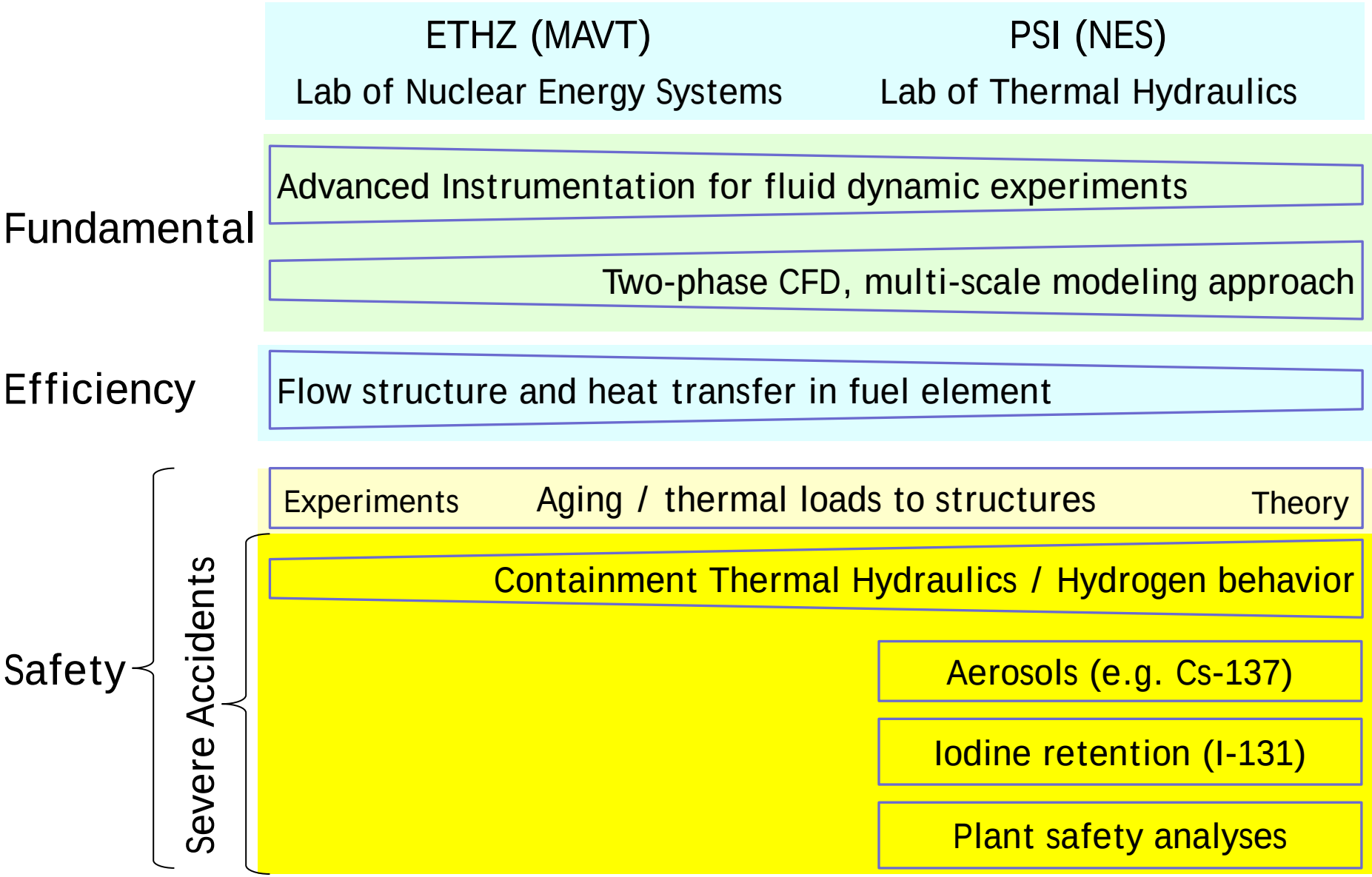
Paul Scherrer Institut, Switzerland

NES Infotag 2015

H.-M. Prasser

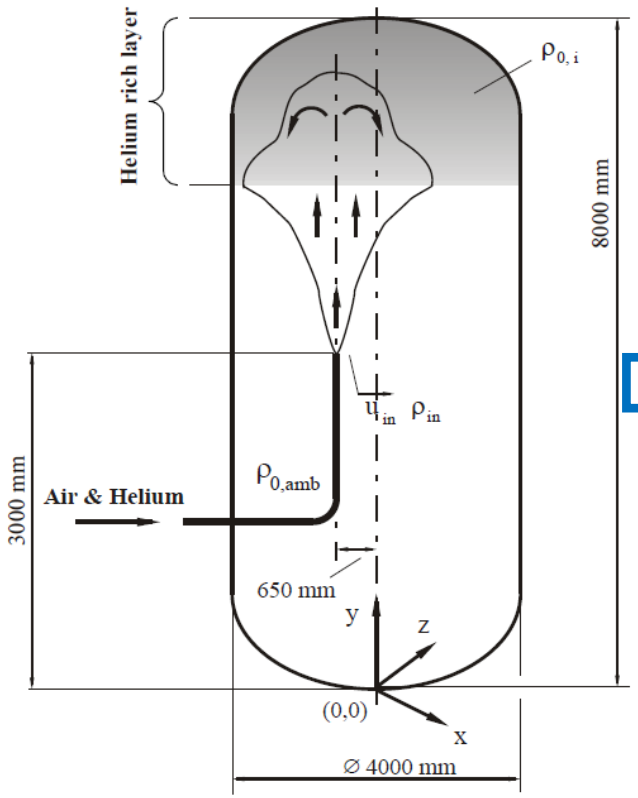
Laboratory of Thermal Hydraulics

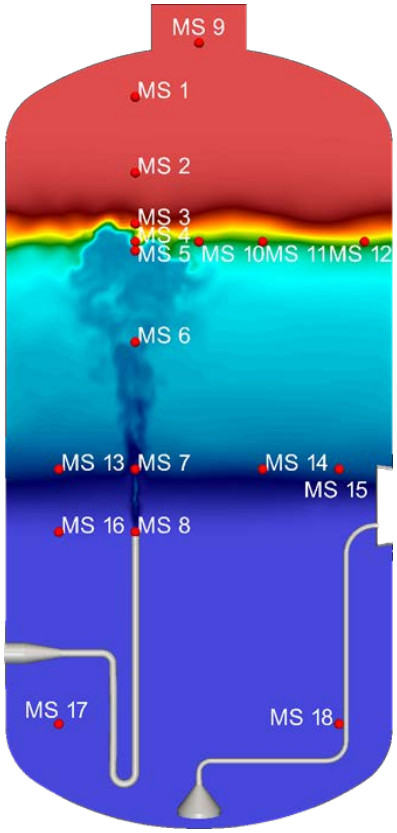
Profile LTH (PSI) – LKE (ETHZ)

