Paul Scherrer Institut, Switzerland

NES Infotag 2014

H.-M. Prasser

Laboratory of Thermal Hydraulics

Scope and strategy of LTH

- **Model development & validation for reactor and plant Thermal Hydraulics**
- **Containment Thermal Hydraulics**
- **Passive safety systems**
- **Severe accidents, aerosols, iodine, accident management methods**
- **Innovative fluid dynamic instrumentation**
- **Support and integrate education (Master in Nuclear Engineering)**

Theoretical methods

- **Solution of the Navier-Stokes equation (1D, 2D, 3D, steady-state, transient)**
  - Velocity field in (very) complex geometries, forces acting on structures
+ **Energy conservation, heat sources**
  - Temperature fields in fluid and walls, temperature fluctuations
+ **Two-fluid model**
  - Two-phase flow, phase transition
+ **Transport equations for additional fluid components**
  - Complex mixing cases
+ **Chemical reactions**
  - Reactive flows, *e.g. combustion, cladding oxidation, severe accidents*
+ **Transport equations for particles**
  - Aerosol flow fields, deposition, re-mobilization
+ **Transport equations for gas-liquid interfaces**
  - Fundamental studies of boiling, condensation, two-phase flow structure

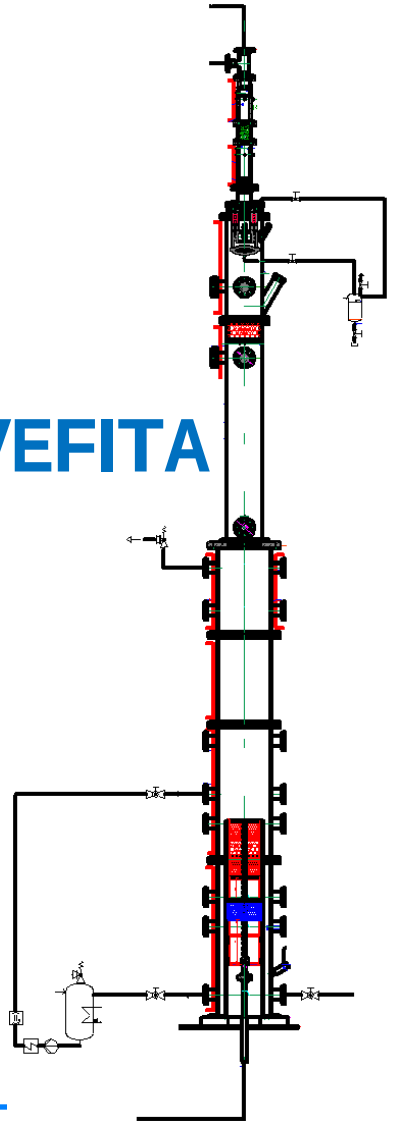
Experimental methods

- **Fluid-dynamic models (small, medium, large scale)**
  - Containment models
  - Fuel rod bundle models (adiabatic, heated), steam generator bundles
  - Testing of Filtered Containment Venting System
  - Simplified reactor models (e.g. for mixing studies)
  - Component models (e.g. steam generators, t-junctions)
- + **Media supply (steam, gas, water)**
- + **Aerosol generators**
- + **Advanced fluid dynamic instrumentation** (+ standard instruments, of course)
  - Wire-mesh sensors, neutron imaging, film sensors, infrared techniques, gas sampling techniques with mass spectrometer, special local sensors
- + **Aerosol/particle sensors and measuring techniques**
- + **Chemical sensors for specific components**
- + **Fast neutrons for imaging and special measurements**

DRAGON – LINX - VEFITA

DRAGON

VEFITA



DRAGON – aerosol generator

DRAGON 1

SnO_2 – plasma torch →

DRAGON 2

TiO_2, SiO_2, Cu – fluidized bed

Latex, SiO_2, DEHS[1] – atomizer

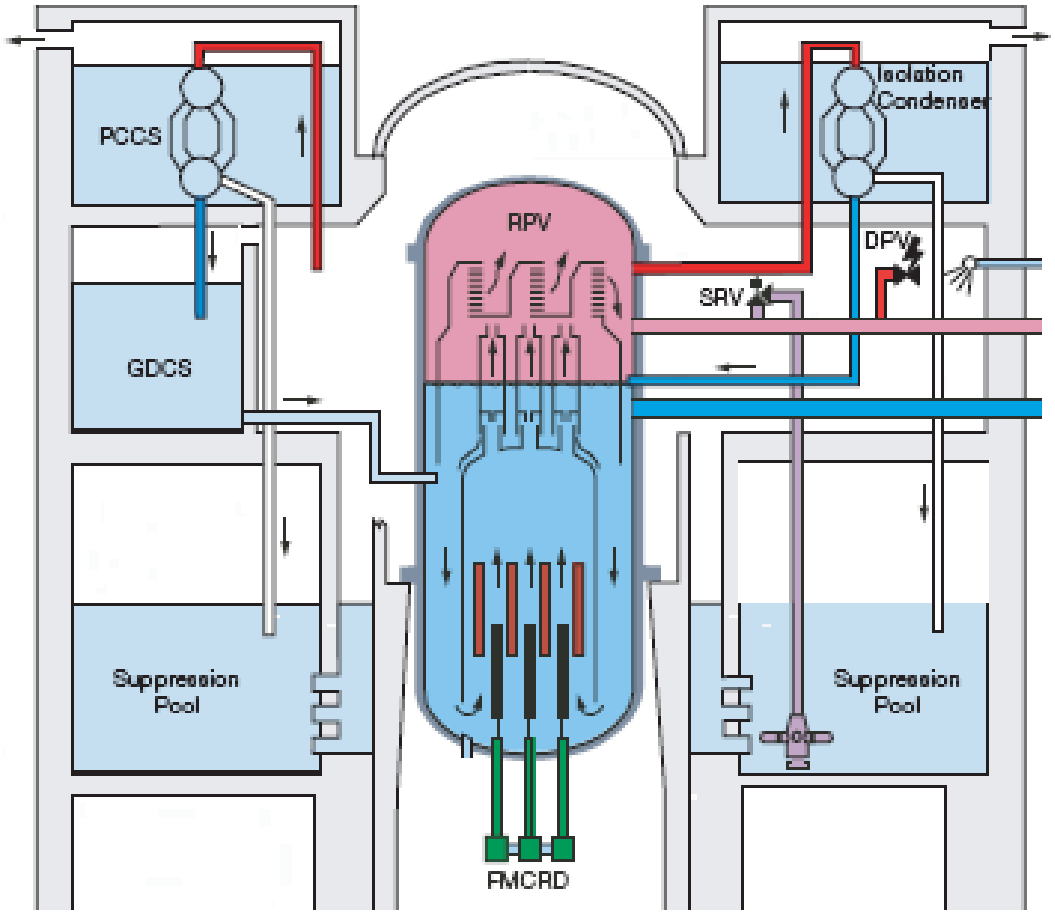
[1]DEHS = Di-Ethyl-Hexyl-Sebacat

+ Steam generator + Mixing chamber →

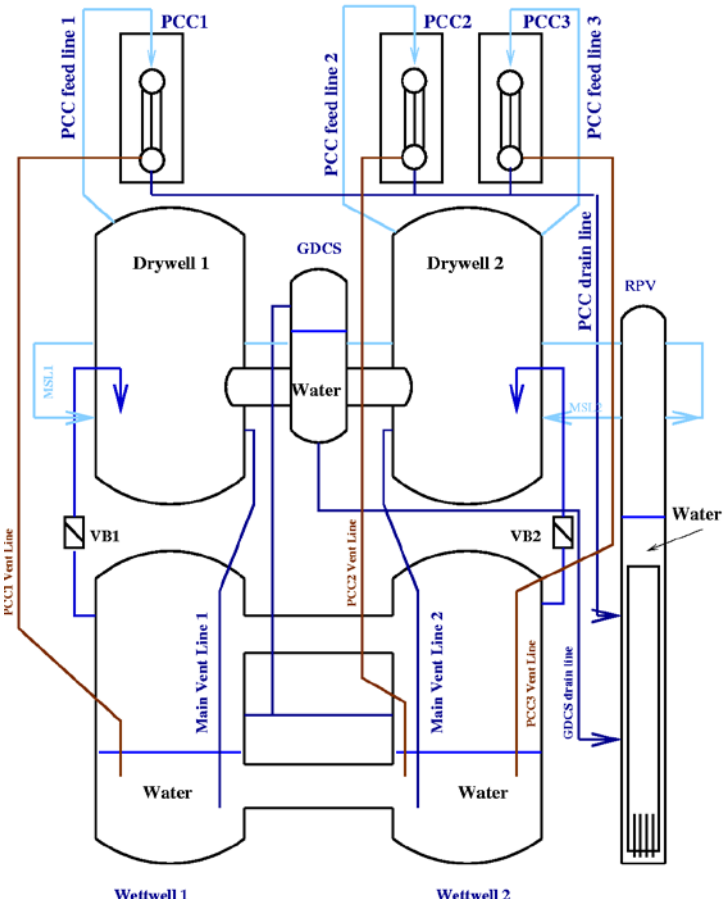
- Model fluid of the containment atmosphere under severe accident conditions

PANDA – large containment test

ESBWR

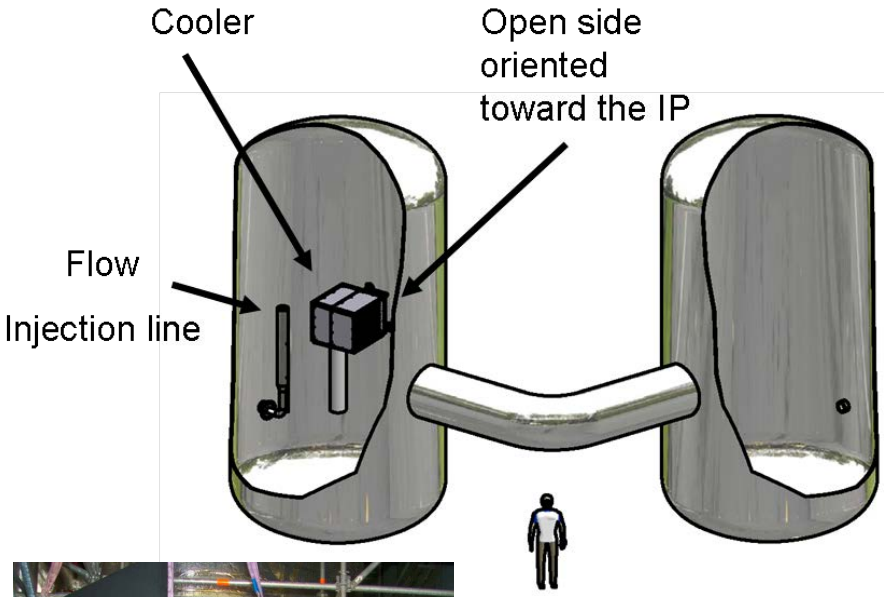


PANDA



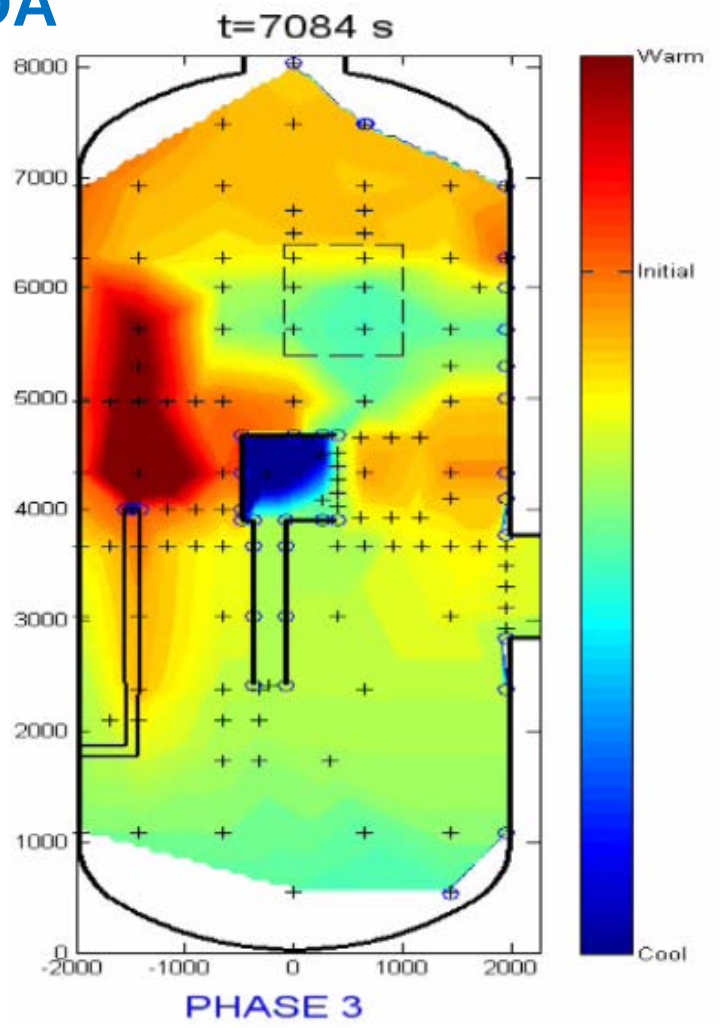
Focus: Gen-III reactors and passive safety systems

