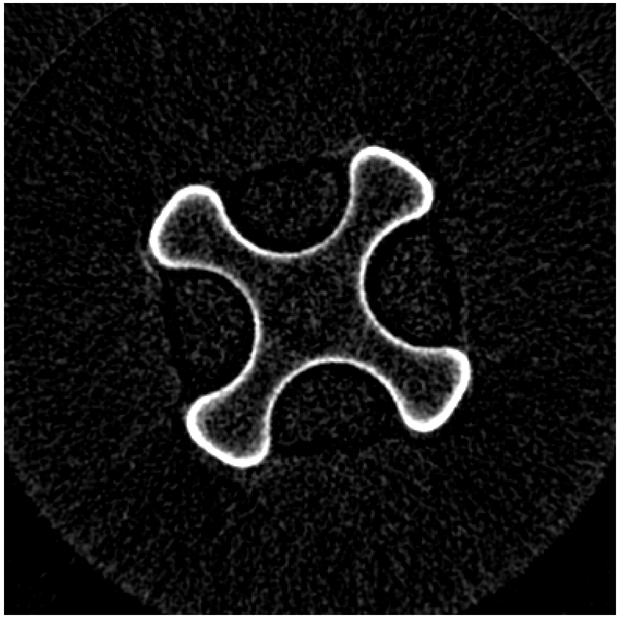
Model fluid $CHCl_3$

Bolesch, Zboray

First X-ray images



Sequence of X-ray images



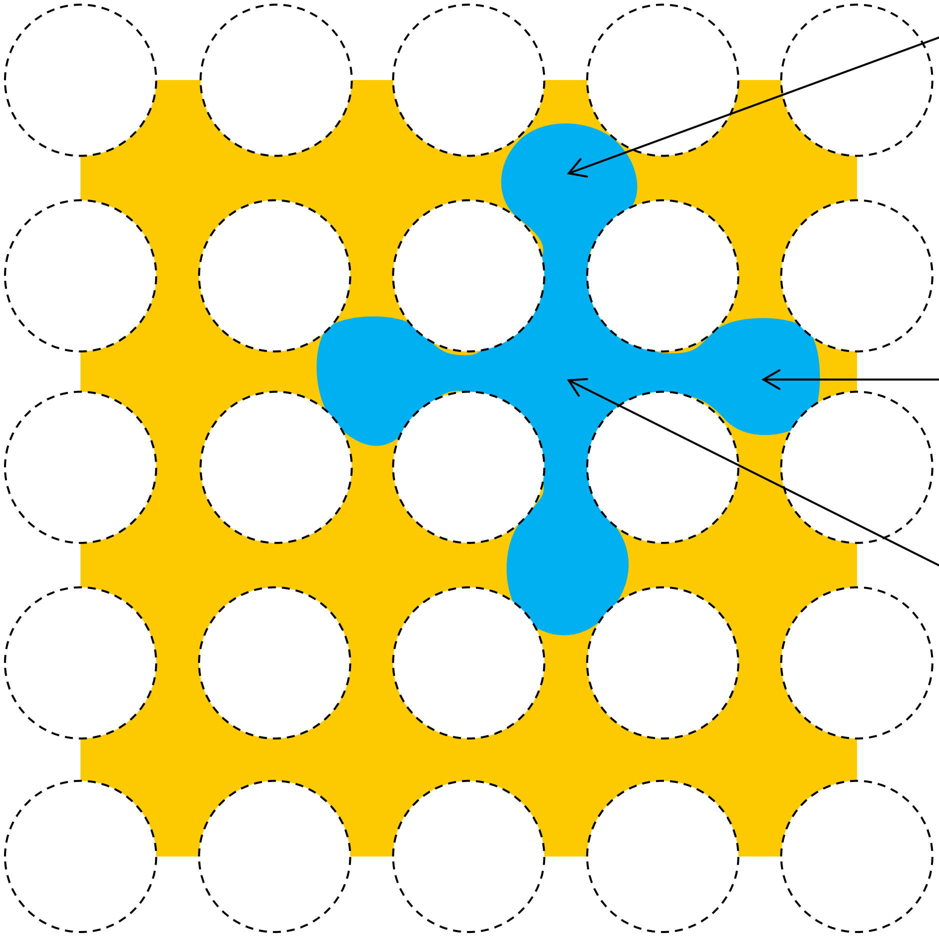
Tomographic reconstruction of a single cross-section