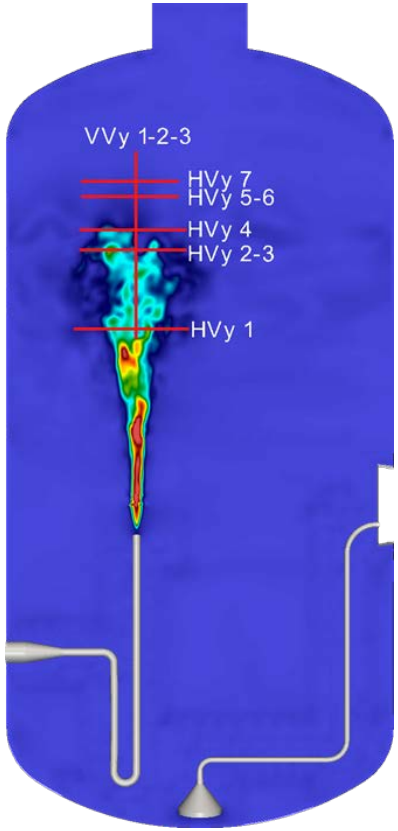


International PANDA benchmark at CFD4NRS-5

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





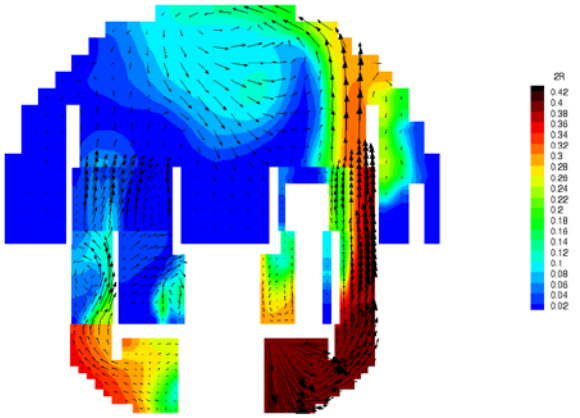


⇒ **Large result scatter among participants – identifies open issues!**

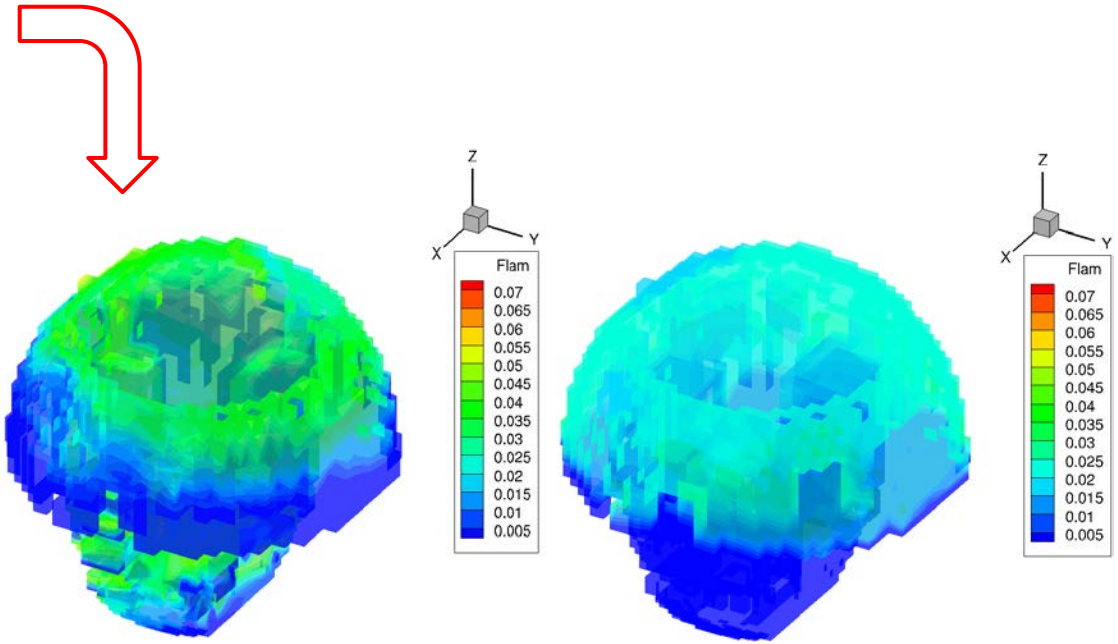
⇒ **Good results by own CFD calculations (FLUENT, ANSYS)**

Full 3D NPP Models in GOTHIC

- Fast hydrogen release following SBO
- ~ 37'000 cells in the model; cell size = 0.8 - 1 m



Flow & concentration field



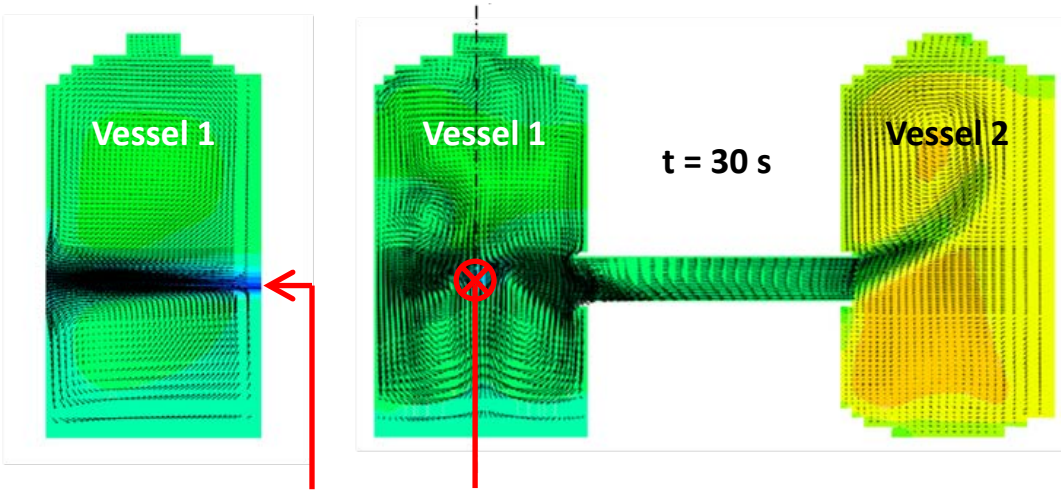
3D maps of "flammability index" in containment