Complex mixing experiments

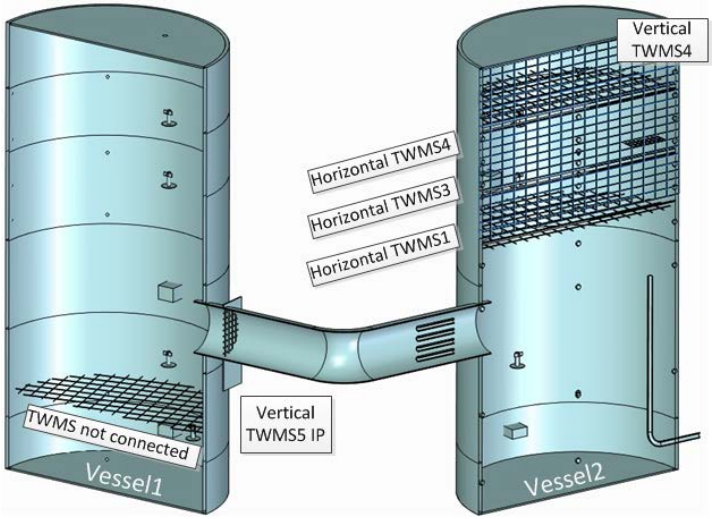


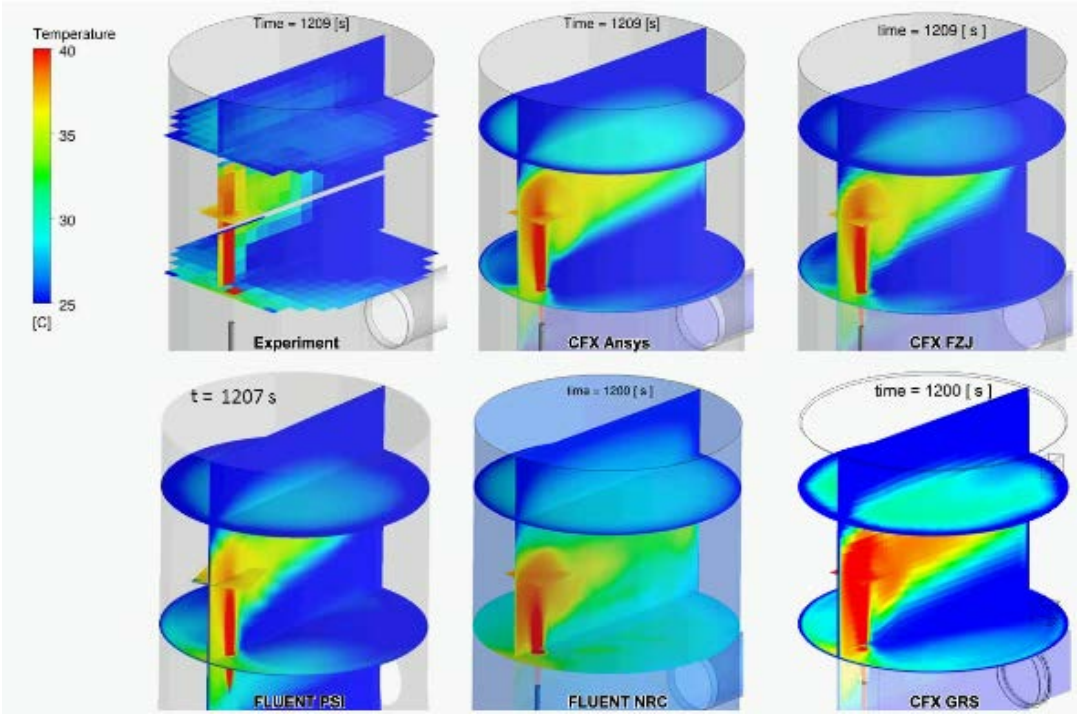
- Containment cooler performance under presence of hydrogen
  - HT blockage
  - Local H_2 conc.
- Effect of cooler position

PANDA



ETH MiniPanda Benchmark on the ‚Erosion of a Stratified Layer‘

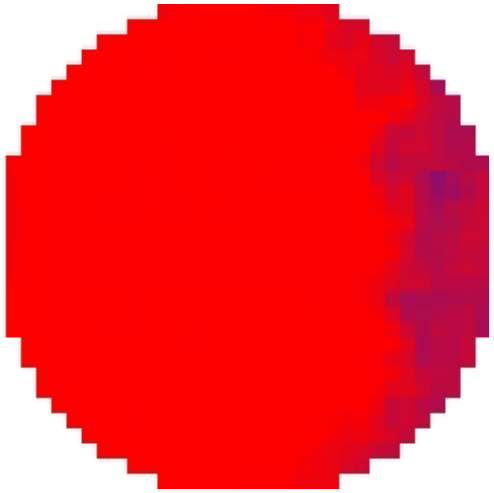




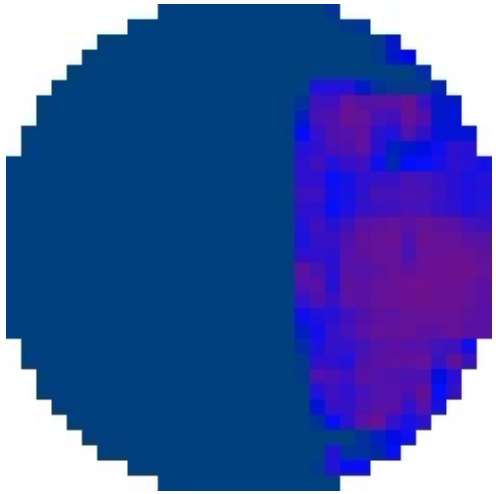
Duration:	July 2012 – March 2013
Purpose:	CFD code validation applied to hydrogen management in NPP
Participants:	ANSYS, GRS, KIT, FZ Jülich/RWTH Aachen (Germany), IBRAE (Russia), PSI (Switzerland), U.S.NRC (USA)