In December 2015: First cold neutron tomography at ICON of SINQ

→ Report of Robert Zboray

→ PhD student: Chris Bolesch

Status boiling test with fluid heating



5 subchannels

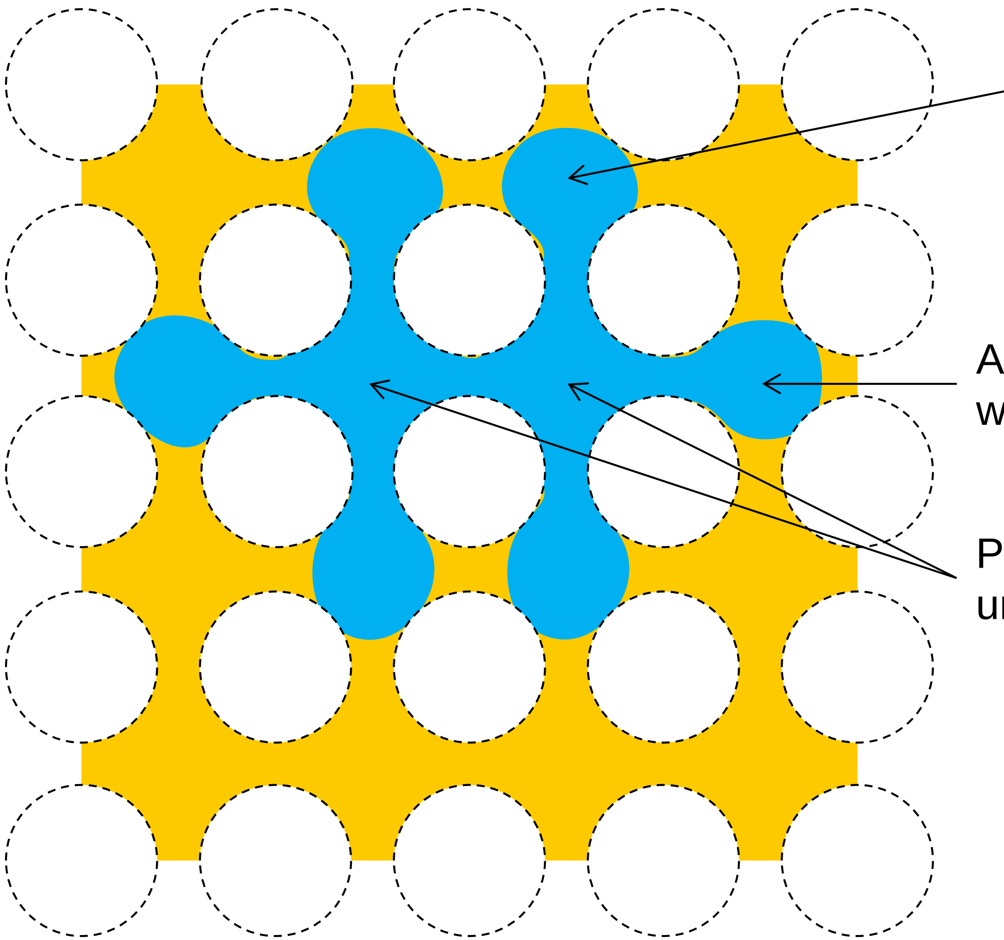
- cold neutrons (ICON)
- X-ray imaging (ETHZ)

Auxiliary side-subchannel without sharp edges

Main subchannel without unrealistic no-slip conditions

Rectangular lattice

Potential extension of boiling test



8 subchannels

- cold neutrons (ICON)
- X-ray imaging (ETHZ)

Auxiliary side-subchannel without sharp edges

Pair of subchannels without unrealistic no-slip conditions

Goal: Study influence of inter-subchannel oscillations on film boiling

Summary: Tools of LTH

Laboratory of Thermal Hydraulics
Head: Prof. Dr. H.-M. Prasser
Deputy head: R. Zboray

Secretary
Andrea Mohr

Group Experimental Thermal Hydraulics
Leader: Dr. D. Paladino

- PANDA
- LINX
- GEMIX
- HOMER/GAMILO
- SUBFLOW
- FLORIS
- Neutron Tomo (MCNP…)

Group Modeling and Simulation
Leader: Dr. B. Niceno

- PSI-Boil
- FLUENT
- STAR-CCM+
- GOTHIC
- Multi-scale mod.

Group Severe Accidents
Leader: Dr. Terttallisa Lind

- VEFITA
- MiniVefita
- Aerosol tests
- MELCOR
- ASTEC
- Eul.-Lagr. CFD

Thank you for the attention