Validation of the GOTHIC code

Andreani

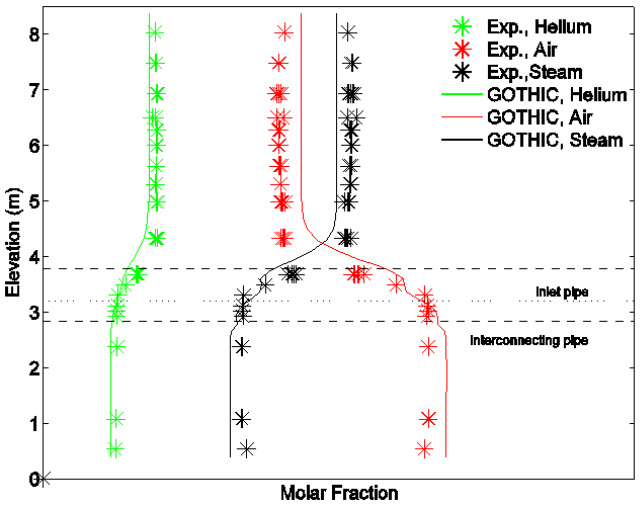
❖ Several EU and OECD projects using PANDA data

- Capability of the code to capture the **helium distribution** (simulant of hydrogen) during a **fast injection** (~ 100 m/s) of mixtures of steam, air and helium in air-filled vessel (**OECD-SETH 2 project**)



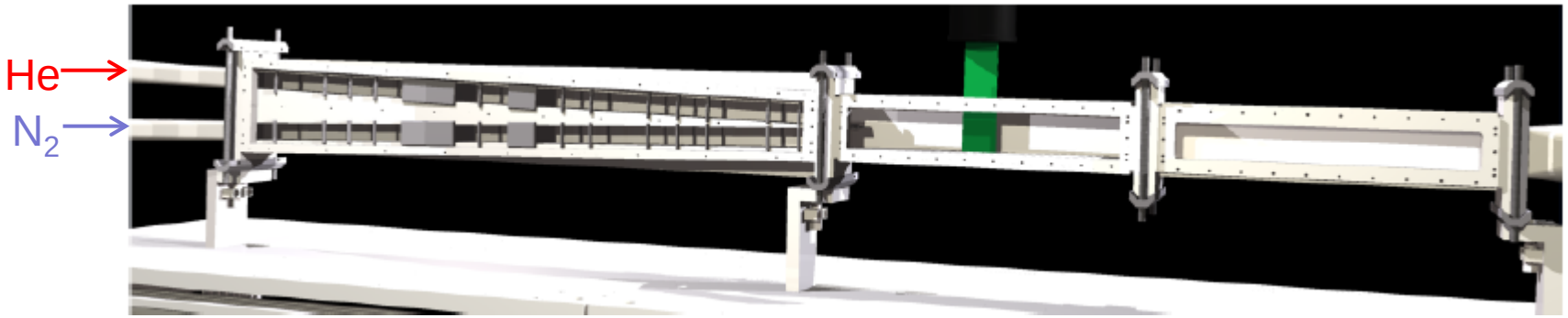
Fast air/H_2O/He release from lower vessels