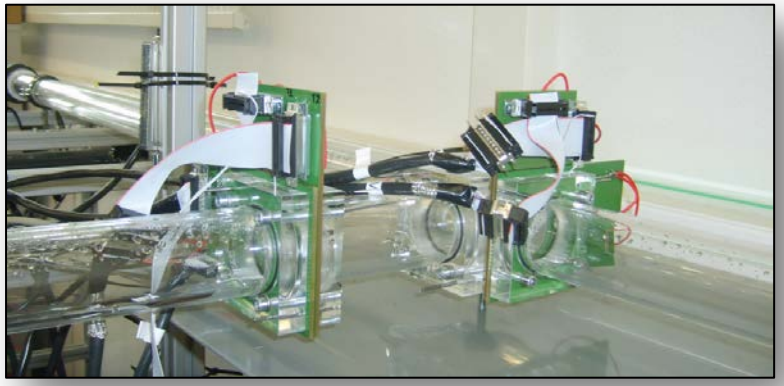
Mixing Tee / low side flow

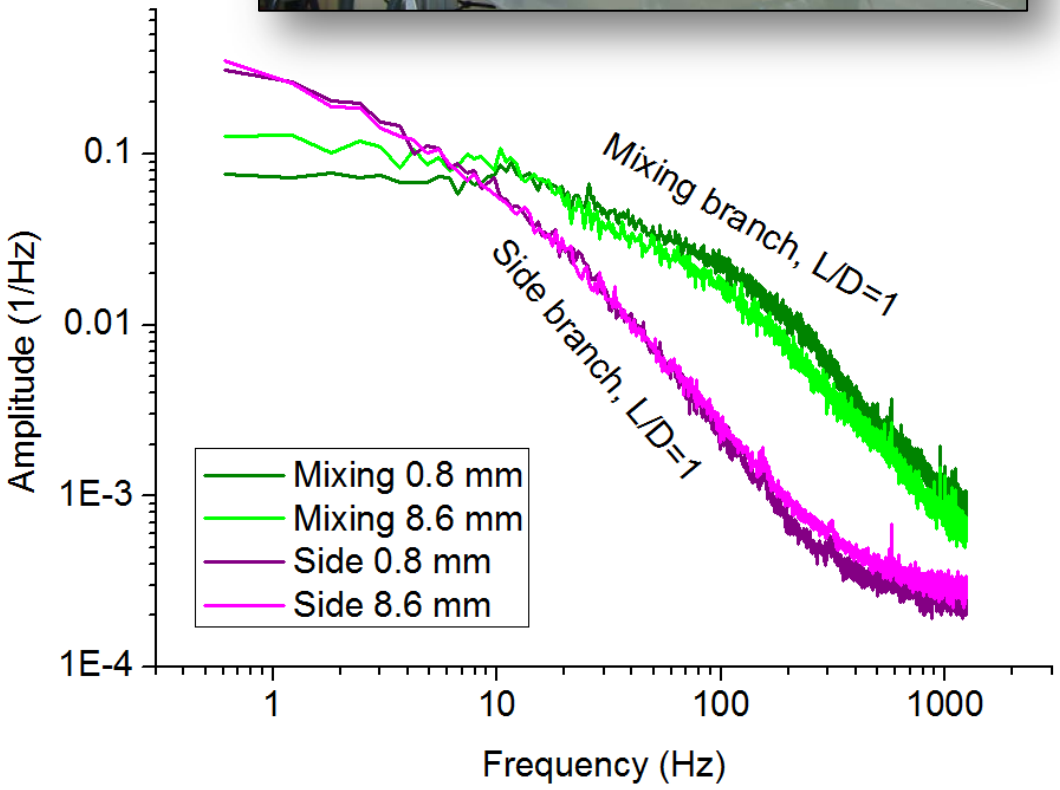
mixing pipe



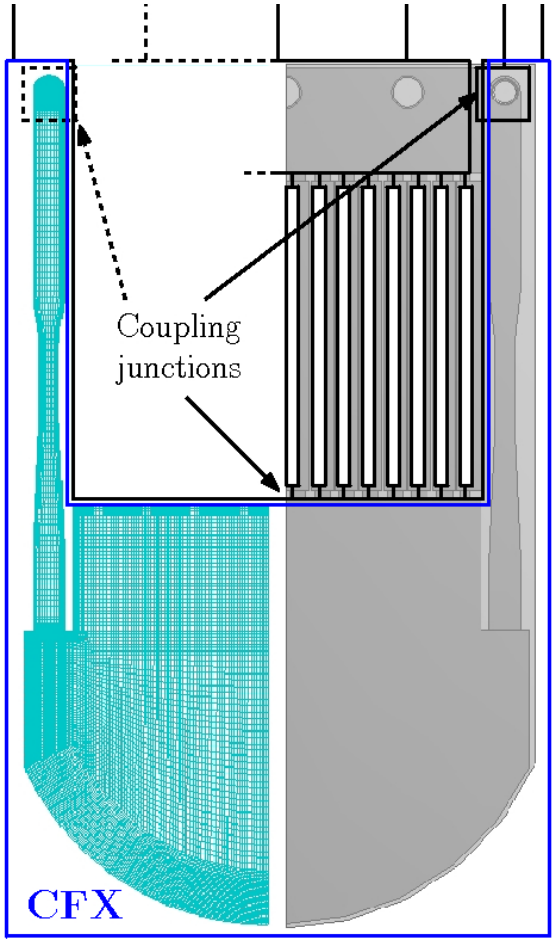
side branch

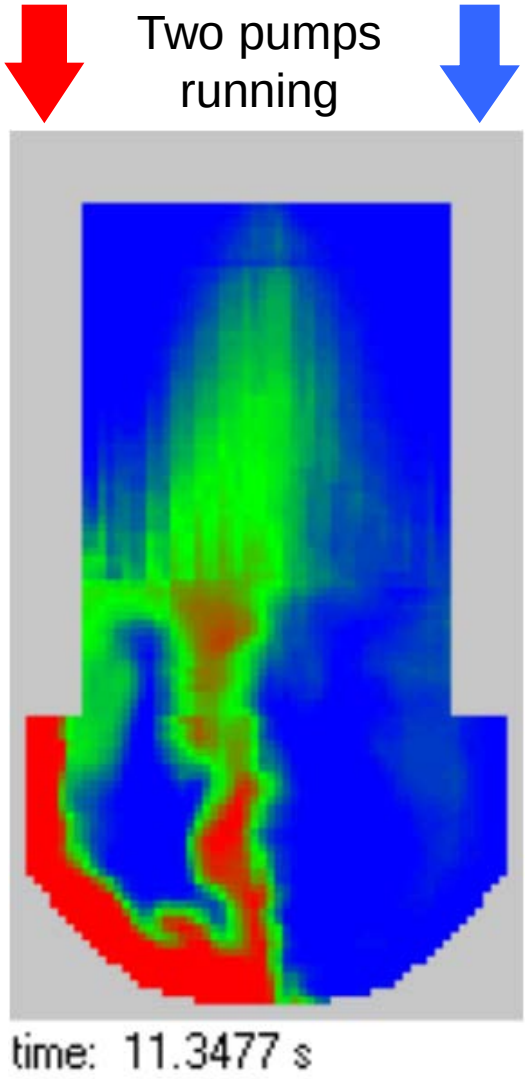






Mixing in reactors





Flat generic model of a boiling water reactor

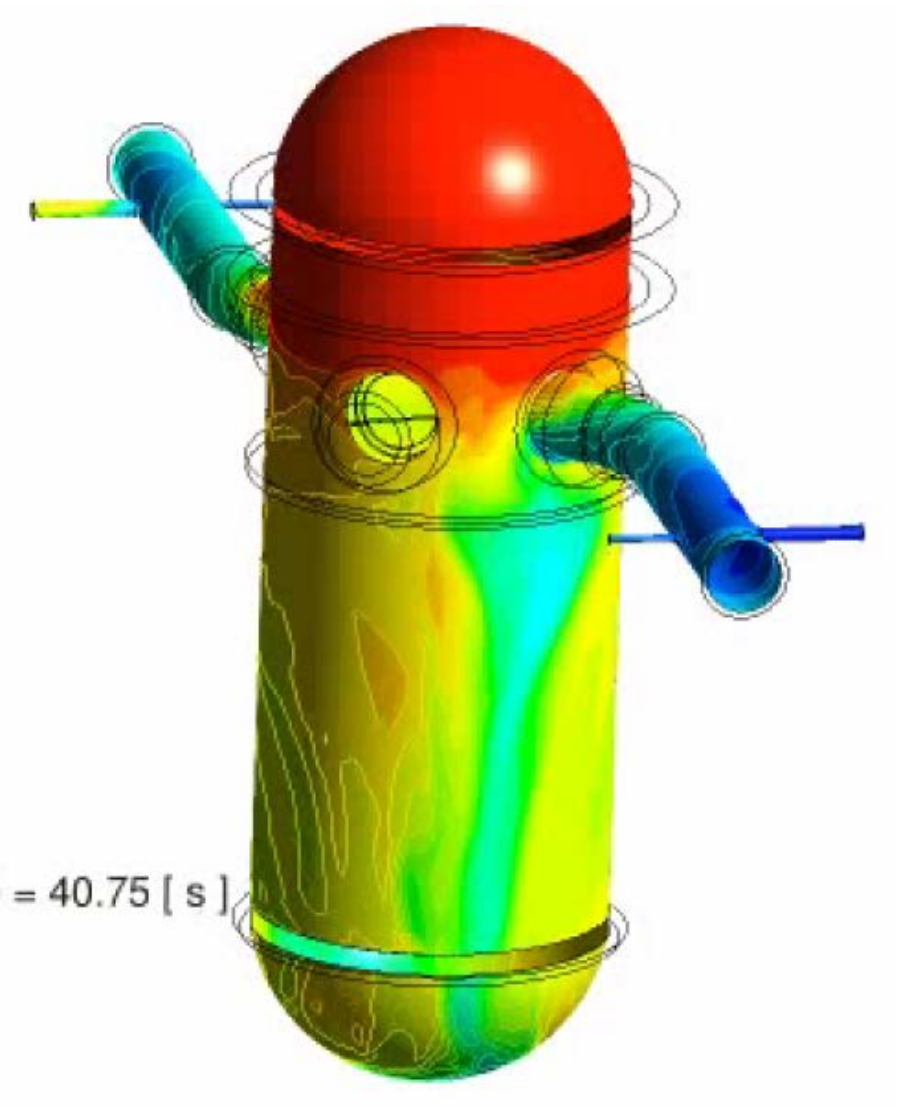
- Validation of CFX - TRACE coupling (with LRS)
- Cold lake formation and erosion in lower plenum of BWR
- Demonstration for a full 3D BWR model

⇒ Ability to measure mixing in any geometry (e.g. PWR downcomer...)

Complex mixing, theoretical (1)

FLUENT simulation of ECC injection into PWR reactor pressure vessel

Flow field + temperature field
Feedback of density effects to flow field taken into account



Complex mixing, theoretical (2)

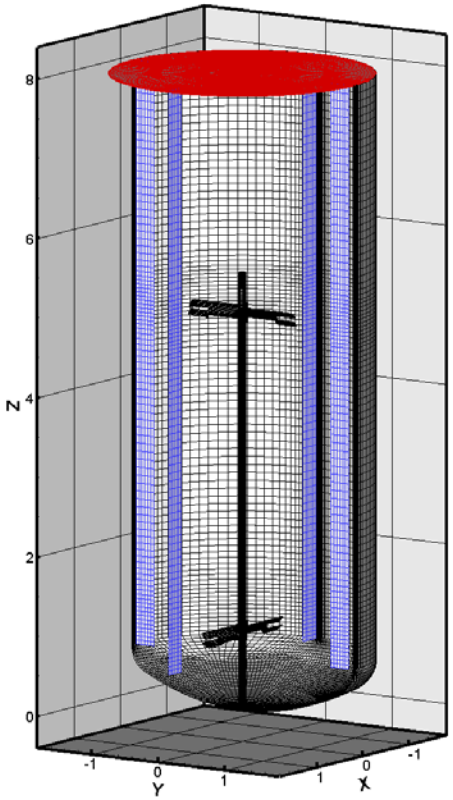
ThyssenKrupp-Uhde

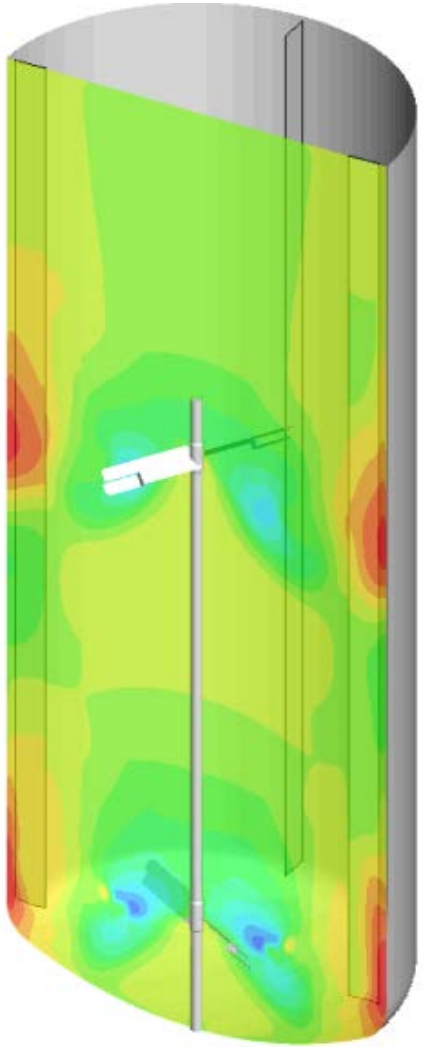
Bio-reactor, 80 – 800 m³

FLUENT (ANSYS)

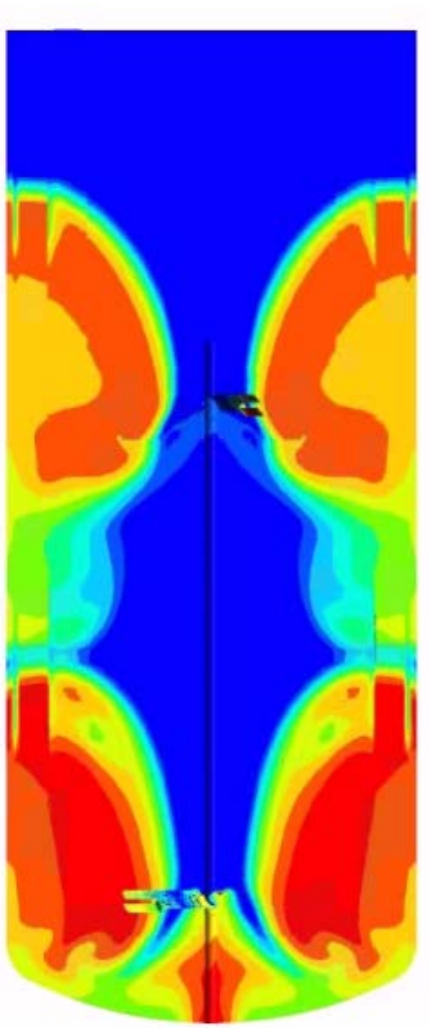
>1 million cells

Stirrer: sliding mesh





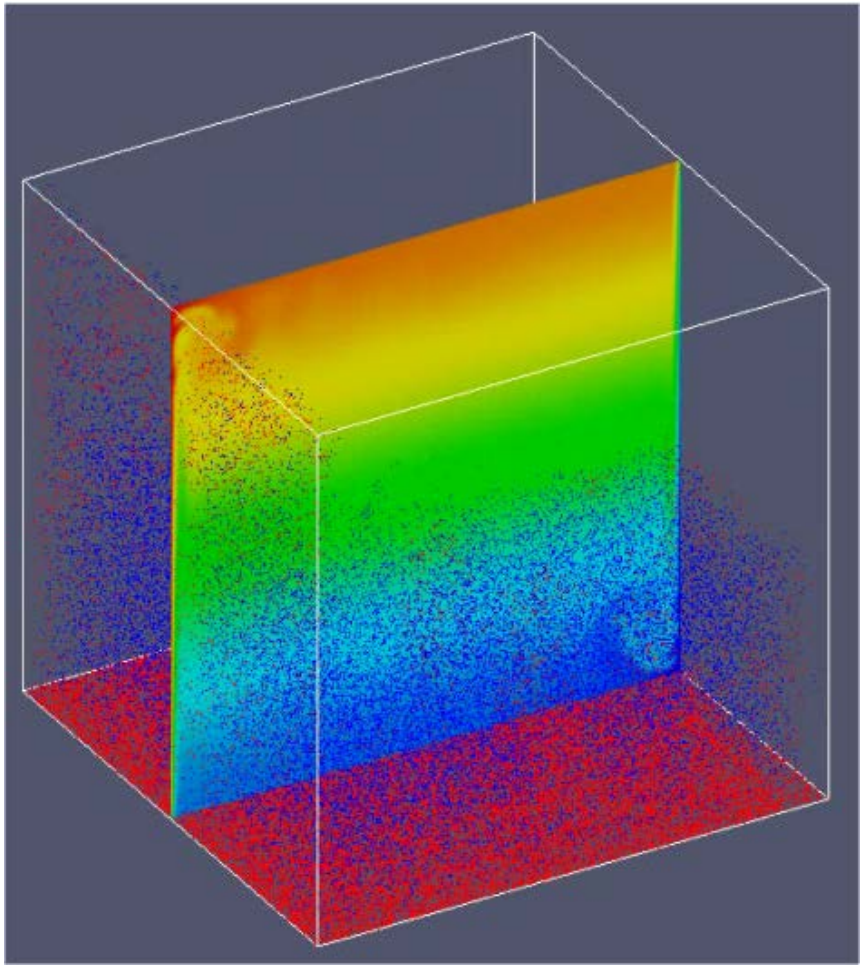
Velocity field



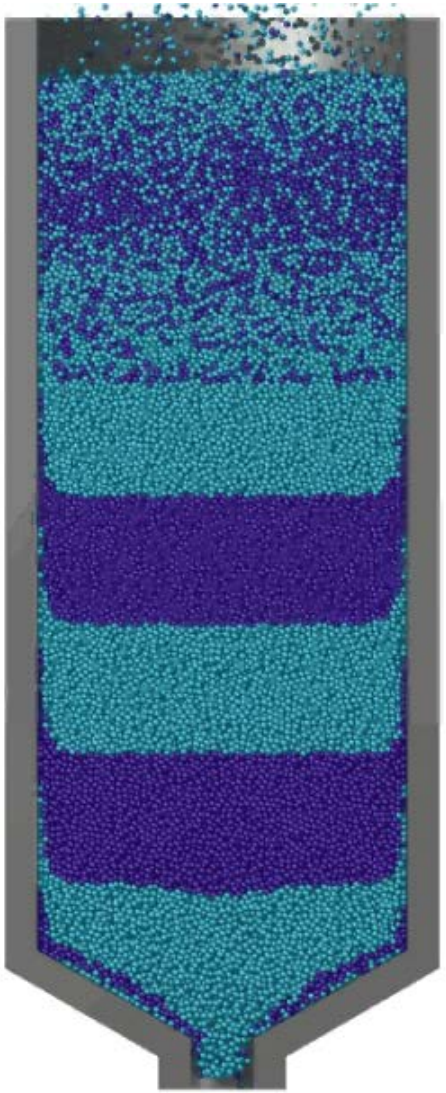
Bacteria feedstock

Particle flows

CFD Euler-Lagrange: Aerosol settling

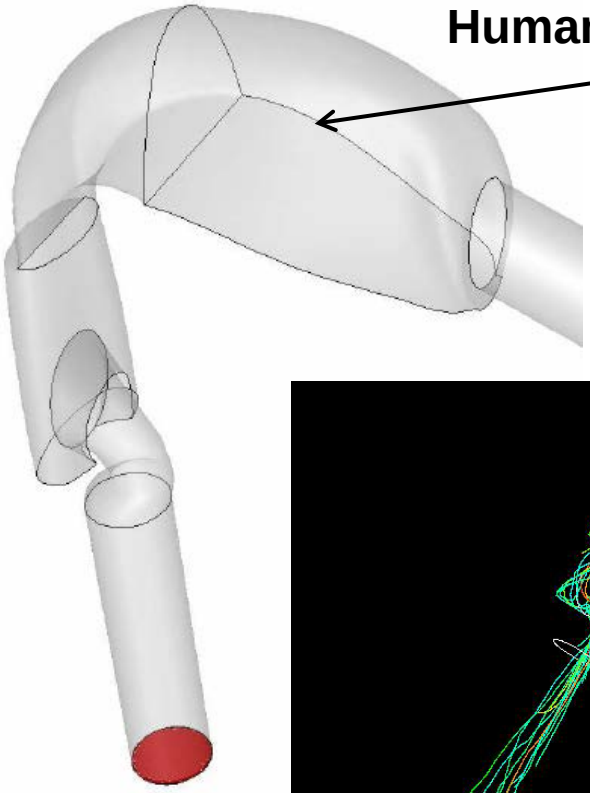


Discrete Particle Tracking

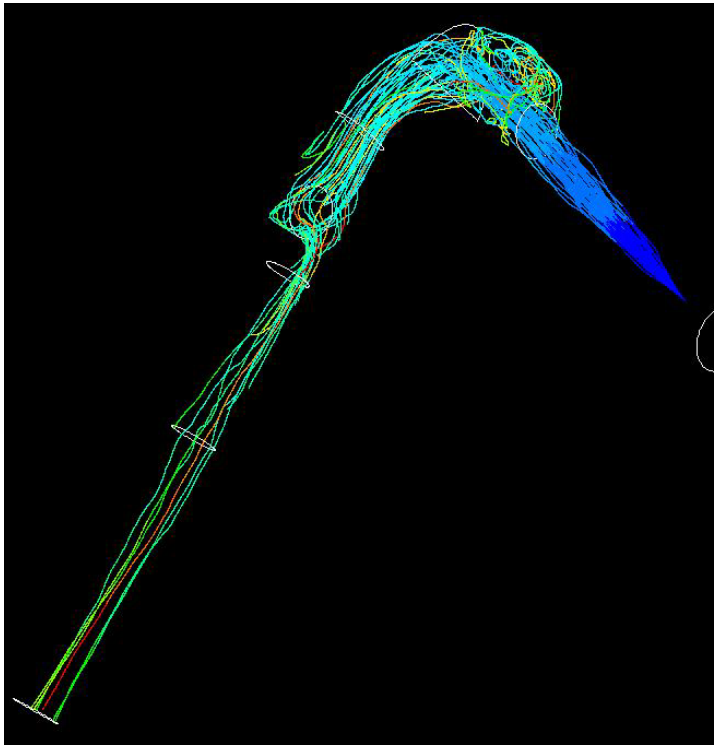


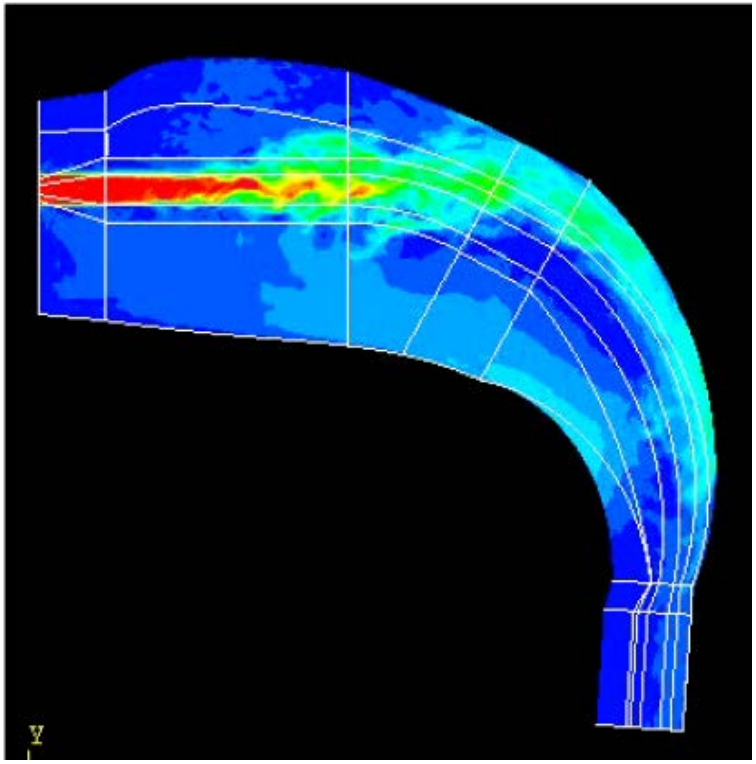
Aerosol transport and deposition

Human respiratory tract



Aerosol particle tracking



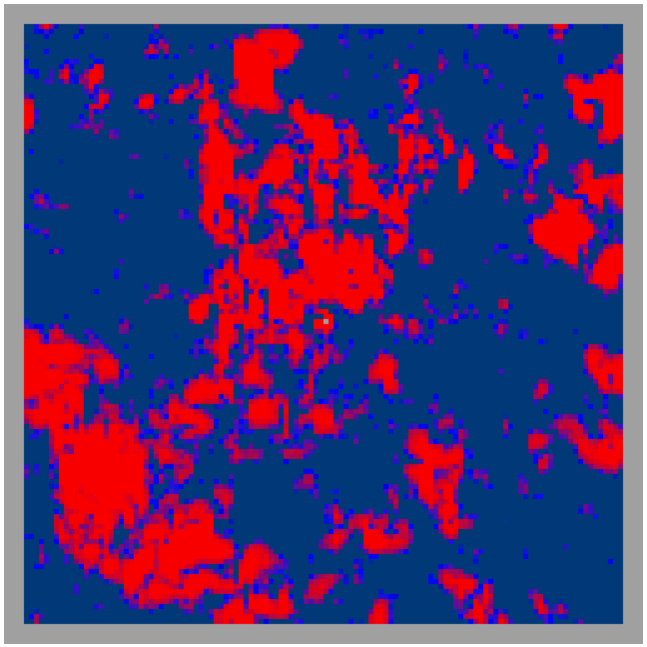


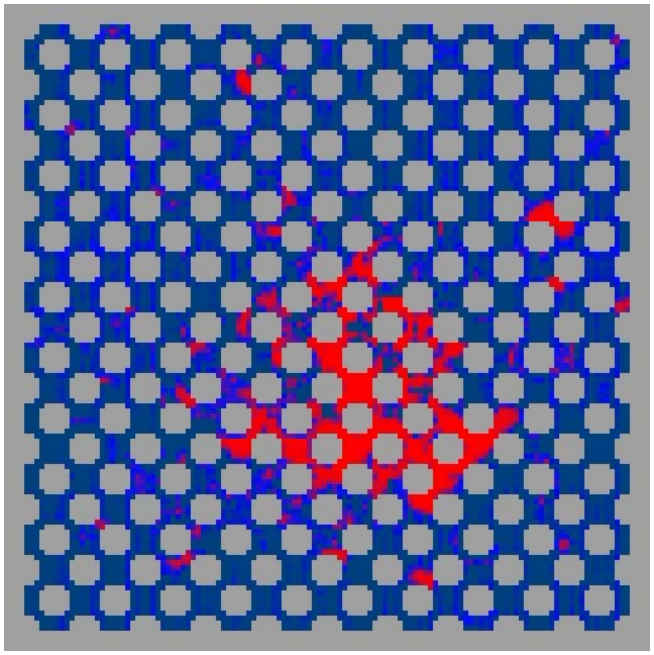
Flow field

CFD, Euler-Lagrange particle tracking

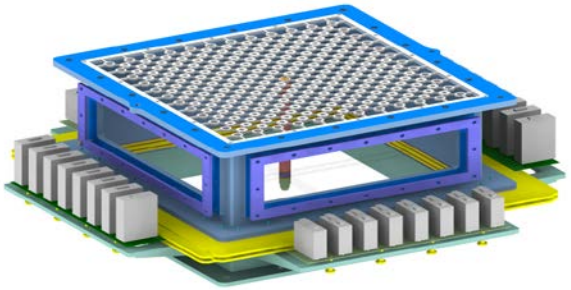
TRISTAN

Universal experiment for two-phase flows in pools and bundles
(Aerosol scrubbing in SG bundles, suppression pools, FCVS…)