Gas temperature and velocity fields

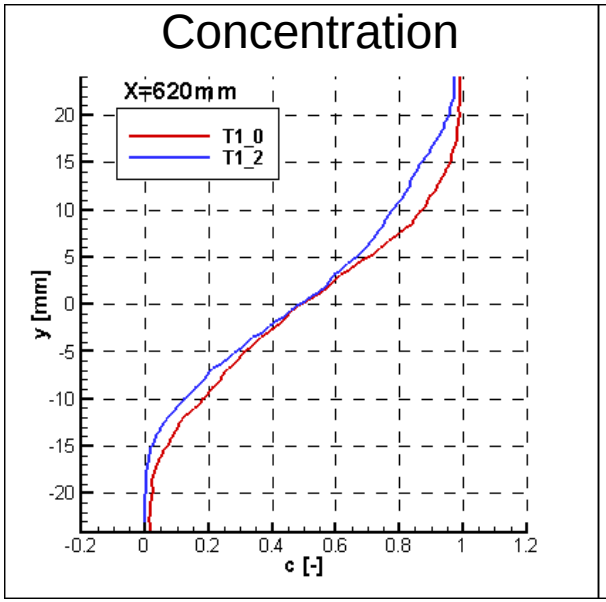


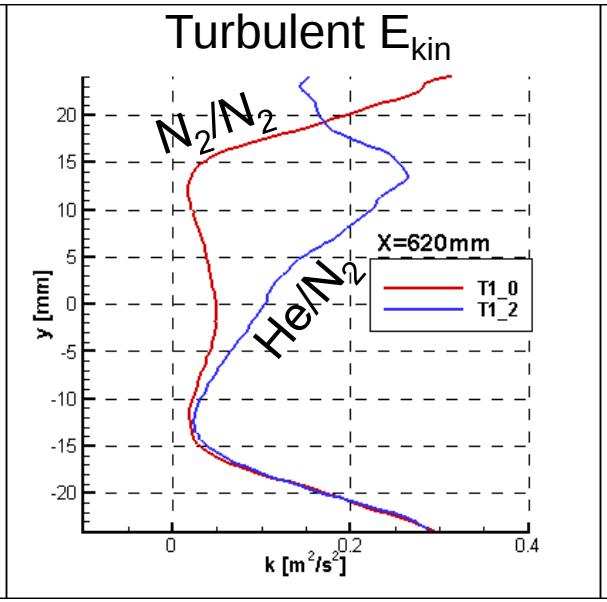
Final gas distributions in Vessel 1

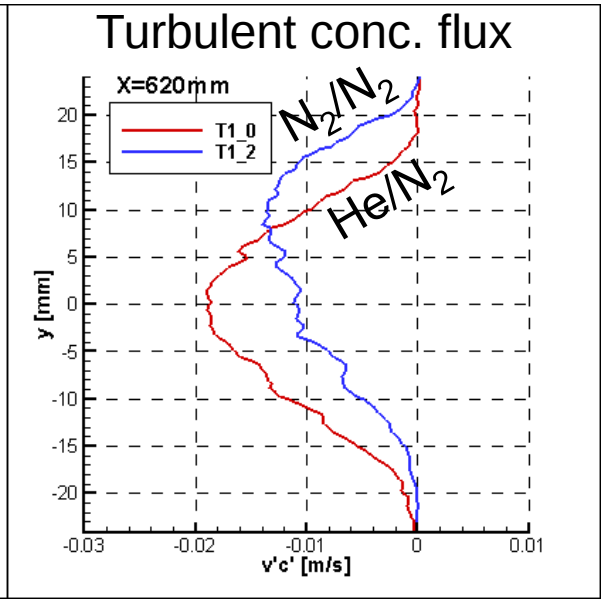
Strong non-Boussinesq mixing tests



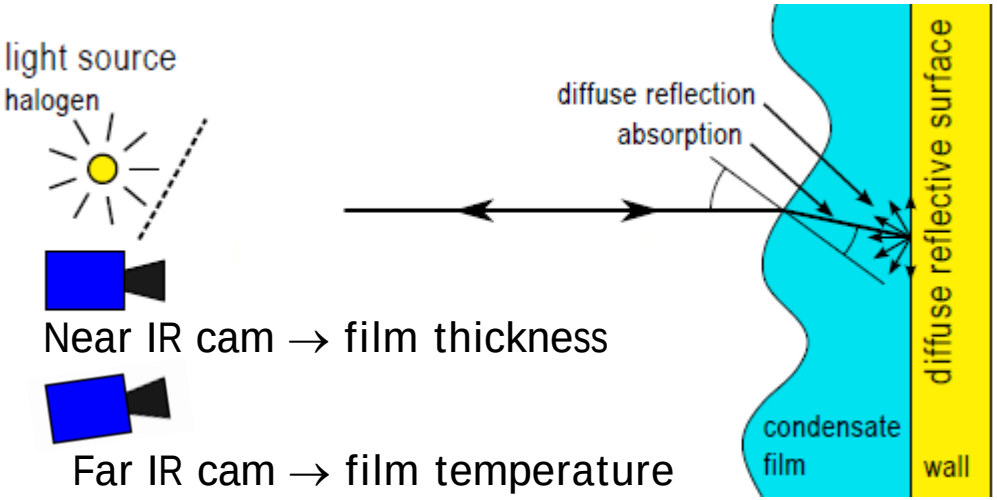
PIV and LIF of He/N_2 mixing (ρ_{N2}/ρ_{He} = 7) – contribution to **THINS (EU project)**

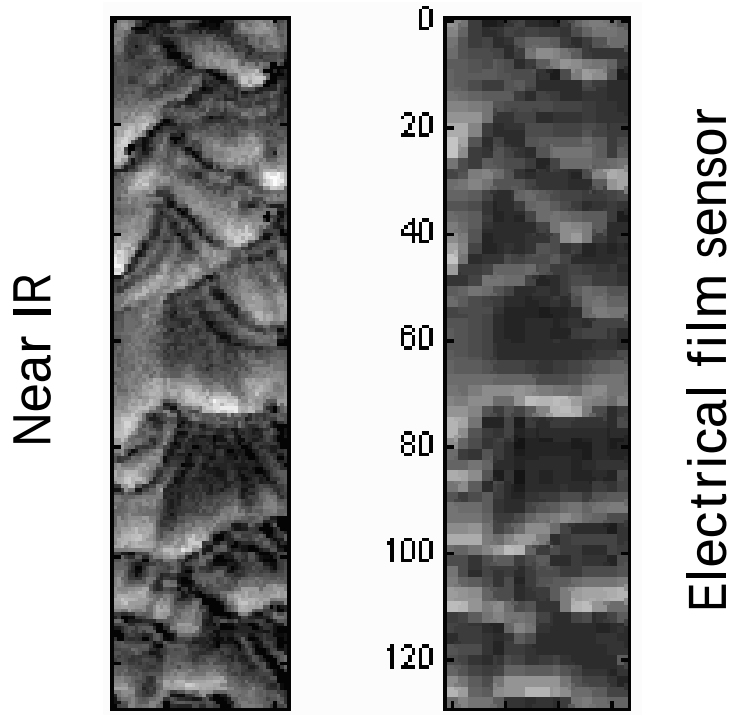


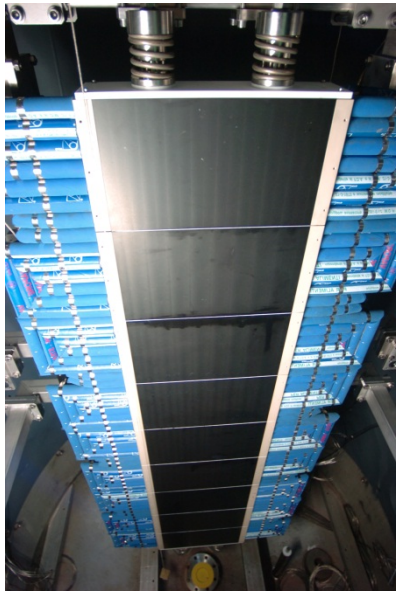




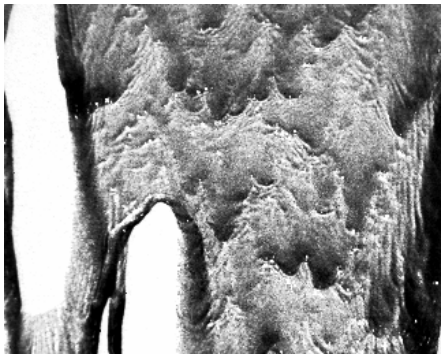
Innovative Containment Thermal Hydraulics



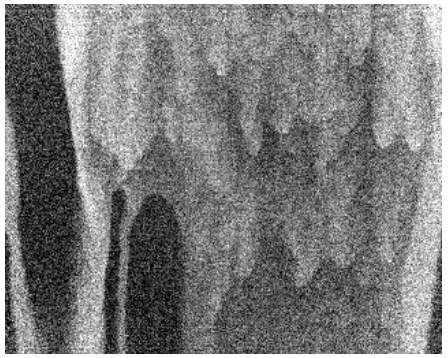




LINX



Film thickness

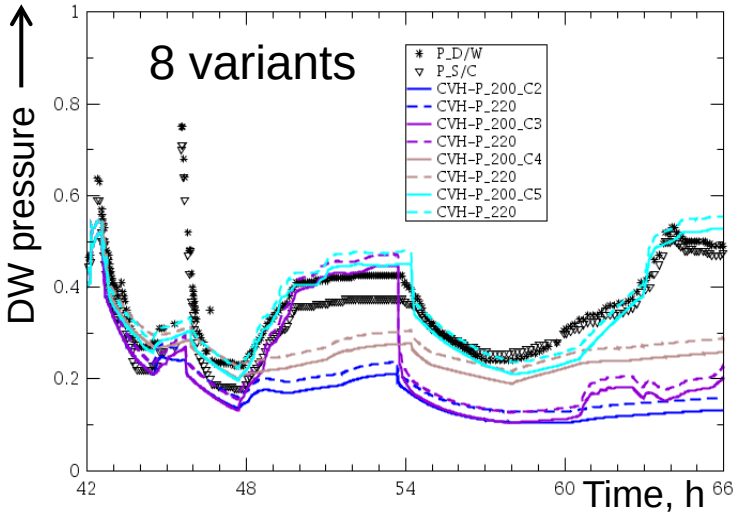


Film temperature

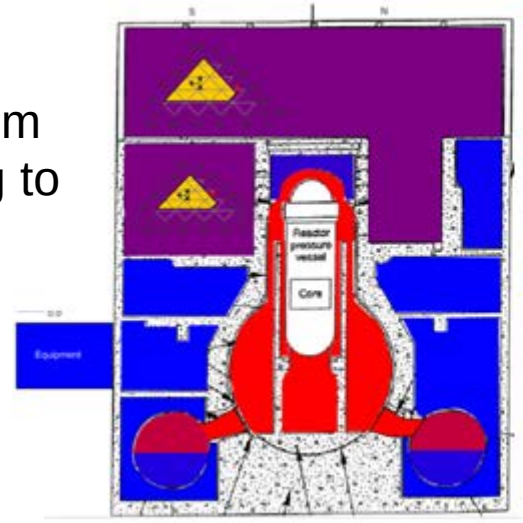
Supported by ENSI, IRSN

Fukushima Daiichi unit 3 forensics

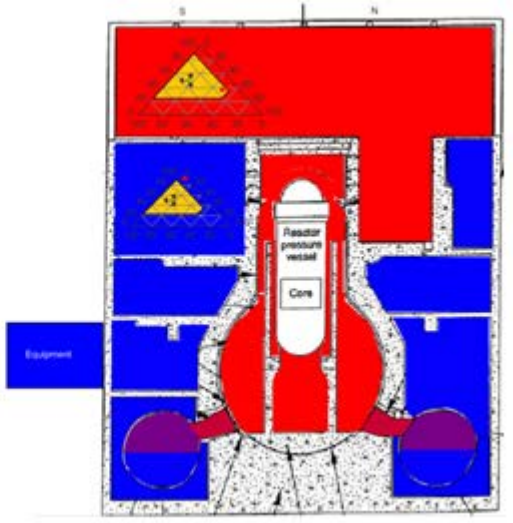
- **PSI: Unit 3, MELCOR 2.1 (6 days of process!)**
- The most relevant data evaluated to be:
  - Timing of the hydrogen explosions
  - The pressure of the reactor pressure vessel
  - The pressures of the drywell and wetwell
- Simulations of various postulated scenarios to match observations



e.g. hydrogen transfer from drywell to reactor building to explain explosions



Normal venting (valve)
→ no detonable mixture

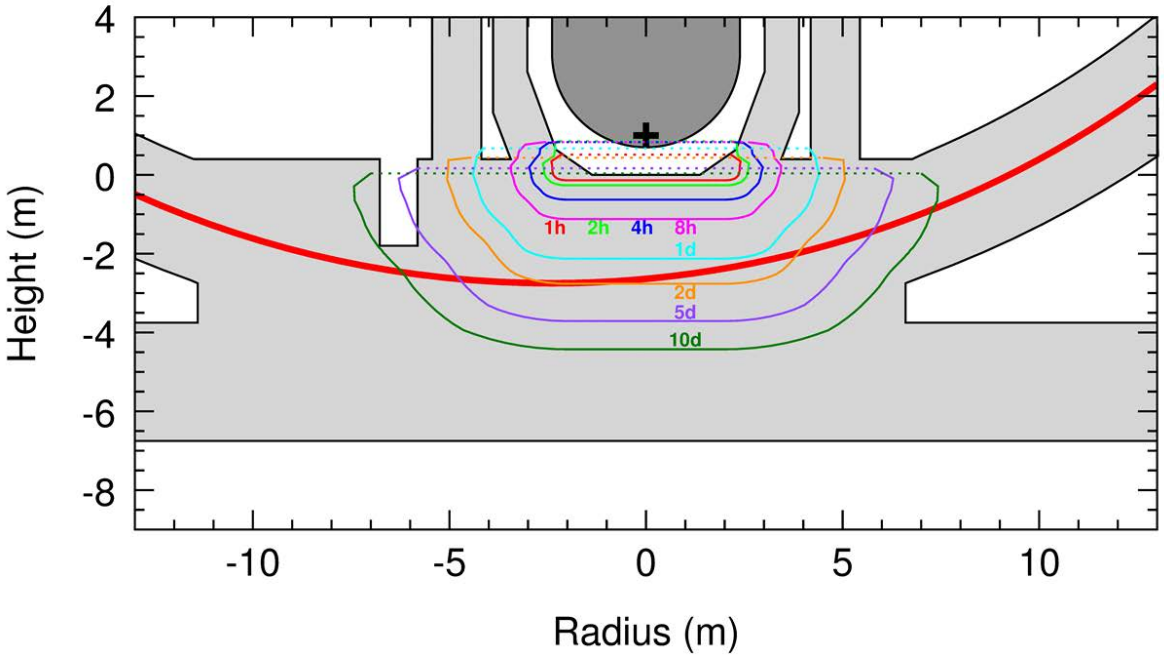


Drywell leakage
→ detonable mixture

Plant **analysis** – MCCI in a PWR

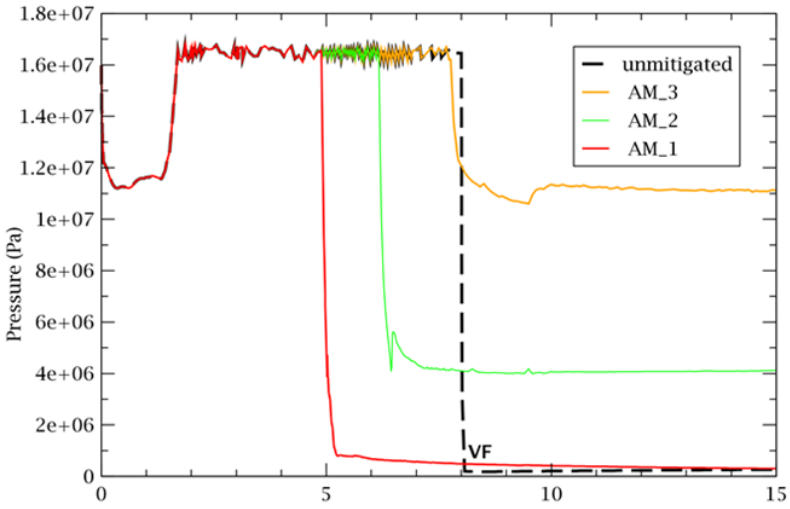
- Long-term station black-out chosen as the scenario
  - ❖ No core cooling available, only hydroaccumulators
  - ❖ No recombiners active
  - ❖ Filtered venting of the containment at 7.2 bar
  - ❖ Lower head failure by overheating
- Sensibility study, test of mitigating measures (water addition)