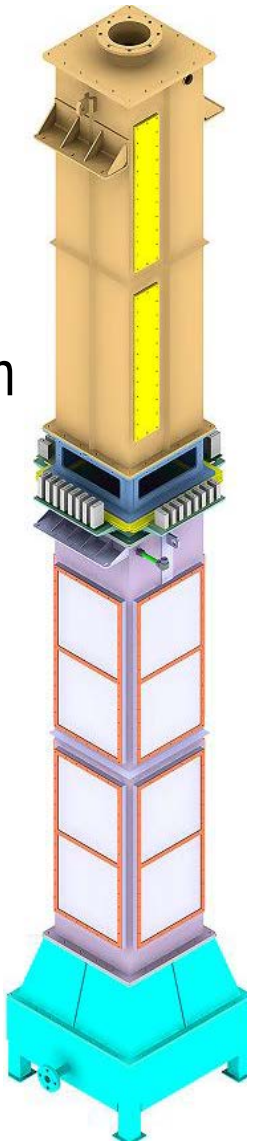




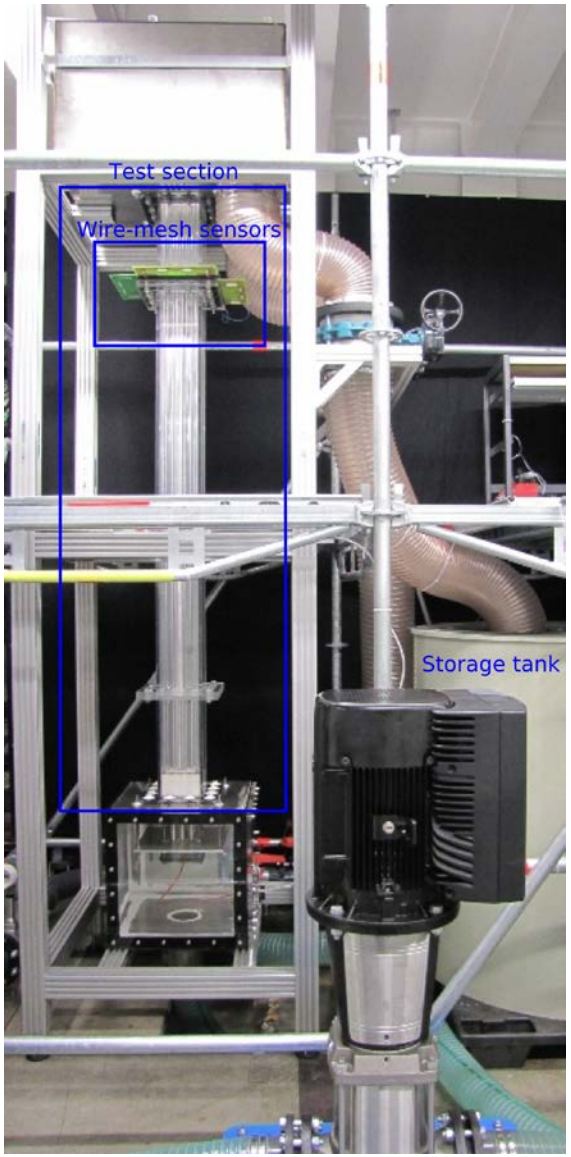
Wire-mesh sensor
120x120
1280 Hz

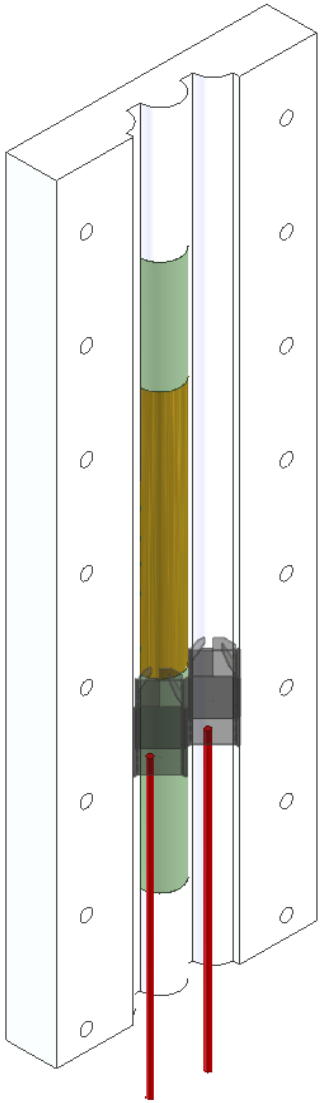


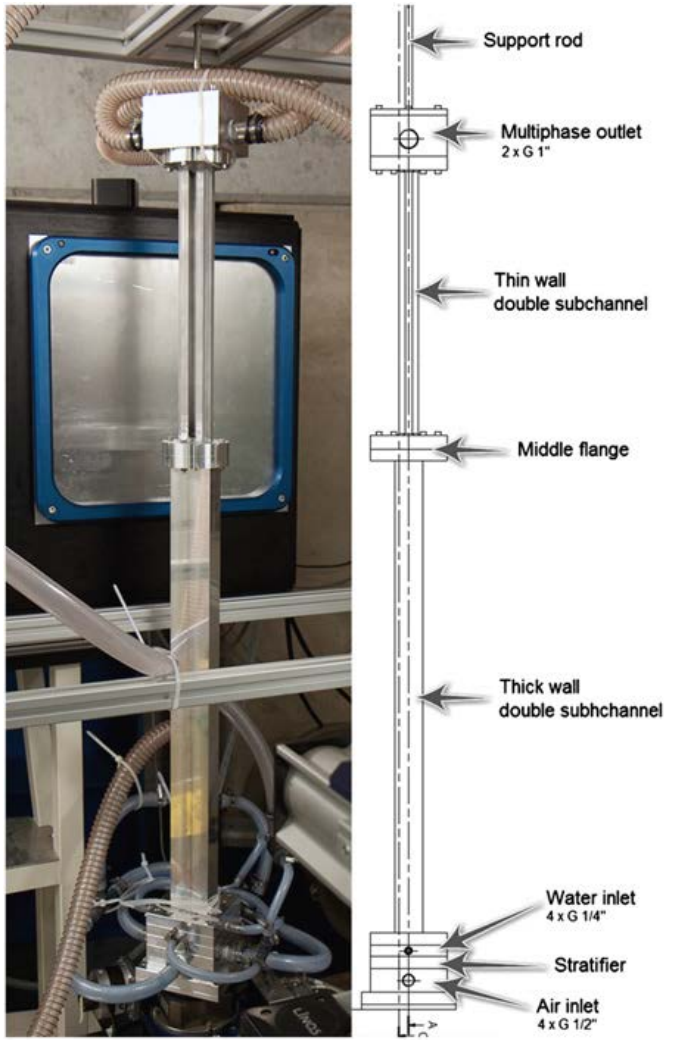
6 m



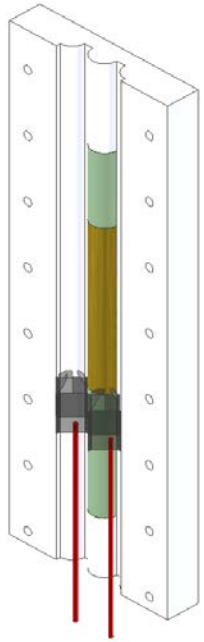
Strömung im Brennelement

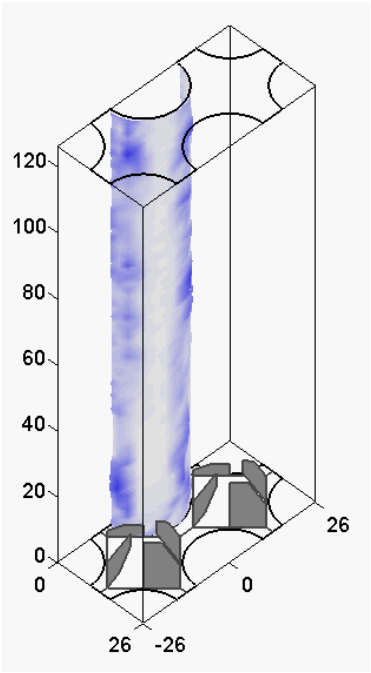


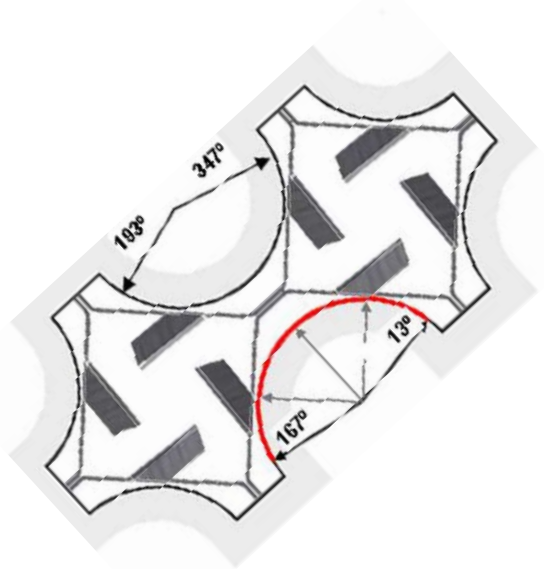


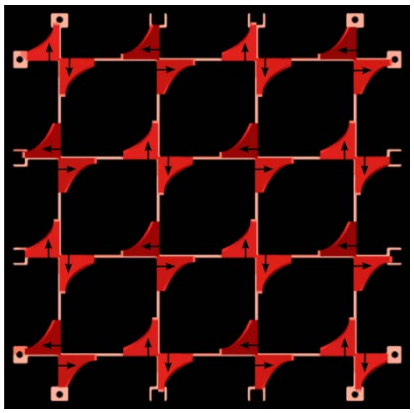


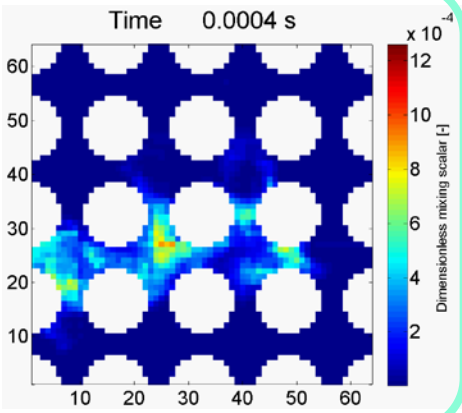
Advanced instrumentation

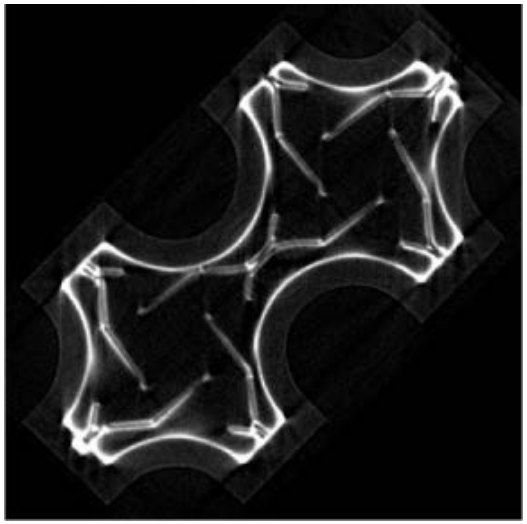




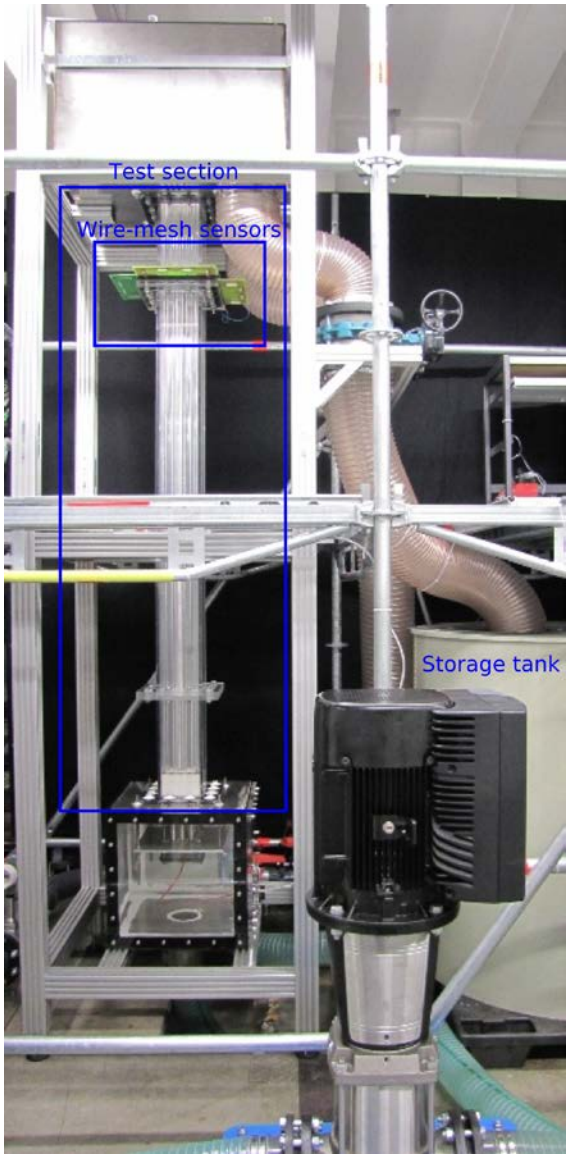


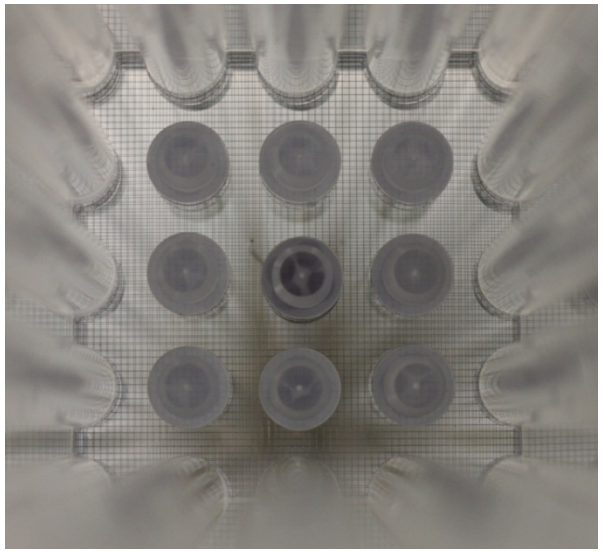


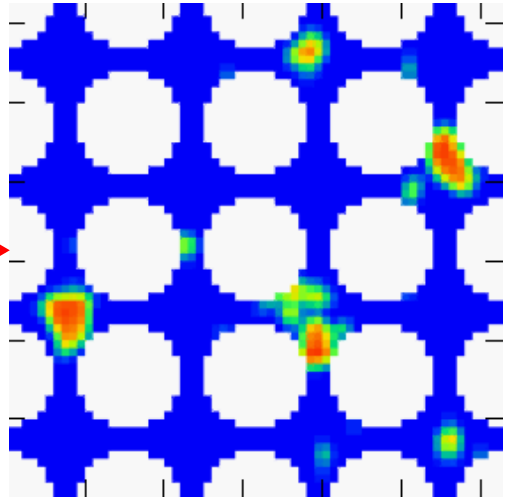