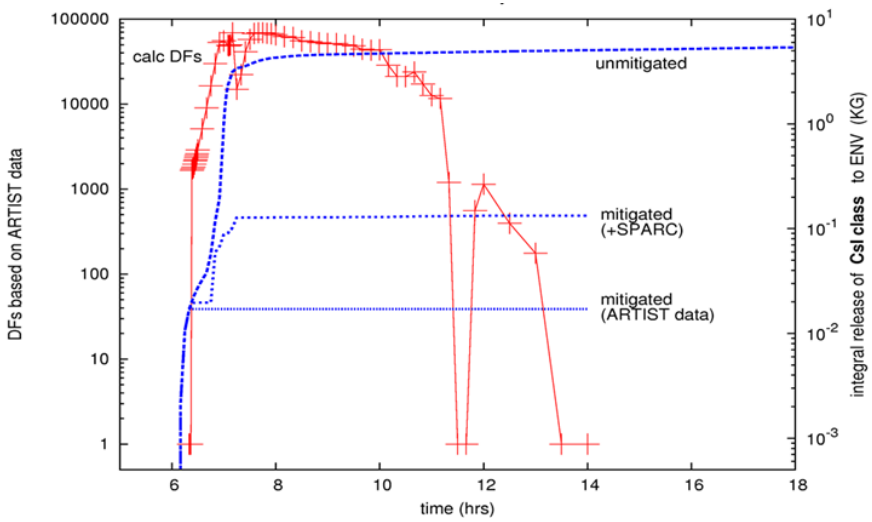
MELCOR (CORCON) and CORQUENCH



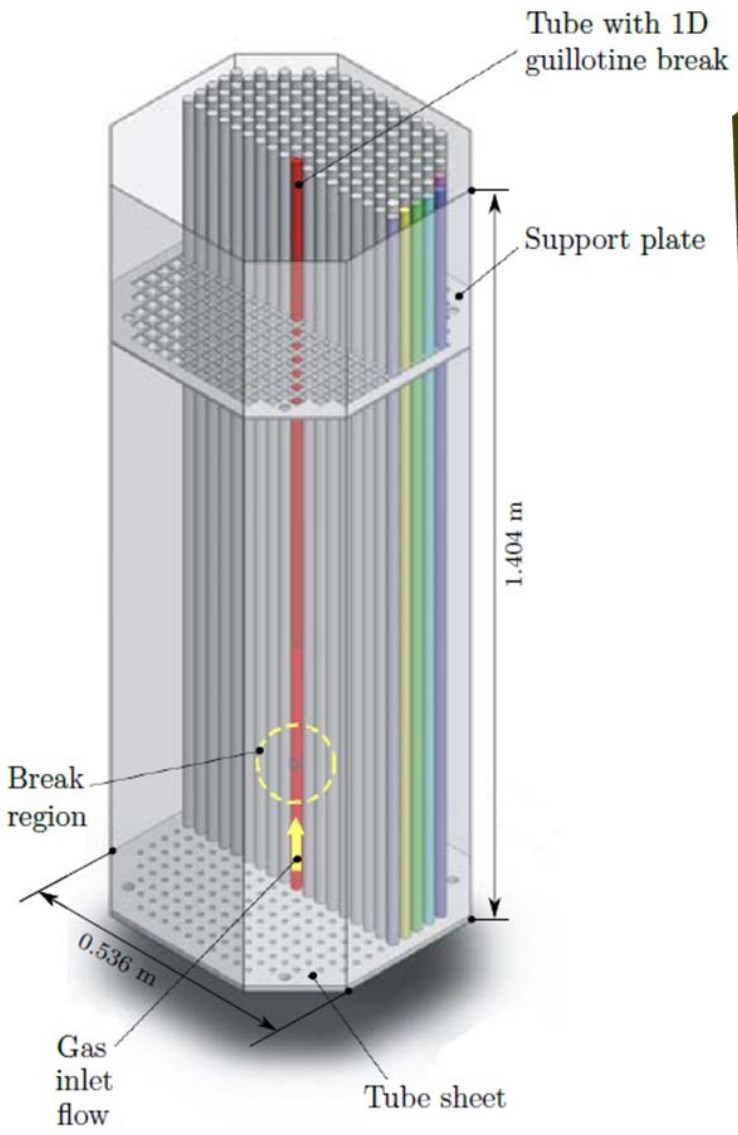
Plant analysis – source term

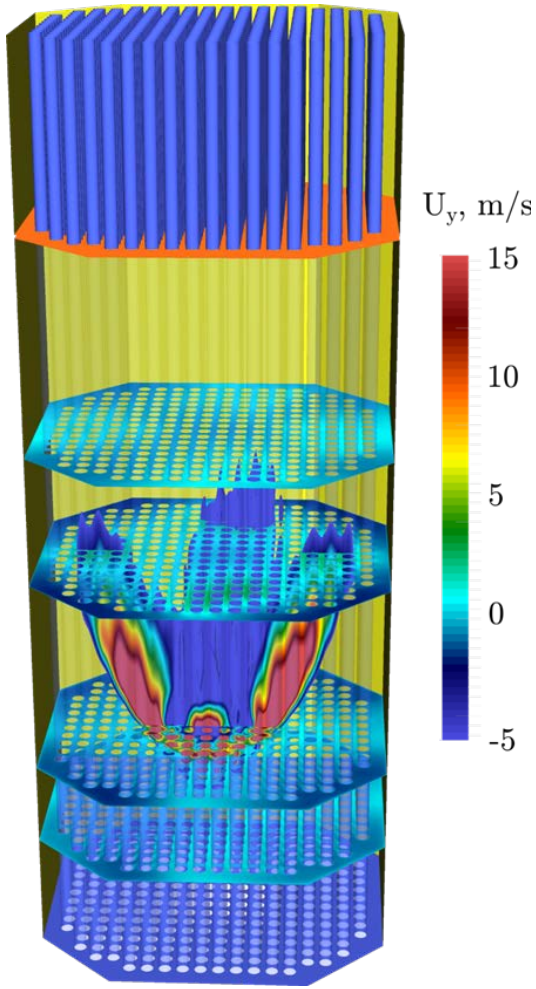
- Mitigation of a long-term station black-out (SBO) in a PWR
  - The effect of re-filling the secondary side
    - Accident progression
    - Source term
  - Use own experimental data for aerosol retention
- Mitigation of a LT-SBO in a BWR
  - Timing of the containment venting
  - Application of a filtered vent
    - Own experimental data for aerosols and iodine
    - Development of improved pool scrubbing models for gas phase species in FCVS





ARTIST post-analyses





Retention in break vicinity

- Break stage, one support plate
- 270 tubes + 4 support rods
- Tube length after support plate 14D
- 1-D Guillotine break

Method

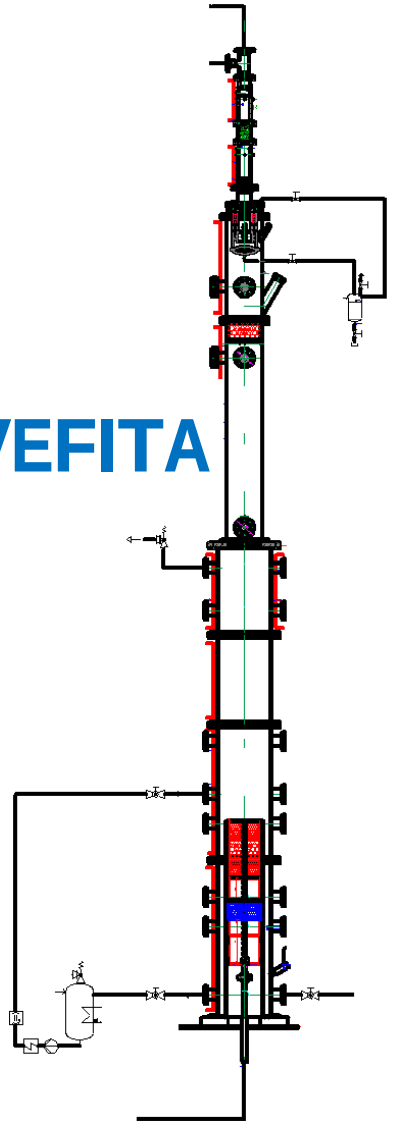
- Euler-Lagrange
- LES/RANS
- Continuous random walk
- OpenFoam

DRAGON – LINX - VEFITA

DRAGON

LINX

VEFITA



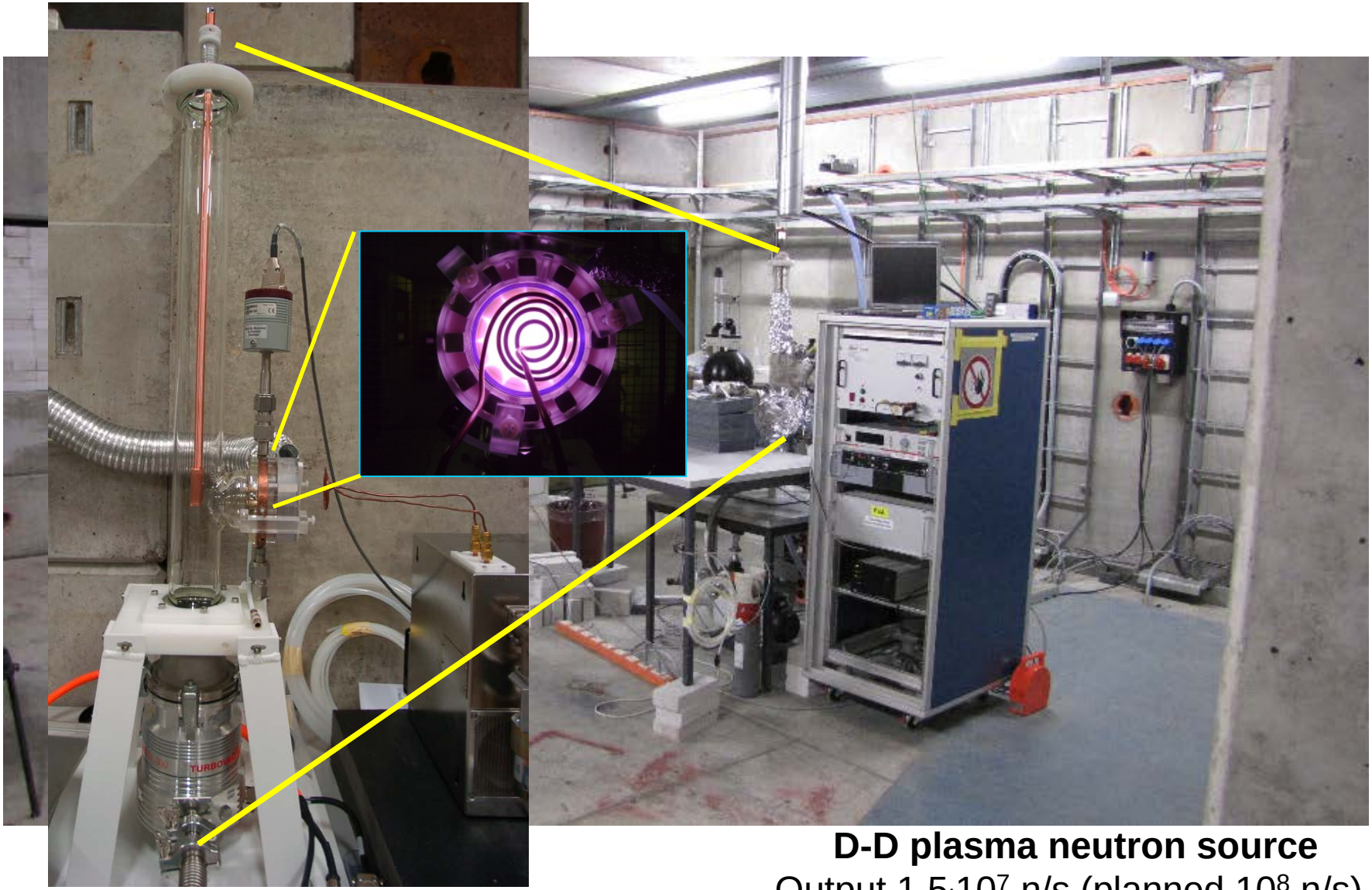
Plant analysis – model development

- Cladding oxidation in air / effect of nitrogen
  - Faster cladding degradation due to the volume difference of ZrO_2 and ZrN
  - PSI air oxidation model implemented in MELCOR and SCDAP/RELAP5
  - PhD work to include nitrogen as an active species
    - Development of a mechanistic model
    - Thermodynamics of the Zr-O-N system
    - Collaboration with KIT

Relevance

- Spent fuel pools
- Spent fuel transport
- Late phase after RPV failure
- Refueling RPV head removed