SUBFLOW Loop – fuel rod bundle studies

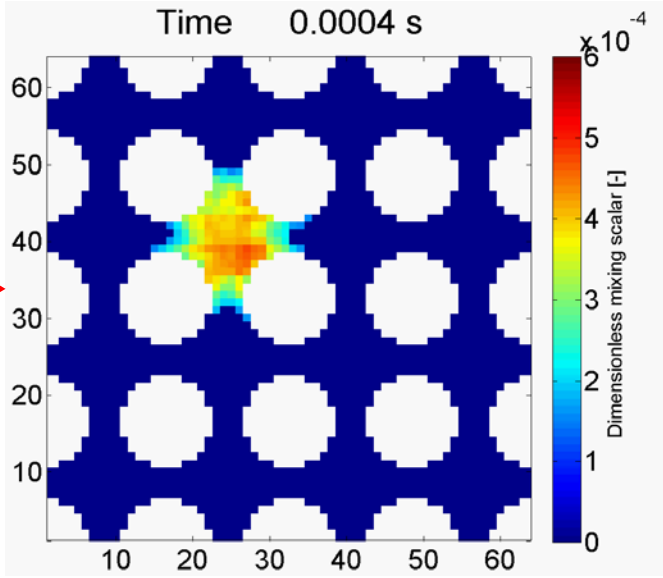




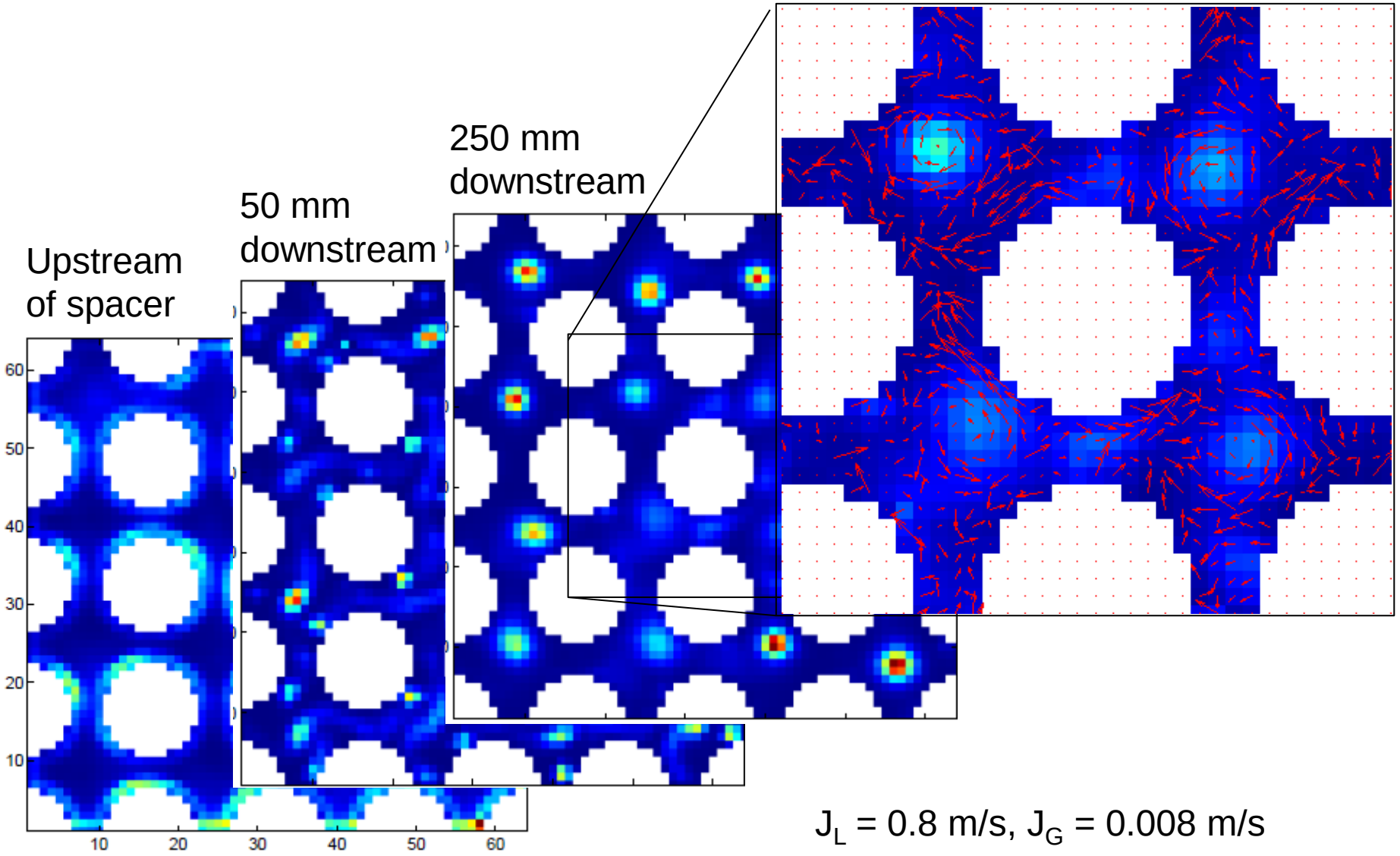


Single and two-phase flow in a 4x4 rod bundle

- Dynamic gas-liquid interface
- Mixing and cross-flows between sub-channels
- Spacer studies
- Code validation

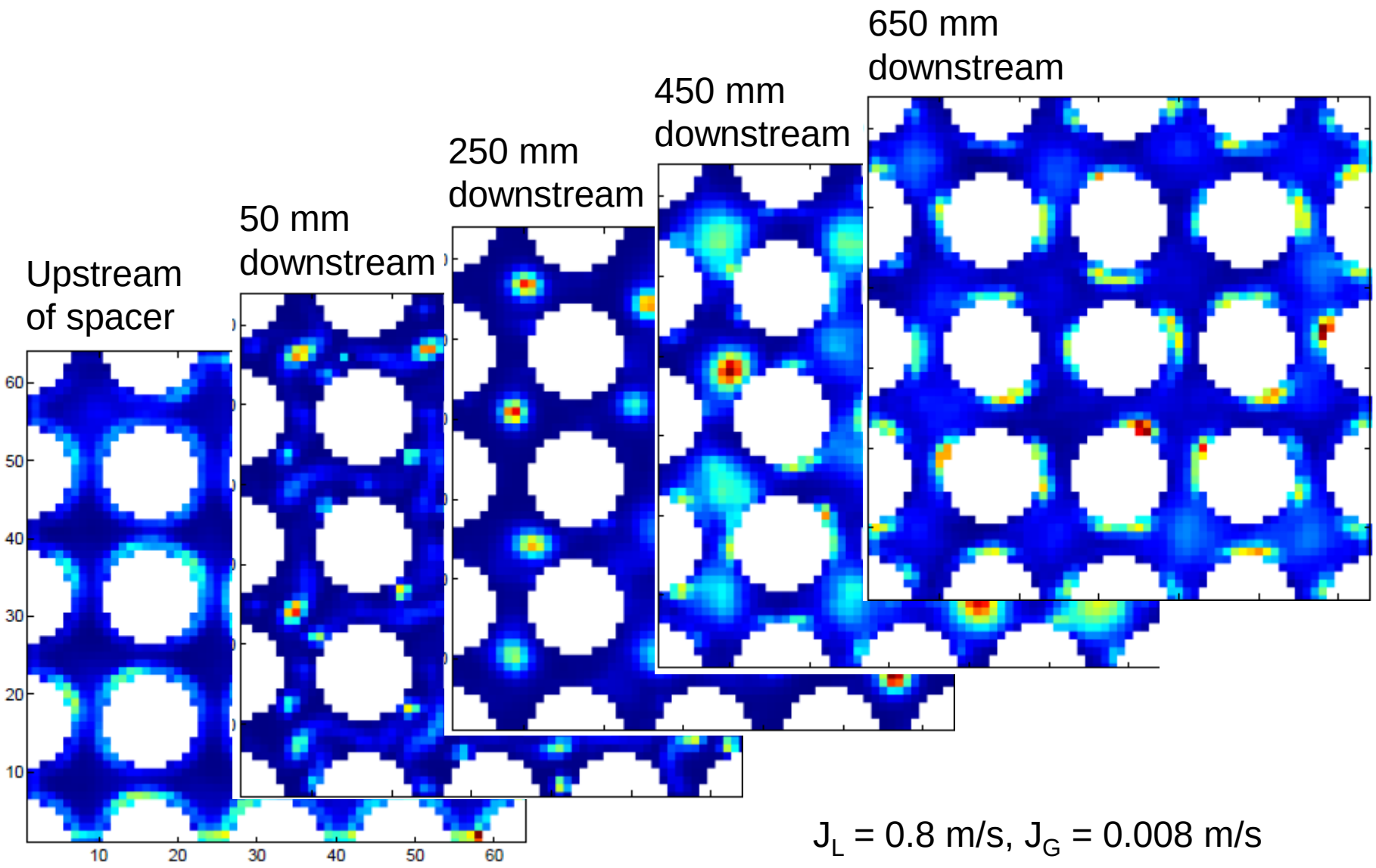


Spacer effect on bubbly flow



J_L = 0.8 m/s, J_G = 0.008 m/s

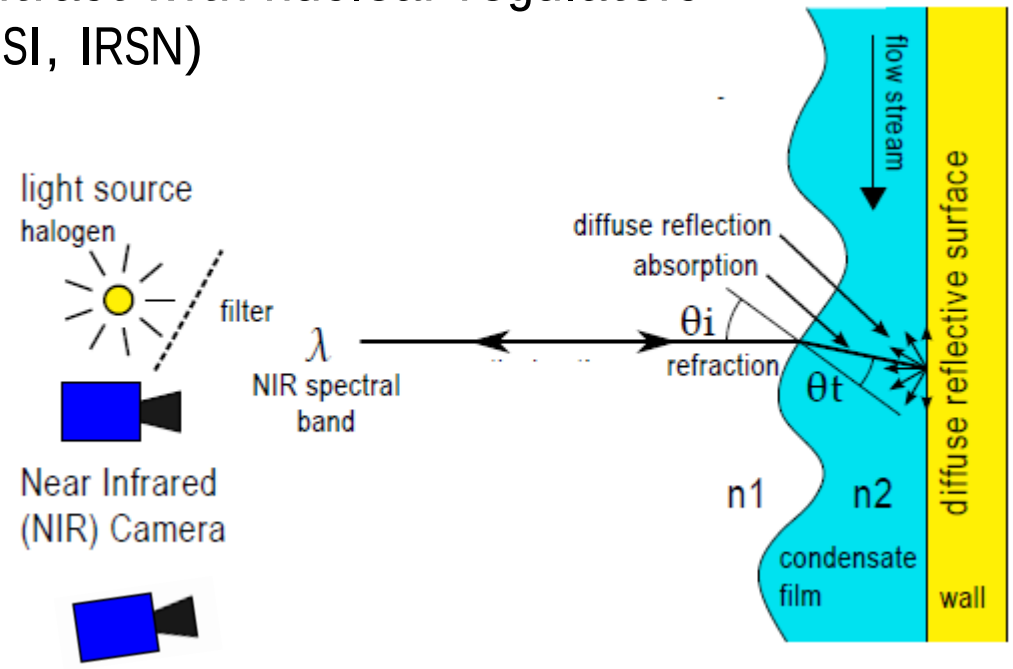
Spacer effect on bubbly flow



J_L = 0.8 m/s, J_G = 0.008 m/s

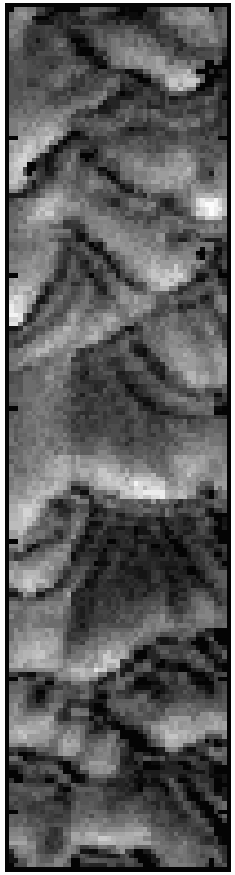
Condensate films on containment walls

Contract with nuclear regulators (ENSI, IRSN)