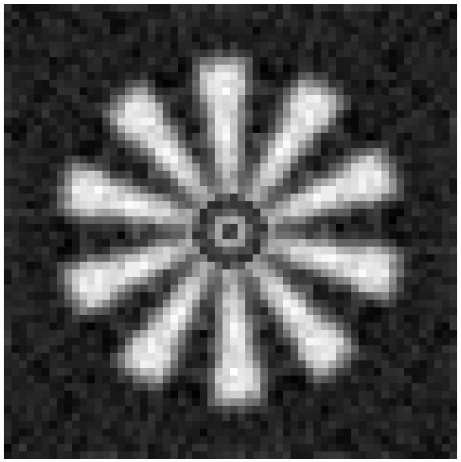
Imaging with fast neutrons



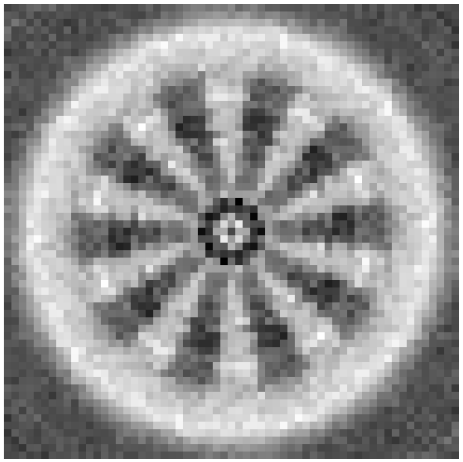
D-D plasma neutron source
Output $1.5 \cdot 10^7$ n/s (planned 10^8 n/s)

First tomographic image with fast neutrons

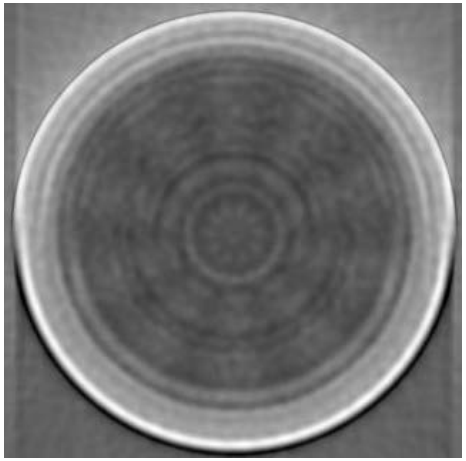
Reconstructed Siemens star (5 cm diameter)



Fast neutrons,
"naked" Siemens star

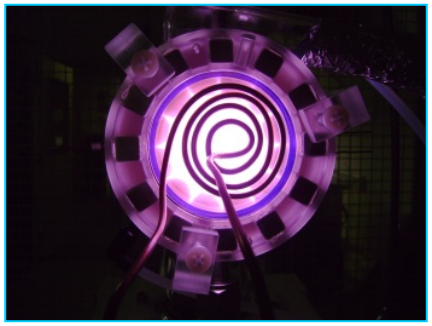


Fast neutrons, Siemens
star in steel case



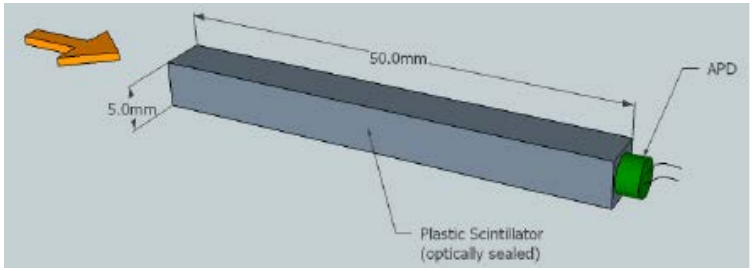
Cs-137 (γ), Siemens
star in steel case

D-D fusion source



2 mm spot size

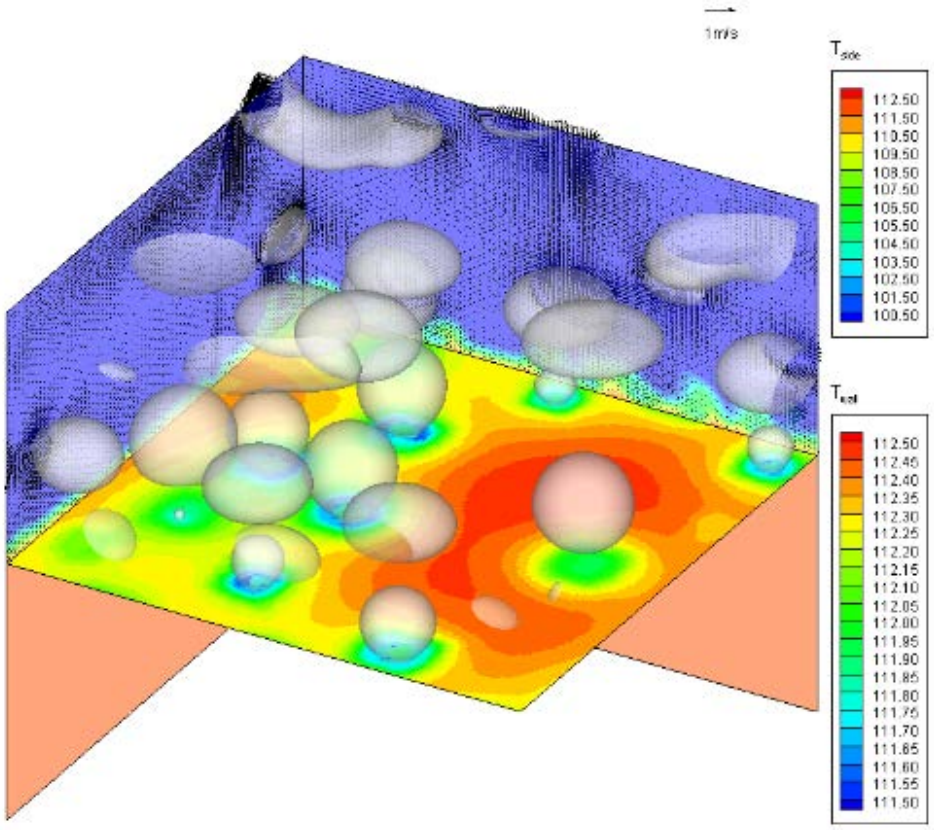
High-efficient detectors (100 chan.)



Robert Zboray (PSI scientist)
Robert Adams (PhD student, SNSF)

Boiling LES with multiple nucleation

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



World leadership!
Planned: SNSF application

- 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)

Industrial internships

- 14 Students of Nuclear Engineering from ETHZ and EPFL are looking for industrial internship positions
- Very good average performance! Majority of top students!
- 3 month (min) industrial internship is compulsory. Without internship, no master.
- Optimal period: July – August – September 2015
- Flexibility possible (longer periods, individual schedules...)
- No need to involve universities / PSI, official defense, no grade, no final report to university needed (but a collaboration is not excluded, if of advantage)
- Company has just to issue a letter confirming the accomplishment of internship
- Students send generic applications OR company may issue announcement
- Announcements of internship positions to: **hprasser@ethz.ch**