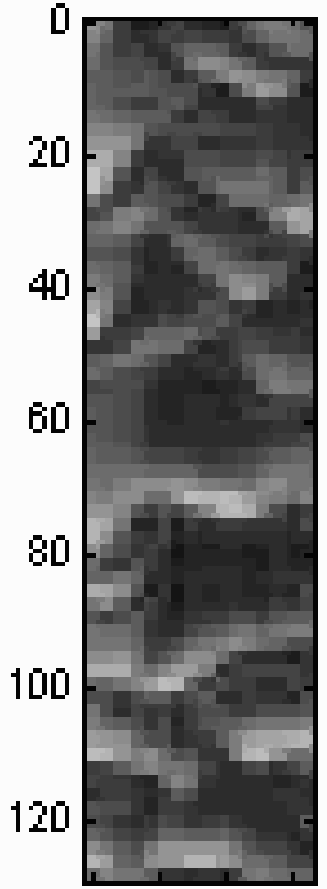


Far IR camera
→ film temperature

Near IR



Film sensor

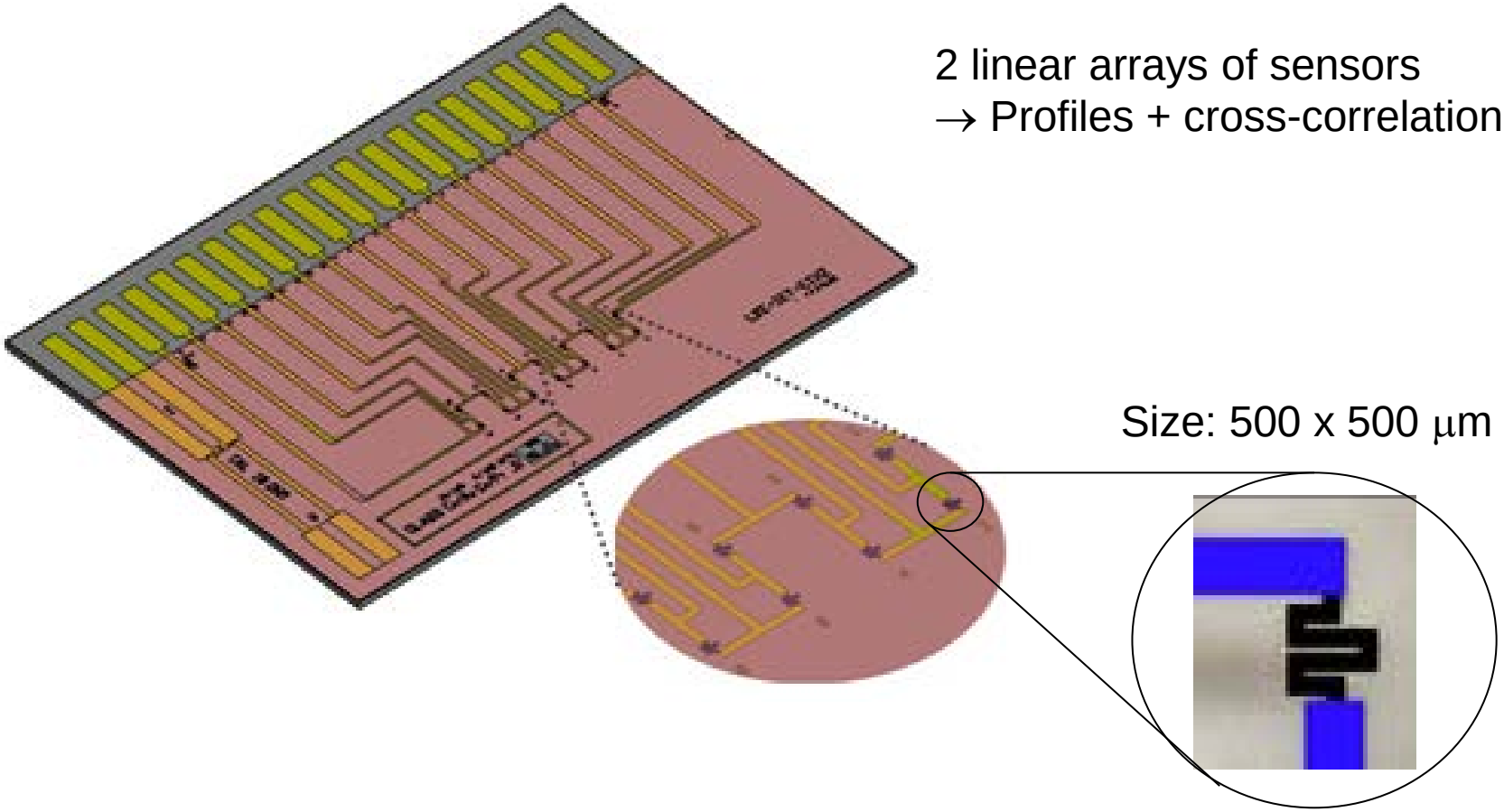


Innovative: Simultaneous contactless film thickness and temperature measurement

Julien Dupont (PhD student)

Surface temperature

Micro-fabricated thermo-resistive elements (clean room)
Substrate: glass / aluminum / silicon

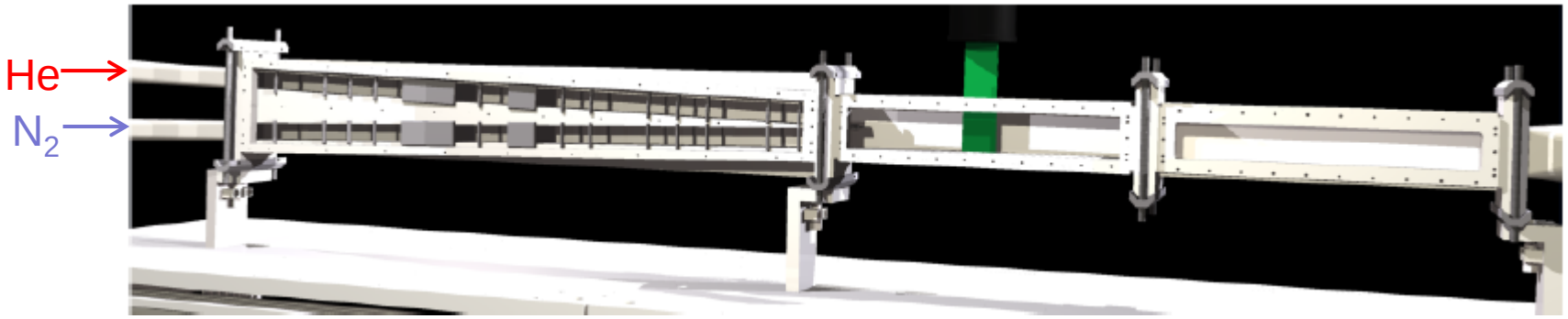


2 linear arrays of sensors
→ Profiles + cross-correlation

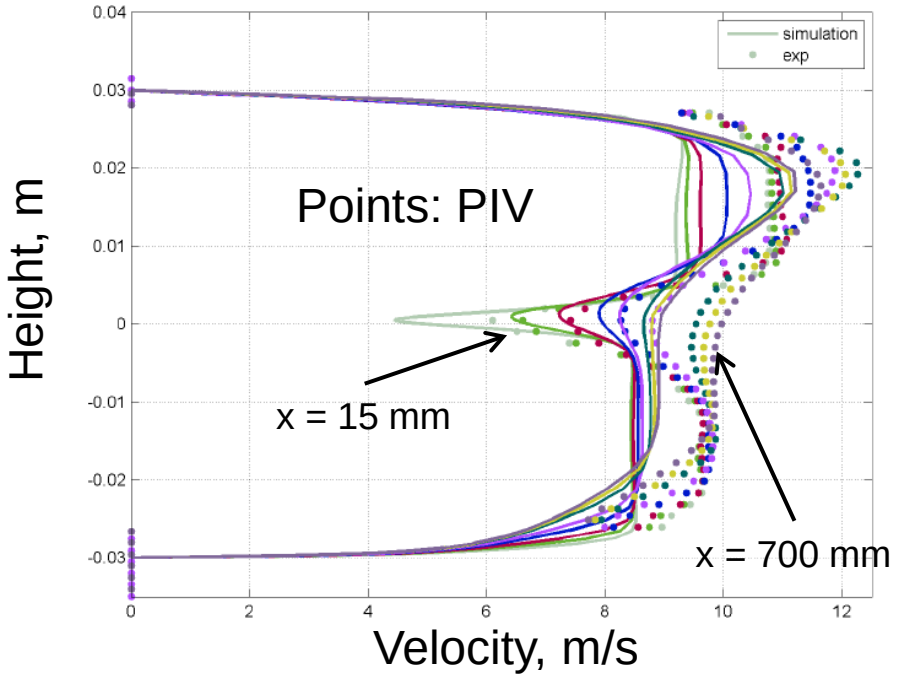
Size: 500 x 500 μm

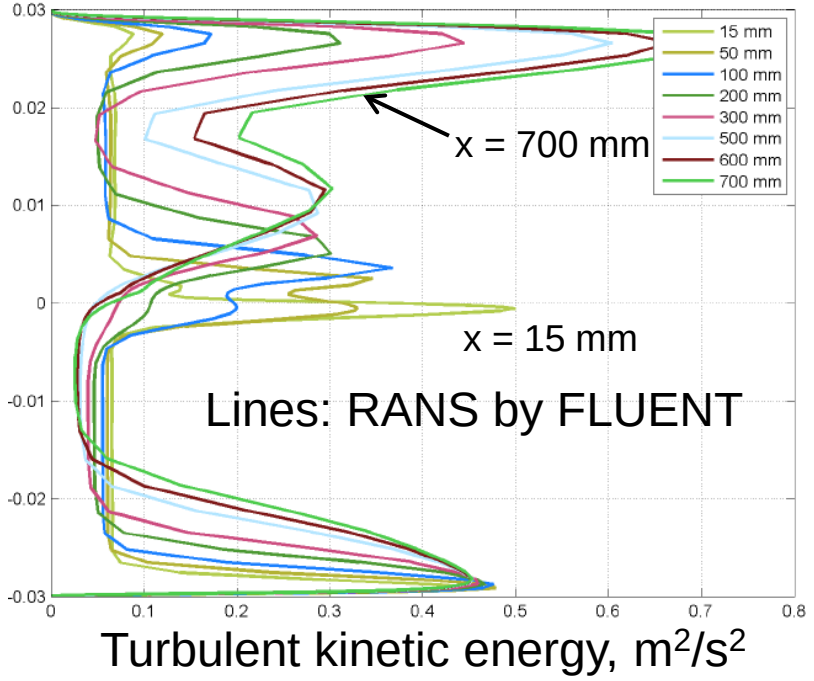
Thickness sensitive element: 100 nm of platinum

Gas mixing in HTGR



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



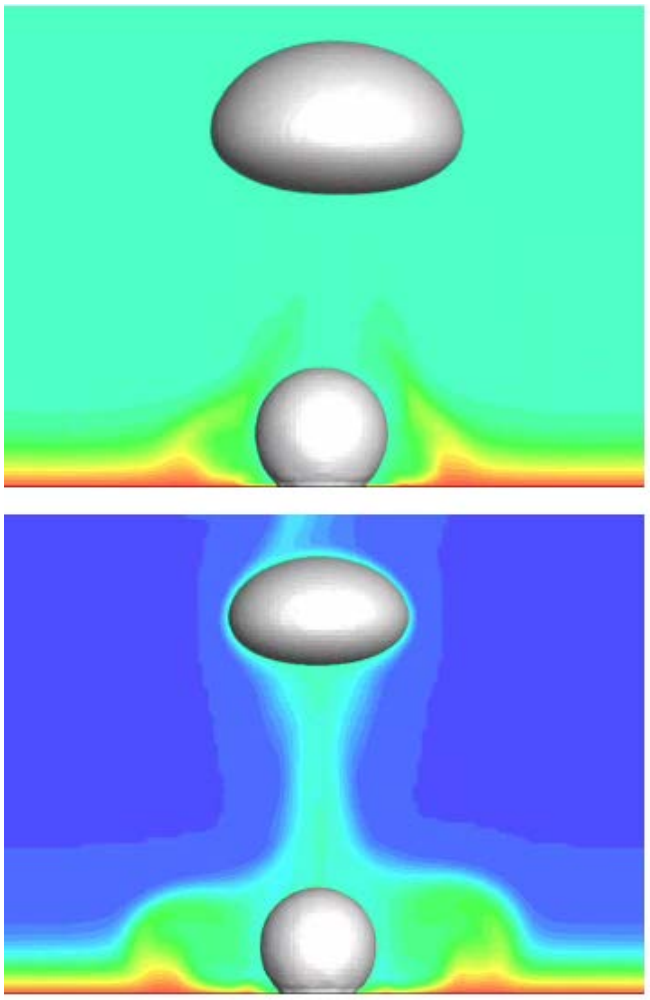


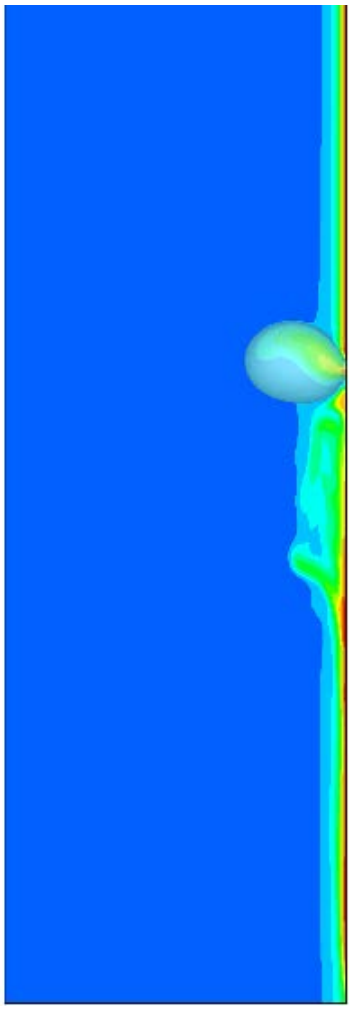
Boiling - High Performance Computing

LES + Interface tracking + super computing

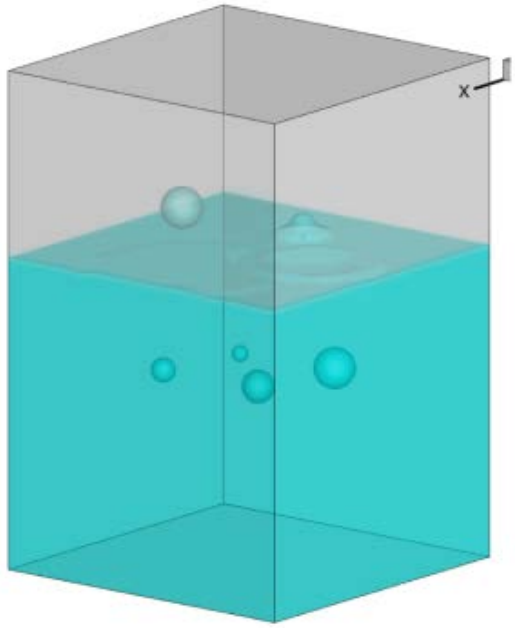
$T_L = T_S$

$T_L < T_S$





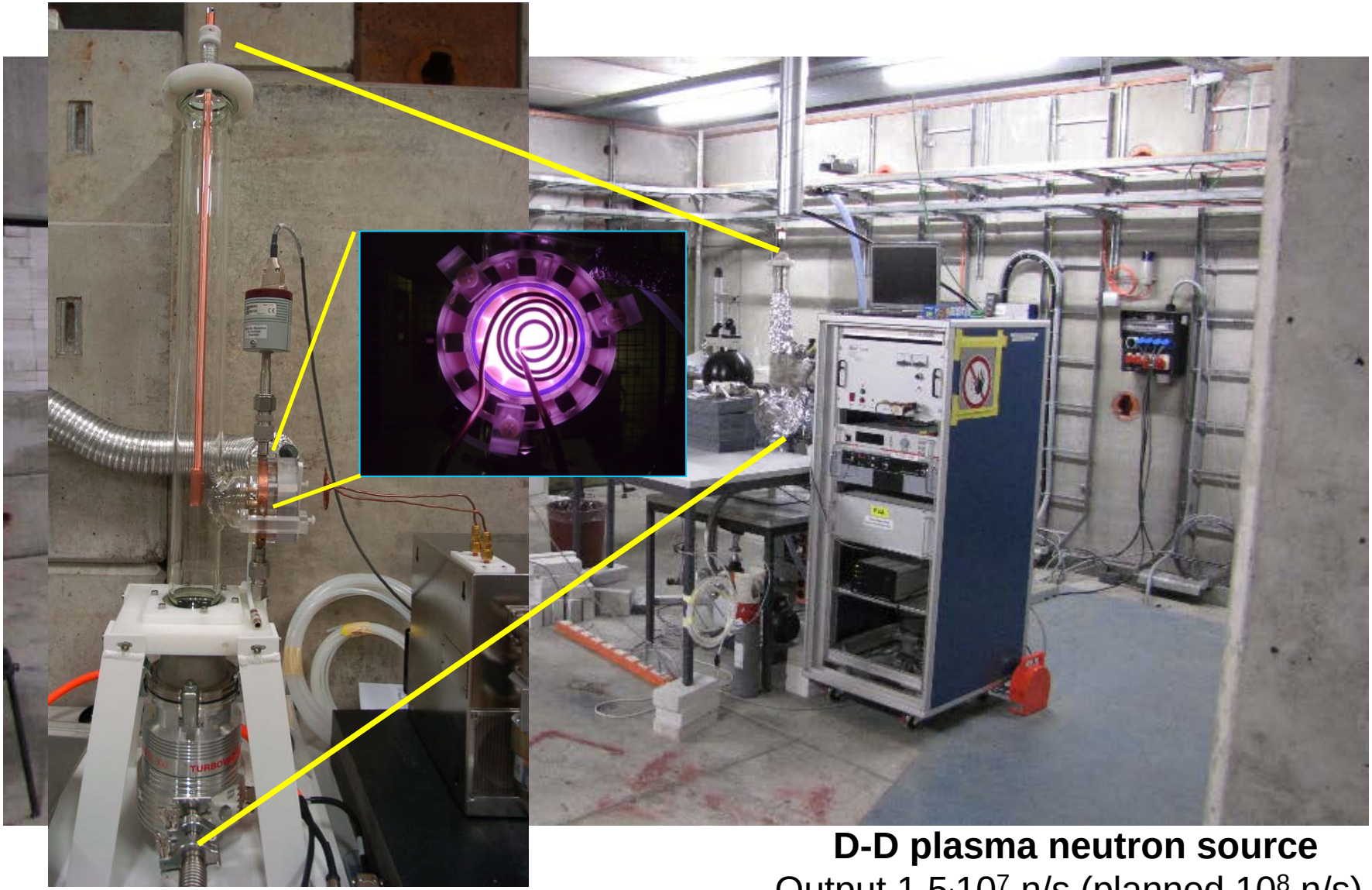
vertical wall



adiabatic, multi-scale

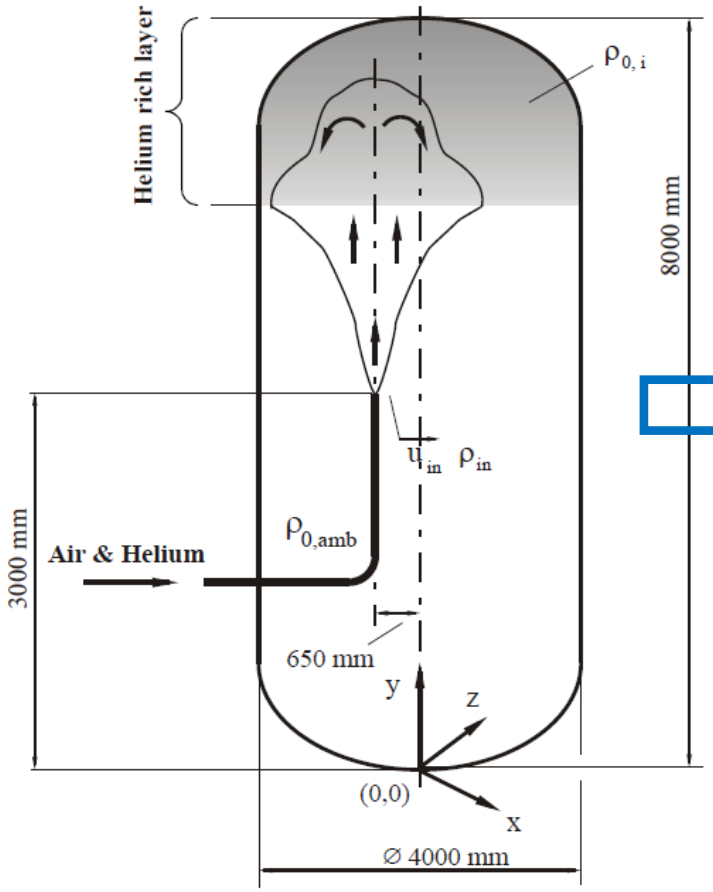
Dr. Bojan Niceno, Dr. Yohei Sato, Hassan Badreddine (PhD student)

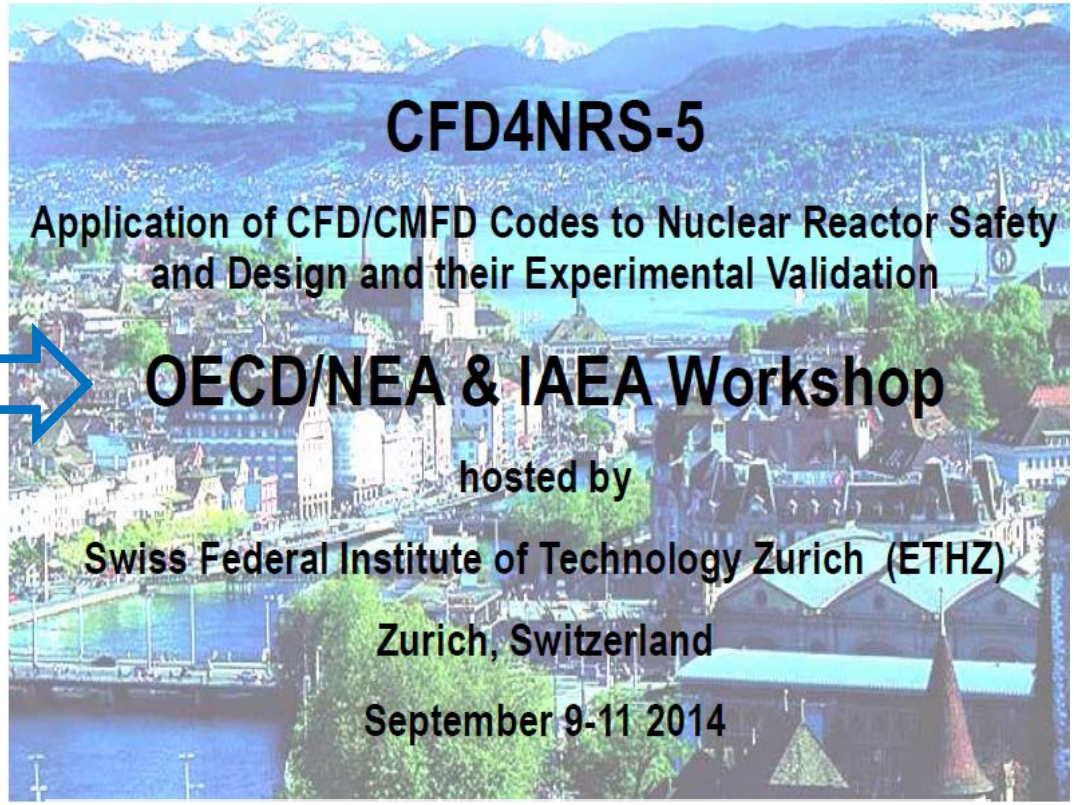
Imaging with fast neutrons



D-D plasma neutron source
Output $1.5 \cdot 10^7$ n/s (planned 10^8 n/s)

OECD/NEA Sponsored CFD Benchmark Exercise: Erosion of a Stratified Layer by a Buoyant Jet in a Large Volume





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